Pedestrian and Bicycle Information Center

Evaluation of Pedestrian-Related Roadway Measures: A Summary of Available Research

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Jill Mead
Charlie Zegeer
Max Bushell

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Introduction

This document represents an effort to compile all known research on the effect of the pedestrian safety countermeasures discussed in *PEDSAFE: Pedestrian Safety Guide and Countermeasure Selection System*. It is intended to serve as a companion document for the guide, providing a complementary overview of the researchers, research methods, and evaluation results that have guided the development and design of pedestrian safety countermeasures.

Methodology

This document grew out of the Highway Safety Manual (HSM) unpublished "Knowledge Document", which was originally written 2006 (by C. Zegeer for an itrans study for NCHRP, as part of the HSM development) and updated in 2008 for the FHWA Office or Research. In March 2014, a thorough review of pedestrian safety research was conducted using the Transportation Research Board's *TRID* database, PubMed, abstracts of presentations at annual Transportation Research Board conferences, research cited in the 2010 report entitled Update of the *AASHTO Guide for the Planning, Design and Operation of Pedestrian Facilities (which listed needed changes to the next AASHTP Pedestrian Guide)*, and general internet keyword searches.

Articles and reports were considered for inclusion in this subject literature review report, if they provided an evaluation of pedestrian safety countermeasures using rigorous research methods. While the majority of sources come from peer-reviewed journals and presentations or Federal Highway Administration (FHWA) reports, a handful come from state Departments of Transportation who have begun to conduct their own in-house countermeasure safety assessments. Results were generally limited to studies that took place within the United States, Canada, Europe, or Australia, where the pedestrian environment more closely resembles the conditions that engineers and planners might encounter in the United States.

Section 1: Along the Roadway

Section 1.1: Sidewalks, Walkways, and Paved Shoulders

Providing well-planned and properly designed sidewalks and walkways is an essential element for accommodating safe travel by pedestrians. Because pedestrian crashes are relatively rare at any given location and because it is difficult to find a sufficient number of new sidewalk additions to conduct a proper before-after evaluation, few studies have quantified the effects of sidewalks or walkways on pedestrian crashes or crash risk. However, there is strong evidence to support the logical assumption that having sidewalks and/or walkways along streets and highways is associated with a substantial reduction in pedestrian walking along roadway crashes. Furthermore, there are certain types of locations where the addition of sidewalks or walkways is likely to be particularly effective, such as on neighborhood streets and/or where there is likely to be regular pedestrian activity at night.

Installing sidewalks or walkways is more likely to reduce specific types of pedestrian crashes, such as those where pedestrians are struck by a motor vehicle while walking along roadways. A 1996 study by Hunter, Stutts, Pein, and Cox of pedestrian crash types in six states found that approximately 7.9 percent (400 of 5,073) of pedestrian crashes involved a pedestrian walking along the roadway (1). Since many of these types of pedestrian crashes occur at night and also where there are no sidewalks or paved shoulders, one may expect that providing appropriate sidewalks or shoulders would reduce the potential for such crashes in many situations.

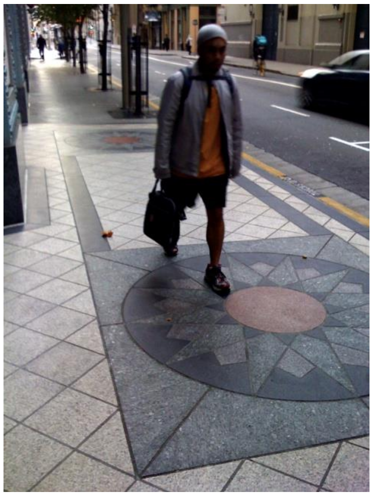

Figure 1: A pedestrian uses a sidewalk in San Francisco, California.

Photo by Neil Kandalgaonkar / www.flickr.com/photos/brevity/3047714786

A 2002 study by McMahon, Zegeer, Duncan, Knoblauch, Stewart, and Khattak was conducted to identify the types of risks to pedestrians who are walking along a roadway and to quantify the relationship of such crash risks with roadway and neighborhood factors (2). The study used case-control methodology and applied conditional and binary logistic models to determine the effects of various roadway features and socioeconomic and other census data on the likelihood that a site is a pedestrian crash site. A total of 47 crash sites were found, which were matched with 94 comparison sites (one nearby and one far-away matched comparison site for each crash site) for analysis purposes. Comparison sites were selected which were similar to the crash sites in terms of number of lanes, traffic volume, roadway and shoulder width, vehicle speeds, area type, etc. Nearby comparison sites were selected within the same neighborhood and/or within approximately one mile of the crash site. Far-away sites were matched sites in neighborhoods or areas on the other side of the county (2).

Physical roadway features found to be associated with a significantly higher likelihood of having a walking along roadway pedestrian crash included lack of a walkable area, and the absence of sidewalk augmented by higher traffic volume and higher speed limits. Using risk ratio and controlling for other roadway factors, at the sites studied, the likelihood of a site with a sidewalk or wide shoulder (4 feet or wider) having a walking along roadway pedestrian crash was 88.2 percent lower than a site without a sidewalk or wide shoulder. Increased pedestrian crash risk existed for higher speed limits and for higher traffic volumes. The authors state that these results "should not be interpreted to mean that installing sidewalks would necessarily reduce the likelihood of pedestrian/motor vehicle crashes by 88.2 percent in all situations. However, the presence of a sidewalk clearly has a strong beneficial effect of reducing the risk of a "walking along roadway" pedestrian/motor vehicle crash" (2).

When the authors controlled for roadway features, socio-economic factors found to be associated with significantly higher risk of such pedestrian crashes included high levels of unemployment, older housing units, lower proportions of families within households, and more single-parent households. The authors concluded that such results may suggest that some neighborhoods, due to increased pedestrian exposure or certain types of exposure, may be especially appropriate for adding such pedestrian safety measures as sidewalks, wide grassy shoulders, traffic calming measures, and/or other treatments. The study also developed guidelines and priorities for installing sidewalks and walkways, based on roadway and land use characteristics (2).

References

1. Hunter, W. W., J. S. Stutts, W. E. Pein, and C. L. Cox. *Pedestrian and Bicycle Crash Types of the Early 1990s*. Publication FHWA-RD-95-163, FHWA, U.S. Department of Transportation, 1995.
2. Zegeer, C. V., C. Seiderman, P. Lagerwey, M. J. Cynecki, M. Ronkin, and R. Schneider. *Pedestrian Facilities Users Guide - Providing Safety and Mobility*. Publication FHWA-RD-01-102, FHWA, U.S. Department of Transportation, 2002.

Section 1.2: Street Furniture/Walking Environment

No information for this section.

Section 2: At Crossing Locations

Section 2.1: Curb Ramps

No information for this section.

Section 2.2: Marked Crosswalks and Enhancements

Marked Crosswalks

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 U.S. 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 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) (*2*). 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. [See crosswalk enhancements section for a discussion of these types of treatments.]

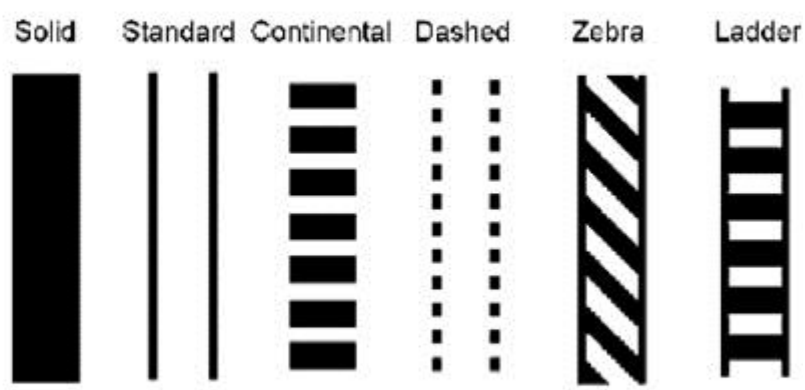

Figure 2: Examples of crosswalk marking patterns.

Examples of crosswalk marking patterns used in the United States and in the United Kingdom. The solid and dashed patterns are commonly used in Europe, but not used in the 2009 MUTCD (3).

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 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 (8).

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" (8). 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 (*2*). 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 no raised median.

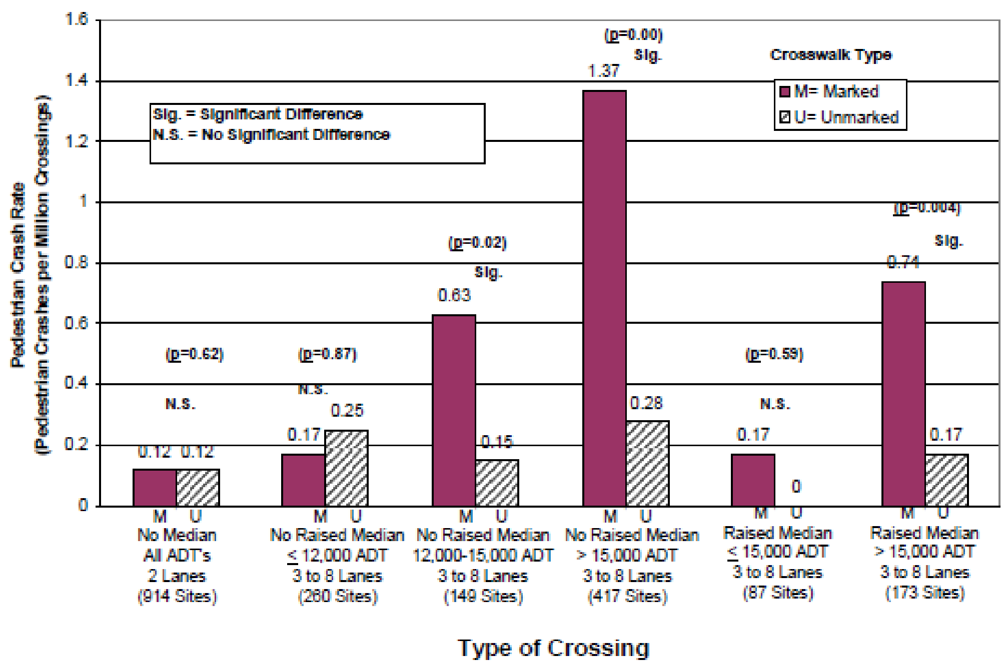

Figure 3: Pedestrian crash rate separated by type of crossing.

Figure 18 from report showing the pedestrian crash rate separated by type of crossing (2).

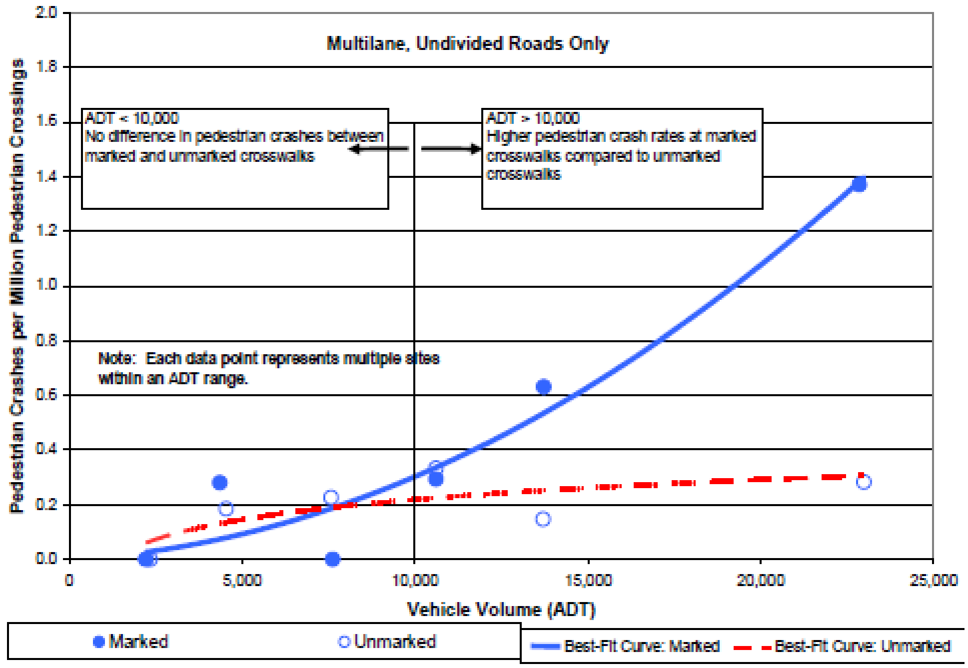

Figure 4: Pedestrian crash rates by traffic volume and presence/absence of crosswalk markings.

Figure 19 from the report comparing the pedestrian crash rate by traffic volume and marked or unmarked crosswalk (2).

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 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) (*2*).

Table 1: Recommended guidelines for installing marked crosswalks & 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 report 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 find that marked crosswalks are associated with higher pedestrian crash risk only on high-volume, multi-lane roads (i.e., ADT above 12,000 vehicles/day). Similarly, in 1967, the Los Angeles County Road Department found that accident frequency increased from four to 15 after marked crosswalks were installed at 89 non-signalized intersections (as cited in (*11*)). All the locations that showed an increase in crashes after crosswalk installation had an ADT of 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 (less 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 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, Vernen 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 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 was 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 less 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 (2). On many roads (particularly for multi-lane roads with ADT above about 12,000 vehicles/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 which involved evaluating pedestrian behavior on marked vs. unmarked crosswalks. Based on studies of pedestrian and motorist behavior, 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 eleven 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 towards 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 significantly 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 of 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 less, when there was a group of pedestrians, and when the pedestrians did not make eye contact with the driver (as cited in (*4*)).

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 (10).

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 if 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 (11).

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 (12).

Figure 5: Bar pair markings

Photo of bar pair markings as evaluated in the Fitzpatrick, Chrysler, Iragavarapu, and Park study (13).

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, 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 (13).

Figure 6: High visibility crosswalks and raised crossing islands help pedestrians cross safely.

High visibility crosswalks with a raised crossing island for helping pedestrians cross safely. Photo by Michael Ronkin. http://safety.transportation.org/htmlguides/peds/description_of_strat.htm

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 pretest-posttest research design to compare collision statistics following the implementation of pedestrian scramble timing at 72 sites throughout New York City. Pedestrian collision statistics were collected for the five 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 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 (14).

Figure 7: High visibility crosswalk at an intersection in Las Vegas.

A high visibility crosswalk as studied by Pulugartha, Vasudevan, Nambisan, and Dangeti in Las Vegas (16).

A 2012 paper by Pulugartha, Vasudevan, Nambisan, and Dangeti, evaluated four different infrastructure-based countermeasures including the high-visibility crosswalk, installed individually or in combination with other countermeasures (median refuge, Danish offset, and pedestrian channelization) at 8 different sites in Las Vegas, Nevada. Pre- and post-treatment observations were collected on weekdays to record data regarding the following measures of effectiveness (MOE): 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 statistical significance of post-treatment measurements. When the high-visibility crosswalk was installed individually, it led to a statistically significant increase in the proportion of pedestrians who looked for vehicles before beginning to cross along with a significant increase in the distance at which drivers yielded to pedestrians. At the same time, a statistically significant decrease was observed in the number of pedestrians trapped in the middle of the street. When the high-visibility crosswalk was deployed with other countermeasures, a statistically significant increase in the proportion of drivers who yielded to pedestrians was observed (15).

References

1. Federal Highway Administration. *Manual on Uniform Traffic Control Devices for Streets and Highways*. Washington, D.C., 2009.
   http://mutcd.fhwa.dot.gov/htm/2009/part3/part3b.htm#section3B18
2. Zegeer, C. V., R. Stewart, H. Huang, and P. Lagerwey. *Safety Effects of Marked Versus Unmarked Crosswalks at Uncontrolled Locations: Executive Summary and Recommended Guidelines*. Publication FHWA-RD-01-075, FHWA, U.S. Department of Transportation, 2002.
3. Zegeer, C.,V, J. Stutts, H. Huang, M. Cynecki J, R. Van Houten, B. Alberson, R. Pfefer, T. Neuman R, K. Slack L, and K. Hardy K. *Guidance for Implementation of the AASHTO Strategic Highway Safety Plan. Volume 10: A Guide for Reducing Collisions Involving Pedestrians*. NCHRP Report, No. 500, 2004.
4. Campbell, B. J., C. V. Zegeer, H. H. Huang, and M. J. Cynecki. *A Review of Pedestrian Safety Research in the United States and Abroad*. Publication FHWA-RD-03-042, FHWA, U.S. Department of Transportation, 2004.
5. Knoblauch, R. L., M. Nitzburg, and R. F. Seifert. *Pedestrian Crosswalk Case Studies: Richmond, Virginia; Buffalo, New York; Stillwater, Minnesota*. Publication FHWA-RD-00-103, FHWA, U.S. Department of Transportation, 2001.
6. Knoblauch, R. L. and P. D. Raymond. *The Effect of Crosswalk Markings on Vehicle Speeds in Maryland, Virginia and Arizona*. Publication FHWA-RD-00-101, FHWA, U.S. Department of Transportation, 2000.
7. Koepsell, T., L. McCloskey, M. Wolf, A. Vernez Moudon, D. Buchner, J. Kraus, and M. Patterson. Crosswalk Markings and the Risk of Pedestrian-Motor Vehicle Collisions in Older Pedestrians. *Journal of the American Medical Association*, Vol. 288, No. 1, 2002, pp. 1-8.
8. Mitman, M.F., D. R. Ragland, and C. V. Zegeer. The Marked Crosswalk Dilemma: Uncovering Some Missing Links in a 35-Year Debate. Presented at 87th Annual Meeting of the Transportation Research Board, Washington, D.C., 2008.
9. Jones, T. L. and P. Tomcheck. Pedestrian Accidents in Marked and Unmarked Crosswalks: A Quantitative Study. *ITE Journal*, Vol. 70, No. 9, 2000, pp. 42-46.
10. Nitzburg, M., and R. Knoblauch. *An Evaluation of High-Visibility Crosswalk Treatments—Clearwater, Florida*. Publication FHWA-RD-00-105, FHWA, U.S. Department of Transportation, 2001. http://www.fhwa.dot.gov/publications/research/safety/pedbike/0105.pdf
11. Chicago Department of Transportation. Evaluation of School Traffic Safety Program Traffic Control Measure Effectiveness. Report to the FHWA, 2005. http://mutcd.fhwa.dot.gov/resources/policy/ygcrosswalkmarking/chicagostudy/index.htm
12. Feldman, M., J. G. Manzi and M. Mitman. An Empirical Bayesian Evaluation of the Safety Effects of High-Visibility School (Yellow) Crosswalks in San Francisco. In *Transportation Research Record: Journal of the Transportation Research Board*, No. 2198, Transportation Research Board of the National Academies, Washington, D.C., 2010, pp. 8-14.
13. Fitzpatrick, K., S. Chrysler, V. Iragavarapu, and E. S. Park. Detection Distances to Crosswalk Markings: Transverse Lines, Continental Markings, and Bar Pairs. In *Transportation Research Record: Journal of the Transportation Research Board*, No. 2250, Transportation Research Board of the National Academies, Washington, D.C., 2011, pp. 1-10. Also summarized in Fitzpatrick, K., S. Chrysler, R. Van Houten, W. Hunter, and S. Turner. *Evaluation of Pedestrian and Bicycle Engineering Countermeasures: Rectangular Rapid-Flashing Beacons, HAWKs, Sharrows, Crosswalk Markings, and the Development of an Evaluation Methods Report*. Publication FHWA-HRT-11-039, FHWA, U.S. Department of Transportation, 2011.

14. Chen, L., C. Chen, R. Ewing, C. McKnight, R. Srinivasan, and M. Roe. Safety Countermeasures and Crash Reduction in New York City—Experience and Lessons Learned. *Accident Analysis and Prevention*. In print, 2012. Retrieved July 23, 2012. http://dx.doi.org/10.1016/j.aap.2012.05.009

15. Pulugartha, S. S., V. Vasudevan, S. S. Nambisan, and M. R. Dangeti. Evaluating the Effectiveness on Infrastructure-Based Countermeasures on Pedestrian Safety. Presented at the 91st Annual Meeting of the Transportation Research Board, Washington, D.C., 2012.

16. Pecheux, K., J. Bauer, P. McLeod. *Pedestrian Safety Engineering and ITS-Based Countermeasures Program for Reducing Pedestrian Fatalies, Injury Conflicts, and Other Surrogate Measures Final System Impact Report*. Federal Highway Administration, U.S. Department of Transportation, 2009.

Crosswalk Enhancements

Crosswalk enhancements are features added at marked crosswalks in order to make them more visible to motorists. This section discusses four types of crosswalk enhancements: pedestrian-activated overhead beacons, illumination of crosswalk and crosswalk signs, in-pavement flashing beacons, and experimental measures.

Installing pedestrian-activated flashing yellow beacons

Pedestrian-activated yellow beacons are sometimes used to alert motorists that pedestrians are crossing the roadway. Research has shown that overhead pedestrian signs with flashing beacons do encourage motorists to yield for pedestrians more often (*1, 2, 3*). These positive effects, however, are modest because 1) yellow warning beacons are not exclusive to pedestrian crossings, so drivers do not necessarily expect a pedestrian when they see a flashing beacon; and 2) motorists learn that many pedestrians are able to cross the road more quickly than the timing on the beacon allows and therefore may think the person has already finished crossing the road if a yielding or stopped car blocks the pedestrian from sight.

In 1998, Van Houten, Healey, Malenfant, and Retting evaluated two strategies for increasing the percentage of motorists yielding to pedestrians at crosswalks equipped with pedestrian-activated flashing beacons. One strategy involved adding an illuminated sign, with the standard pedestrian symbol next to the beacons. The second strategy involved placing signs 50 m before the crosswalk that displayed the pedestrian symbol and requested motorists to yield when the beacons were flashing. Both interventions increased yielding behavior and the effect of both together was greater than either alone. However, only the sign requesting motorists to yield when the beacons were flashing was effective in reducing motor vehicle-pedestrian conflicts (4). This is probably due to the following: 1) electronic signs display the actual pedestrian symbol when someone is in the crosswalk, so these signs are associated with pedestrian activity rather than other traffic situations; 2) by showing which direction a person is crossing, the electronic sign alerts the driver to look vigilantly in the appropriate direction; and 3) the electronic sign also lets drivers know when pedestrians are crossing from both directions simultaneously (4).

Figure 8: A sign reminding drivers to yield to pedestrian, used in conjunction with the two beacons suspended over the roadway to the right and the left.

The sign can be seen in the foreground, and the pedestrian flashing beacons can be seen on either side of the sign suspended over the roadway (4).

A 2009 compilation of reports by Pecheux, Bauer, and McLeod gave the results of the evaluation of two flashing beacons, one with a pedestrian push button, and the other equipped with infrared sensors to automatically detect pedestrians, tested at two sites in San Francisco, California. The researchers compared the percentage of diverted pedestrians, the percentage of pedestrians trapped in the roadway, the percentage of drivers yielding to pedestrians, the distance drivers yielded before the crosswalk, and the percentage of pedestrian-vehicle conflicts prior to and following the installation of the countermeasures. At one of the sites, the percentage of diverted pedestrians saw a statistically significant decrease following treatment, while the other site saw no impact. The same site measured a statistically significant decrease in trapped pedestrians, while the other site saw no impact. At both sites, there was a statistically significant increase in the percentage of yielding drivers. Both average pedestrian delay and pedestrian-vehicle conflicts decreased significantly at both sites. It is important to note that both sites also had advance stop lines, and one of the sites had an in-street yield to pedestrian sign. As a result of their observations, the researchers placed the flashing beacons into the "high effectiveness" category of countermeasures (5).

A 2011 paper by Vasudevan, Pulugurtha, Nambisan, and Dangeti evaluated three signal-based countermeasures tested in Las Vegas, Nevada, including a pedestrian-activated flashing yellow signal. The flashing yellow signal was installed at a mid-block location in conjunction with several previously-installed countermeasures: a high-visibility crosswalk, Danish offset, median refuge, and advanced yield markings. Thirteen pedestrian and driver measures of effectiveness (MOE) were studied by field observers before and after the installation of the call button and analyzed using a two-proportion z-test. Of the MOEs studied, there was a significant reduction in the percentage of drivers blocking the crosswalks, as well as a significant increase in driver yielding distance in all distance categories (<10, 10-20, and >20 ft); however, there was no statistically significant increase in the percentage of drivers yielding to pedestrians. Several pedestrian-related MOEs were observed: an increase in the number of pedestrians looking for vehicles while crossing both halves of the street, and an increase in the number of pedestrians diverted to use the crosswalk (6).

Figure 9: A pedestrian-activated flashing yellow signal.

Photo from the Vasudevan, Pulugurtha, Nambisan, and Dangeti article showing the pedestrian-activated flashing yellow signal evaluated in this study (6).

Installing illuminated crosswalks & crosswalk signs

In 2000, Nitzburg and Knoblauch studied the behavioral effects of a novel overhead illuminated crosswalk sign and high-visibility ladder style crosswalk on narrow low-speed roadways in Clearwater, Florida. With these features in place, motorist yielding to pedestrians went up a significant 30 to 40 percent during the daytime, with a smaller increase at night (8percent). The number of pedestrians who used the crosswalk rose by 35 percent. There was no observable change in pedestrian overconfidence, running, or conflicts. In conclusion, it was found that pedestrian and motorist behavior was positively affected by high-visibility crosswalk treatments on narrow low-speed roadways such as those included in this study; additional research is needed to determine their effectiveness on wider streets with higher speed limits (*7*).

A 2009 article by Nambisan, Pulugurtha, Vasudevan, Dangeti, and Virupaksha discussed the effectiveness of smart lighting system that used a pedestrian detection device in order to automatically increase illumination near a mid-block crosswalk in Las Vegas, Nevada. The site was chosen because the majority of motorists failed to yield to pedestrians and a high percentage of collisions occurred at night. Data was collected before and after the treatment was installed at dawn and dusk hours, and included seven measures of effectiveness (MOE) involving pedestrian and driver behavior at the crosswalk. A two-proportions z-test was conducted to analyze change in these variables in the treatment condition. There was a statistically significant increase in the percentage of diverted pedestrians (pedestrians who purposefully used the crosswalk), a significant increase in the percentage of motorists yielding to pedestrians, and a significant increase in the percentage of motorists yielding to pedestrians at greater than 10 ft before the crosswalk. The author concluded that the countermeasure helped to improve pedestrian safety, likely due to the increased visibility and attention to pedestrians provided by enhanced lighting at the site (8).

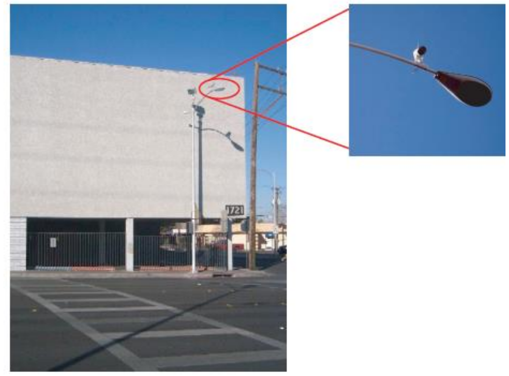

Figure 10: A smart lighting and automatic pedestrian detection device installed in Las Vegas.

Figure 2 from the Nambisan, Pulugurtha, Vasudevan, Dangeti, and Virupaksha article showing the smart lighting and automatic pedestrian detection device used at the site (8).

A 2009 evaluation of the Pedsafe II project in San Francisco by Hua, Gutierrez, Banerjee, Markowitz, and Ragland 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 flashing beacons were evaluated: one that was activated by pedestrians, and a second that automatically detected pedestrians using infrared technology. Each of the flashing beacons was installed at one uncontrolled crosswalk in order to assess their effectiveness. Based on pre- and post-treatment video 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 addition 27 percent of pedestrians crossed 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 six countermeasures that were considered the most effective in increasing pedestrian safety (9).

Installing in-pavement lighting at uncontrolled locations

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 (10, 11). 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 if 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 an in-pavement flashing light systems that automatically detect the presence of pedestrians using infrared sensors at 4 uncontrolled pedestrian crossings in 2 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 (12).

Figure 11: In-pavement flashing lights used at a crosswalk in Vermont.

One of the crosswalks from the Van Derlofske, Boyce, and Gilson study with in-pavement flashing lights installed (13).

Figure 12: Zig-zag pavement markings used in Virginia to call attention to the presence of pedestrians.

Photo by the Virginia Department of Transportation. http://www.virginiadot.org/vtrc/main/online_reports/pdf/11-r9.pdf

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 nine and twelve 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 (13).

A 2006 article by Karkee et al. summarized the effectiveness of an in-pavement flashing light system installed at one uncontrolled crosswalk in the Las Vegas metropolitan area, Nevada. The researchers collected data on driver behavior (yielding, vehicle speeds, yielding distance, and vehicle/pedestrian conflicts) before and after treatment installation, and compared to see if mean values differed statistically at 95 percent confidence levels. Analysis of data 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 conflict. The authors concluded that the in-pavement lighting solution did appear to have pedestrian safety benefits when implemented at a low traffic volume location (14).

Experimental measures at midblock crossings

A 2001 report entitled "Alternative Treatments for At-Grade Pedestrian Crossings" (*15*) contains a discussion of experimental measures used at uncontrolled crossings. However, the effectiveness of these devices on pedestrian crash rates in real-world situations is unknown.

A 2012 presentation by Douglad, 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 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 (16).

References

1. Nitzburg, M. and R. L. Knoblauch. *An Evaluation of High-Visibility Crosswalk Treatment - Clearwater Florida. Publication*. FHWA-RD-00-105, FHWA, U.S. Department of Transportation, 2001.
2. Huang, H. F., C. V. Zegeer, R. Nassi, and B. Fairfax. *The Effects of Innovative Pedestrian Signs at Unsignalized Locations: A Tale of Three Treatments*. Publication FHWA-RD-00-098, FHWA, U.S. Department of Transportation, 2000.
3. Van Houten, R., R. A. Retting, J. Van Houten, C. M. Farmer, and J. E. L. Malenfant. Use of Animation in LED Pedestrian Signals to Improve Pedestrian Safety. *ITE Journal*, Vol. 69, No. 2, 1999, pp. 30-38.
4. Van Houten, R., K. Healey, J. E. Malenfant, and R. A. Retting. Use of Signs and Symbols to Increase the Efficacy of Pedestrian Activated Flashing Beacons at Crosswalks. In *Transportation Research Record: Journal of the Transportation Research Board*, No. 1636, Transportation Research Board of the National Academies, Washington, D.C., 1998, pp. 92-95.
5. Pecheux, K., J. Bauer, P. McLeod. *Pedestrian Safety Engineering and ITS-Based Countermeasures Program for Reducing Pedestrian Fatalies, Injury Conflicts, and Other Surrogate Measures Final System Impact Report*. Federal Highway Administration, U.S. Department of Transportation, 2009.
6. Vasudevan, V., S. S. Pulugurtha, S. S. Nambisan, and M. R. Dangeti. Effectiveness of Signal-Based Countermeasures on Pedestrian Safety: Findings from a Pilot Study. In *Transportation Research Record: Journal of the Transportation Research Board*, No. 2264, Transportation Research Board of the National Academies, Washington, D.C., 2011, pp. 44-53.

7. Nitzburg, M., and R. Knoblauch. *An Evaluation of High-Visibility Crosswalk Treatments—Clearwater, Florida*. Publication FHWA-RD-00-105, FHWA, U.S. Department of Transportation, 2001. http://www.fhwa.dot.gov/publications/research/safety/pedbike/0105.pdf

8. Nambisan, S. S., S. S. Pulugurtha, V. Vasudevan, M. R. Dangeti, and V. Virupaksha. Effectiveness of Automatic Pedestrian Detection Device and Smart Lighting on Pedestrian Safety. In *Transportation Research Record: Journal of the Transportation Research Board*, No. 2140, Transportation Research Board of the National Academies, Washington, D.C., 2009, pp. 27-34.

9. Hua, J., N. Gutierrez, I. Banerjee, F. Markowitz, and D. R. Ragland. San Francisco Pedsafe II Project Outcomes and Lessons Learned. Presented at the 88th Annual Meeting of the Transportation Research Board, Washington, D.C., 2009.

10. Huang, H. *An Evaluation of Flashing Crosswalks in Gainesville and Lakeland*. Florida Department of Transportation, Tallahassee, Florida, 2000.

11. Godfrey, D. and T. Mazella. Kirkland's Experience with In-Pavement Flashing Lights at Crosswalks. Presented at ITE/IMSA Annual Meeting, Lynnwood, Washington, 1999.

12. Hakkert, A. S., V. Gitelman and E. Ben-Shabat. An Evaluation of Crosswalk Warning Systems: Effects on Pedestrian and Vehicle Behaviour. *Transportation Research*, Vol. 5, No. 4, 2002, pp. 275-292.

13. Van Derlofske, J.F., P.R. Boyce, C. H. Gilson. Evaluation of In-Pavement, Flashing Warning Lights on Pedestrian Crosswalk Safety. *International Municipal Signal Association Journal*, Vol. 41, No. 3, 2003.

14. Karkee, G. J., S. S. Nambisan, S. S. Pulugurtha, and A. Singh. An Evaluation of the Effectiveness of an In-pavement Flashing Light System. Presented at the 85th Annual Meeting of the Transportation Research Board. Washington, D.C., 2006.

15. Lalani, N. *Alternative Treatments for At-Grade Pedestrian Crossings*. Institute of Transportation Engineers, Washington, D.C., 2001.

16. Dougald, L. E., R. A. Dittberner and H. K. Sripathi. Creating Safer Mid-Block Pedestrian and Bicycle Crossing Environments: The Zig-Zag Pavement Marking Experiment. Presented at the 91st Annual Meeting of the Transportation Research Board. Washington, DC, 2012.

Section 2.3: 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*).

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 was no pre-treatment data available, nor 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 (MOE) 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 twenty 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 lack of appropriate pedestrian facilities, also contributed to the observed failure to yield to pedestrians (*5*).

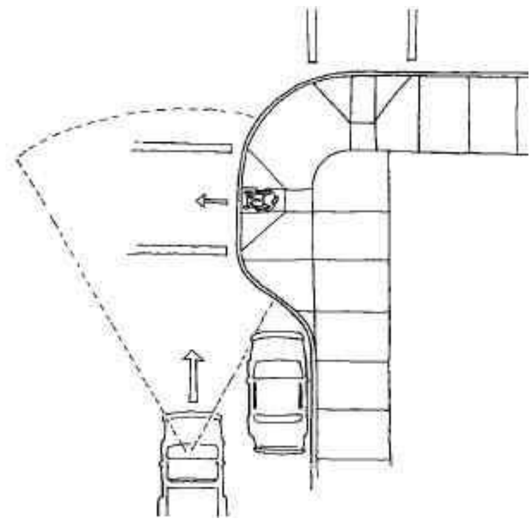

Figure 13: Sketch of a curb extension, demonstration how it increases visibility for both drivers and pedestrians.

Curb extensions extend the curb line into the street, improving visibility for pedestrians and motorists, reducing pedestrian crossing distances, and reducing vehicle turn speeds (1).

A 2013 article by Hengel presented the results of a pedestrian safety study of a site in Santa Barbara, California where a curb extension, pedestrian refuge island, and stop bars were installed. The research team studied crossing delay, motorist yielding, and the distance drivers yielded from the crosswalk prior to and following the installation of the countermeasures. Over 200 staged crossings were conducted, and results were analyzed using cross tabulations and analysis of variance (ANOVA). Analysis of data showed that crossing delay decreased by a statistically significant ($p<.05$) average of 4.9 seconds following the installation of the curb extension and refuge island. While no significant difference in yielding before of near lane drivers was observed, a statistically significant increase in yielding was observed for far lane drivers, from 61.5% in the before condition, to 82% in the after condition. There was also a significant increase in motorist yielding distance following the installation of the countermeasures. The author concluded that the combination of treatments was 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 (*6*).

References

1. Axelson, P. W., D. A. Chesney, D. V. Galvan, J. B. Kirschbaum, P. E. Longmuir, C. Lyons, and K. M. Wong. *Designing Sidewalks and Trails for Access, Part I of II: Review of Existing Guidelines and Practices*. Washington, D.C., Federal Highway Administration, 1999.
2. King, M.R. Calming New York City Intersections. Transportation Research Board Circular E-CO19: Urban Street Symposium, Issue Number 501, Dallas, Texas, 1999.
3. Huang, H. F. and M. J. Cynecki. *The Effects of Traffic Calming Measures on Pedestrian and Motorist Behavior*. Publication FHWA-RD-00-104, FHWA, U.S. Department of Transportation, 2001.
4. Van Houten, R. Research on Improving Motorist Yielding at Crosswalks on Multilane Roads with an Uncontrolled Approach. Presented at the ITE 2001 Annual Meeting and Exhibit, Chicago, Illinois, 2001.
5. Johnson, R. S. *Pedestrian Safety Impacts of Curb Extensions: A Case Study*. Publication FHWA-OR-DF-06-01, Oregon Department of Transportation, Salem, OR, 2005.
6. Hengel, D. Build It and They Will Yield: Effects of median and curb extension installations on motorist yield compliance. Presented at the 92nd Annual Meeting of the Transportation Research Board, Washington, D.C., 2013.

Section 2.4: Crossing Islands

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 mid-block 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 which had no median, those which 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 (*2*). 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.

A 1994 study by Claessen and Jones (*8*) 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 (*7*).

Nearly a decade later 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 (*9*).

Figure 14: A pedestrian crosses in a zebra crosswalk that has been enhanced with a refuge island.

Figure 10 from the Huang and Cynecki article showing a pedestrian in the crosswalk where the refuge island had been installed in Sacramento, California (9).

Table 2: Comparison of the percentage of pedestrians crossing in the crosswalk before and after installation of median islands in Sacramento, California

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 11 from the Huang and Cynecki article showing the percentage of pedestrians who crossed in the crosswalk before and after the installation of median islands (9).

One year later 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 was available, from 22 in the three years before installation to 6 during the three years following installation of the refuge islands. However, there were 46 vehicle-island crashes during the after period, which were not possible during the three 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 mid-block 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 (*10*).

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 (*2*). 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 mid-block 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 4 to 8 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 to 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 (*2*).

A 2003 paper by Kamyab, Andrie, 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 (*12*).

Table 3: Table showing mean vehicle speeds before and following 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

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 3200 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 (*13*).

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 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. They 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 (*14*).

Most recently, a 2012 paper by Pulugartha, Vasudevan, Nambisan, and Dangeti evaluated four different infrastructure-based countermeasures, including median refuge and Danish offset combined with high-visibility crosswalks at 8 different sites in Las Vegas, Nevada. Pre- and post-treatment observations were collected on weekdays to record data regarding the following measures of effectiveness (MOE): pedestrians trapped in the street, pedestrians looking for vehicles before beginning to cross, pedestrians looking for

Figure 15: A removable pedestrian island installed in conjunction with an in-roadway yield to pedestrians sign at a crosswalk in Minnesota.

Photo from the Kamyab, Andrie, Kroeger, and Heyer article showing the removable pedestrian island and pedestrian crossing sign evaluated in the study (12).

Figure 16: Pedestrians making use of a median refuge island

Photo from the report showing one of the median refuge islands evaluated in San Francisco (14).

Figure 17: A Danish offset median refuge island as used in Las Vegas, Nevada.

A Danish offset used at a midblock crossing in Las Vegas, Nevada (14). This type of offset design is configured so that pedestrians view oncoming traffic as they walk to the second half of the crosswalk.

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 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 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 (*15*).

A 2013 article by van Hengel presented the results of a pedestrian safety study of a site in Santa Barbara, California where a curb extension, pedestrian refuge island, and stop bars were installed. The research team studied crossing delay, motorist yielding, and the distance drivers yielded from the crosswalk prior to and following the installation of the countermeasures. Over 200 staged crossings were conducted, and results were analyzed using cross tabulations and analysis of variance (ANOVA). Analysis of data showed that crossing delay decreased by a statistically significant ($p<.05$) average of 4.9 seconds following the installation of the curb extension and refuge island. While no significant difference in yielding before of near lane drivers was observed, a statistically significant increase in yielding was observed for far lane drivers, from 61.5% in the before condition, to 82% in the after condition. There was also a significant increase in motorist yielding distance following the installation of the countermeasures. The author concluded that the combination of treatments was 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 (18).

References

1. Zegeer, C. V., J. Stutts, H. Huang, M. J. Cynecki, R. Van Houten, B. Alberson, R. Pfefer, T. R. Neuman, K. L. Slack, and K. K. Hardy. *NCHRP Report 500 Volume 10: A Guide for Reducing Collisions Involving Pedestrians*. Washington, D.C., Transportation Research Board, National Research Council, 2004.
2. Bowman, B. L. and R. L. Vecellio. Effects of Urban and Suburban Median Types on Both Vehicular and Pedestrian Safety. In *Transportation Research Record: Journal of the Transportation Research Board*, No. 1445, Transportation Board of the National Academies, Washington, D.C., 1994, pp. 169-179.
3. Cairney, P. *Pedestrian Safety in Australia*. Publication FHWA-RD-99-093, FHWA, U.S. Department of Transportation, 1999.
4. Moore, V. M. and A. J. McLean. *A Review of Pedestrian Facilities*. Office of Road Safety, South Australian Department of Transport, 1995.
5. Jonsson, T., J. N. Ivan, and C. Zhang. Crash Prediction Models for Intersections on Rural Multilane Highways: Differences by Collision Type. In *Transportation Research Record: Journal of the Transportation Research Board*, No. 2019, Transportation Research Board of the National Academies, Washington, D.C., 2007, pp. 91-98.
6. Fitzpatrick, K., W. H. Schneider IV, and E. S. Park. Operation and Safety of Right-Turn Lane Designs. In *Transportation Research Record: Journal of the Transportation Research Board*, No. 1961, Transportation Research Board of the National Academies, Washington, D.C., 2006, pp. 55-64.
7. Wang, X., M. Abdel-Aty, and P. Brady. Crash Estimation at Signalized Intersections: Significant Factors and Temporal Effect. In *Transportation Research Record: Journal of the Transportation Research Board*, No. 1953, Transportation Research Board of the National Academies, Washington, D.C., 2006, pp. 10-20.
8. Wang, X. and M. Abdel-Aty. Temporal and Spatial Analysis of Rear-end Crashes at Signalized Intersections. *Accident Analysis and Prevention*, Vol. 38, 2006, pp. 1137-1150.

9. Huang, H. F. and M. J. Cynecki. *The Effects of Traffic Calming Measures on Pedestrian and Motorist Behavior*. Publication FHWA-RD-00-104, FHWA, U.S. Department of Transportation, 2001.

10. Bacquie, R., D. Egan, and L. Ing, L. Pedestrian Refuge Island Safety Audit. Presented at 2001 ITE Spring Conference and Exhibit, Monterey, CA, 2001.

11. Zegeer, C. V., R. Stewart, H. Huang, and P. Lagerwey. *Safety Effects of Marked Versus Unmarked Crosswalks at Uncontrolled Locations: Executive Summary and Recommended Guidelines*. Publication FHWA-RD-01-075, FHWA, U.S. Department of Transportation, 2002.

12. Kamyab, A., S. Andrie, D. Kroeger, and D. Heyer. Methods to Reduce Traffic Speed in High-Pedestrian Rural Areas. In *Transportation Research Record: Journal of the Transportation Research Board*, No. 1828, Transportation Research Board of the National Academies, Washington, D.C., 2003, 31-37.

13. King, M. R., J. A. Carnegie and R. Ewing. Pedestrian Safety Through a Raised Median and Redesigned Intersections. In *Transportation Research Record: Journal of the Transportation Research Board*, No. 1828, Transportation Research Board of the National Academies, Washington, D.C., 2003, pp. 56-66.

14. Pecheux, K., J. Bauer, P. McLeod. *Pedestrian Safety Engineering and ITS-Based Countermeasures Program for Reducing Pedestrian Fatalies, Injury Conflicts, and Other Surrogate Measures Final System Impact Report*. Federal Highway Administration, U.S. Department of Transportation, 2009.

15. Pulugartha, S. S., V. Vasudevan, S. S. Nambisan, and M. R. Dangeti. Evaluating the Effectiveness on Infrastructure-Based Countermeasures on Pedestrian Safety. Presented at the 91st Annual Meeting of the Transportation Research Board, Washington, D.C., 2012.

16. Lalani, N. Road Safety at Pedestrian Refuges. *Traffic Engineering & Control*, Vol. 18, No. 9, 1977, pp. 429-431.

17. Garder, P. Pedestrian Safety at Traffic Signals. *Accident Analysis and Prevention*, Vol. 21, No. 5, 1989, pp. 435-444.

18. Van Hengel, D. Build It and They Will Yield: Effects of median and curb extension installations on motorist yield compliance. Presented at the 92nd Annual Meeting of the Transportation Research Board, Washington, D.C., 2013.

Section 2.5: 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.

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 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 at a site where there was already an overhead flashing beacon, motorist yielding was significantly higher, while at the other 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).

References

1. Huang, H. F. and M. J. Cynecki. *The Effects of Traffic Calming Measures on Pedestrian and Motorist Behavior*. Publication FHWA-RD-00-104, FHWA, U.S. Department of Transportation, 2001.

Section 2.6: Roadway Lighting Improvements

A 2008 report by Gibbons, Edwards, Williams, and Andersen tested driver yielding to pedestrians in midblock crossings using static and dynamic experiments, which included lamp type, vertical illuminance level, color of pedestrian clothing, position of pedestrians in the crosswalk, and glare as experimental variables. The Probeam luminaire and ground installed LEDs were also examined and the report concluded that vertical illuminance of 20 lx at the height of 5 ft over the crosswalk created reasonable detection distances in most examples (1).

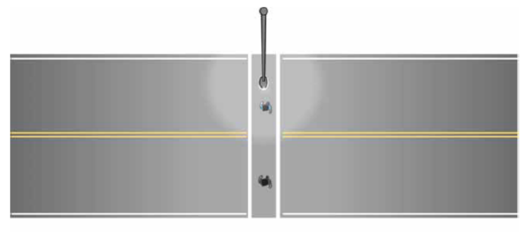

Figure 11. Drawing. Traditional midblock crosswalk lighting layout.

Figure 12. Drawing. New design for midblock crosswalk lighting layout.

Figure 18: Two types of pedestrian lighting placement.

Figures 11 and 12 from the Gibbons, Edwards, Williams, and Andersen report. The above drawing shows traditional crosswalk lighting design in which the lamp is placed directly over the crosswalk. The bottom drawing shows a more effective system in which the lamp is installed in front of the crosswalk on each side, increasing visibility distance (1).

A 2009 article by Nambisan et al discusses the effectiveness of an energy-efficient smart lighting system that uses a pedestrian detection device in order to automatically increase illumination near a mid-block crosswalk in Las Vegas, Nevada. The site was chosen because the majority of motorists failed to yield to pedestrians and a high percentage of collisions occurred at night. Data was collected before and after the treatment was installed at dawn and dusk hours, and included seven measures of effectiveness (MOE) involving pedestrian and driver behavior at the crosswalk. A two-proportions z-test was conducted to analyze change in these variables in the treatment condition. There was a statistically significant increase in the percentage of diverted pedestrians (pedestrians who purposefully used the crosswalk), a significant increase in the percentage of motorists yielding to pedestrians, and a significant increase in the percentage of motorists yielding to pedestrians at greater than 10 ft before the crosswalk. The author concluded that the countermeasure helped to improve pedestrian safety, likely due to the increased visibility and attention to pedestrians provided by enhanced lighting at the site (2).

A 2012 presentation by Bullough, Rea, and Zhang gave the results of an experiment testing four types of pedestrian crosswalk lighting configurations. The researchers set up a roadway simulation with a crosswalk in an unlighted parking lot. One hundred feet from the crosswalk, they set up a testing station with chairs in the position of an approaching vehicle behind two standard-configuration low-beam headlights. Participants were told to record the direction of a pedestrian silhouette placed at various positions along the crosswalk as soon as they could, and the results were analyzed for speed and accuracy under different crosswalk lighting conditions. Condition A was the lighting from the headlights alone. Condition B was overhead lighting from a single 60W cobra-style luminaire mounted at 18 ft directly over the crosswalk, while Condition C was the same style of light mounted at 20 ft before the crosswalk. Condition D were bollard luminaires using linear fluorescent wall-washer 28 W lamps developed by the research team positioned 7 ft ahead of the crosswalk at both ends. Mean identification times were the shortest for Condition D, as well as for the larger, adult-sized silhouettes. Citing lower installation and operating costs for the bollard luminaires, the research team concluded that they can be an effective lighting solution for increasing pedestrian safety at crosswalks (3).

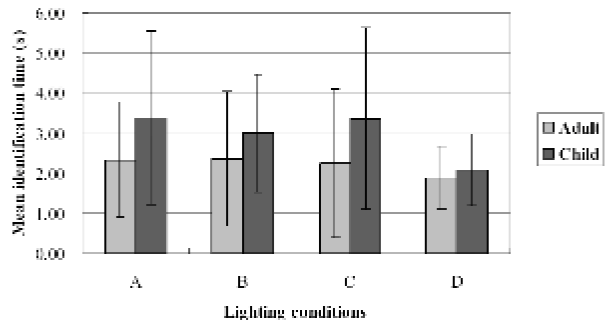

Figure 19: Pedestrian lighting evaluation results.

Graph from the article showing the mean identification times and standard deviations for each of the lighting conditions and silhouette sizes (3).

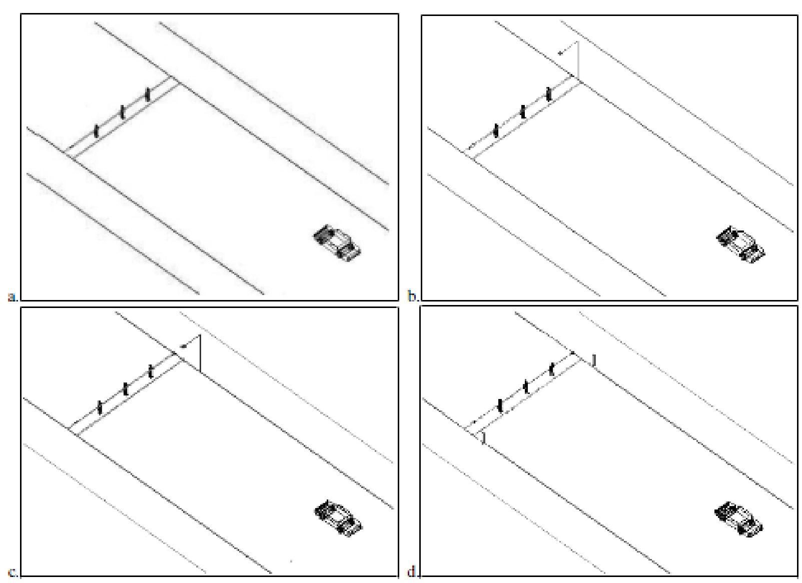

Figure 20: Four configurations of pedestrian lighting.

Figure 1 from the Bullough, Rea, and Zhang article showing the four lighting configurations tested by the researchers: a) headlights alone, b) pole-mounted lighting directly over the crosswalk, c) pole-mounted lighting 20 ft in advance of the crosswalk and d) bollard luminaires placed 7 ft in advance of the crosswalk (3).

References

1. Gibbons, R., C. Edwards, B. Williams, and C. Andersen. *Informational Report on Lighting Design for Midblock Crosswalks*. Publication FHWA-HRT-08-053, FHWA, U.S. Department of Transportation, 2008.
2. Nambisan, S. S., S. S. Pulugurtha, V. Vasudevan, M. R. Dangeti, V. Virupaksha. Effectiveness of Automatic Pedestrian Detection Device and Smart Lighting on Pedestrian Safety. In *Transportation Research Record: Journal of the Transportation Research Board*, No. 2140, Transportation Research Board of the National Academies, Washington, D.C., 2009, pp. 27-34.
3. Bullough, J. D., M.S. Rea, X. Zhang. Evaluation of Visual Performance from Pedestrian Crosswalk Lighting. Presented at the 91st Annual Meeting of the Transportation Research Board, Washington, D.C., 2012.

Section 2.7: Parking Restrictions

No information for this section.

Section 2.8: Pedestrian Overpasses/Underpasses

Pedestrian overpasses and underpasses can be effective in reducing pedestrian crashes in certain locations. However, grade-separated crossings are very expensive structures and may not be used by pedestrians if not perceived to be safer and more convenient than crossing at street level.

Figure 21: A pedestrian overpass.

Pedestrian overpasses increase pedestrian safety, but many pedestrians weigh the potential safety benefits against the added time and distance needed to cross. Photo by Yan Jai. http://safety.transportation.org/htmlguides/peds/description_of_strat.htm

An important measure of effectiveness for overpasses and underpasses is how much they are used by pedestrians. According to Moore and Older (1965), usage depends on walking distances and how convenient the overpass is for potential users (as cited in (*1*)). Moore and Older developed a measure of convenience (R), defined by the ratio of the time it took to cross the street on an overpass divided by the time it took to cross at street level. According to this study, about 95percent of pedestrians opt for the overpass if R=1, meaning that it takes the same amount of time to cross using the overpass as it does at street level. If the overpass route takes 50 percent longer (R=1.5), almost no one uses it. For similar values of R, the use of underpasses by pedestrians was not as high as for overpasses (*1*).

In 1980, a before and after comparison of pedestrian crashes was made at 31 locations in Tokyo, Japan, where pedestrian overpasses had been installed (as cited in (1)). Crashes occurring in 200 m (218 yard) and 100 m (109 yard) sections on either side of each site were tabulated. After overpasses were installed, pedestrian crossing accidents decreased substantially, although non-related accidents increased by 23 percent in the 200 m sections. It is not known whether this increase could have been the results of other factors unrelated to the overpass. The researchers also found that daytime pedestrian crashes were reduced more than nighttime crashes by the installation of pedestrian overpasses (1). This may be related to the volumes of pedestrians crossing the road.

Table 4: Comparison of crashes before and after installation of pedestrian overpasses in Tokyo, Japan

Type of Crash	200 m sections			100 m sections		
	Before	After	Index of Effectiveness	Before	After	Index of Effectiveness
Pedestrian crossing crashes	2.16	0.31	0.144	1.81	0.16	0.088
Non-pedestrian crossing crashes	2.26	2.77	1.23	1.65	1.87	1.133
Total	4.42	3.09	0.699	3.46	2.03	0.567

Table showing a comparison of crashes before and following the installation of pedestrian overpasses in Tokyo, Japan (1).

Overpasses can present certain problems for pedestrians, as suggested by a panel of disabled residents commenting on three pedestrian overpasses in San Francisco (Swan, 1978 as cited in (*1*). Potential hazards or barriers include: inadequate or nonexistent railings on bridge approaches; steep cross slopes; lack of a level platform at the base on bridge ramps where wheelchairs can stop prior to entering the street; inadequate sight distance to see opposing flow of pedestrians and also lack of level rest areas on spiral ramps; maze-like barriers on bridge approaches which are used to slow down bike traffic but can also impede the progress of wheelchair-bound or visually impaired users; and lack of sound screening on the overpass so that the visually impaired can hear people coming the other way and avoid crashes (1). The Americans with Disabilities Act (*2*) required gentler slopes to be used on approaches to crossing structures, which has enhanced accessibility for wheelchair users and bicyclists, but the resultant lengthening of ramps has also been found to discourage use of the facilities. On the other hand, devices such as fencing are sometimes employed to channel pedestrians toward overpasses and underpasses.

References

1. Campbell, B. J., C. V. Zegeer, H. H. Huang, and M. J. Cynecki. *A Review of Pedestrian Safety Research in the United States and Abroad*. Publication FHWA-RD-03-042, FHWA, U.S. Department of Transportation, 2004.
2. Americans with Disabilities Act (ADA) of 1990. Vol. S. 933, Washington, D.C., U.S. Department of Justice, 1990.

Section 2.9: Automated Pedestrian Detection

Automated pedestrian detection systems sense the presence of people who are waiting to cross the street and mechanically activate the WALK signal without any action required from the pedestrian to push a button. An additional feature of the detectors at some locations is that another sensor can be aimed to monitor slower-walking pedestrians in the street, so it will extend the clearance interval until the pedestrian is safe on the other side.

In 2000, Hughes, Huang, Zegeer, and Cynecki tried to determine whether these automated systems combined with standard pedestrian push buttons could reduce pedestrian-vehicle conflicts and reduce the number of people entering the roadway during the DON'T WALK (or flashing DON'T WALK) display. Videos were taken before and after installation of the automated systems at intersections in Los Angeles, Phoenix, and Rochester, NY, with results showing a statistically significant reduction in pedestrian-vehicle conflicts as well as the percent of pedestrian crossings initiated during the DON'T WALK phase. Both infrared and microwave sensors were tested, with no significant differences found. However, field testing of the microwave equipment in Phoenix suggested a need for fine turning the detection zone in order to reduce false and missed calls (1).

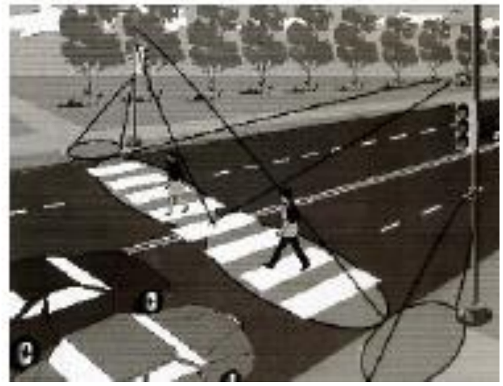

Figure 22: A pedestrian using a crosswalk that has been enhanced with an automated pedestrian detection system.

Figure 1 from the article showing an automated pedestrian detection system as used in the Hughes, Huang, Zegeer, and Cynecki report (1).

A 2009 report compilation by Pecheux, Bauer, and McLeod gave the results of the evaluation of two automated pedestrian detection systems in San Francisco and Miami. In San Francisco, video detection technology was used to provide up to 3 seconds of additional time for late-crossing pedestrians at an intersection and in Miami, video detection was used to detect pedestrians approaching a mid-block crossing and change the signal accordingly. The field teams measured various pedestrian and motorist behaviors in order to assess the effectiveness of the countermeasures on improving pedestrian safety at the sites. The only significant finding measured by the researchers was a 9percent decrease in the percentage of cycles where a pedestrian was trapped in the roadway. There were no significant effects on pedestrian-vehicle conflicts or pedestrian clearance at the sites. The San Francisco field team concluded that while the technology needed to be tested and refined, it appeared to have potential (2).

Figure 23: A camera used for automated pedestrian detection.

Figure 24 from the Pechuex, Bauer, and McLeod report showing one of the cameras used for automated pedestrian detection in the evaluation report (2).

A 2009 article by Nambisan, Pulugurtha, Vasudevan, Dangeti, and Virupaksha discusses the effectiveness of smart lighting system that used a pedestrian detection device in order to automatically increase illumination near a mid-block crosswalk in Las Vegas, Nevada. The site was chosen because the majority of motorists failed to yield to pedestrians and a high percentage of collisions occurred at night. Data was collected before and after the treatment was installed at dawn and dusk hours, and included seven measures of effectiveness (MOE) involving pedestrian and driver behavior at the crosswalk. A two-proportions z-test was conducted to analyze change in these variables in the treatment condition. There was a statistically significant increase in the percentage of diverted pedestrians (pedestrians who purposefully used the crosswalk), a significant increase in the percentage of motorists yielding to pedestrians, and a significant increase in the percentage of motorists yielding to pedestrians at greater than 10 ft before the crosswalk. The author concluded that the countermeasure helped to improve pedestrian safety, likely due to the increased visibility and attention to pedestrians provided by enhanced lighting at the site (3).

A 2012 presentation at the Transportation Research Board annual meeting by Lovejoy, Markowitz, and Montufar evaluated the effects of the installation of automated pedestrian detection with signal extension that was installed in 2006 at an intersection in San Francisco, California. The researchers evaluated the device's performance in general as well as its impact on the percentage of pedestrians finishing crossing during the crossing interval. Analyzing pre- and post-treatment pedestrian-related data, the researchers recorded a non-statistically significant decrease in late crossings, which they theorized may have been due to low incidence of late crossing at the intersection before the installation of the device. They concluded that the device had a relatively small impact on improving safety at its particular location (4).

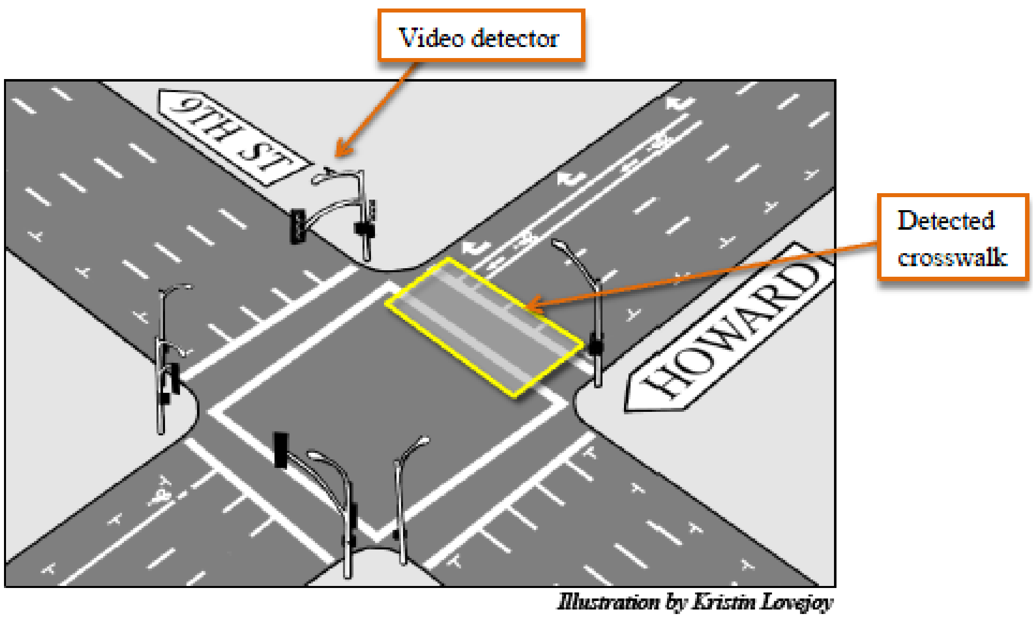

Figure 24: Illustration of an automated pedestrian detection study site.

An illustration of the study site evaluated in the Lovejoy, Markowitz, and Montufar article (4).

Table 5: Comparison of pedestrian behaviors in presence or absence of an automated pedestrian detection device.

Percent of Pedestrians Finishing Late, With and Without Device					
	With device (installed or actuated)		Without device (installed or actuated)		p-value for chi-square test
	Percent	N	Percent	N	
Among all pedestrians					
Percent late: with device installed vs. without	16	663	15	707	0.463
Percent very late: with device installed vs. without	3	663	4	707	0.306
With device installed, percent late: when actuated vs. not actuated	32	152	12	512	0.000
With device installed, percent very late: when actuated vs. not actuated	3	152	4	512	0.523
Among all late pedestrians					
Percent very late: with device installed vs. without	20	108	30	105	0.122
With device installed, percent very late: when actuated vs. not actuated	8	48	31	61	0.004

Table 3 from the Lovejoy, Markowitz, and Montufar article showing the percent of pedestrians finishing late, with and without the automated pedestrian detection device (4).

References

1. Hughes, R., H. Huang, C. V. Zegeer, and M. J. Cynecki. *Evaluation of Automated Pedestrian Detection at Signalized Intersections*. Publication FHWA-RD-00-097, FHWA, U.S. Department of Transportation, 2001.
2. Pecheux, K., J. Bauer, P. McLeod. *Pedestrian Safety Engineering and ITS-Based Countermeasures Program for Reducing Pedestrian Fatalies, Injury Conflicts, and Other Surrogate Measures Final System Impact Report*. Federal Highway Administration, U.S. Department of Transportation, 2009.
3. Nambisan, S. S., S. S. Pulugurtha, V. Vasudevan, M. R. Dangeti, V. Virupaksha. Effectiveness of Automatic Pedestrian Detection Device and Smart Lighting on Pedestrian Safety. In *Transportation Research Record: Journal of the Transportation Research Board*, No. 2140, Transportation Research Board of the National Academies, Washington, D.C., 2009, pp. 27-34.
4. Lovejoy, K., F. Markowitz and J. Montufar. Use of Video for Automated Pedestrian Detection and Signal-Timing Extension: Results from a Pilot Installation in San Francisco, California. Presented at the 91st Annual Meeting of the Transportation Research Board. Washington, D.C., 2012.

Section 2.10: Leading Pedestrian Intervals

A 1999 presentation by King on the subject of traffic calming gave the results of an evaluation of the leading pedestrian interval (LPI) on pedestrian crash statistics in New York City. Collision data were collected for the 5 years preceding and 5 years following LPI installation for treatment and surrounding control intersections. The LPI had the effect of decreasing both collision occurrence and severity at treatment intersections, especially at intersections with heavy turning volumes. The results of this study and others led the New York City Department of Transportation to decide to install more LPIs as a pedestrian safety countermeasure (1).

In 2000, Van Houten, Retting, Farmer, and Van Houten studied the introduction of a three-second leading pedestrian interval (LPI) at three signalized intersections in downtown St. Petersburg, Florida. Using WALK/DON'T WALK signal heads that were automatically coordinated with the signal timer, signal phasing at the intersections was programmed to release pedestrian traffic three seconds before vehicle traffic. A one-second all-red interval was used at all intersections. Based on observations of pedestrians older than age 12 on weekdays between 8:30 am and 5:00 pm (excluding periods of heavy rain), logistic regression models were used to estimate the safety effects of the LPI at the intersections. The models included vehicle-pedestrian conflicts, pedestrian yielding, time, site location, and pedestrian age (senior vs. non-senior). Van Houten et al. concluded that the introduction of a three-second LPI reduced conflicts between pedestrians and turning vehicles as well as reduced the incidence of pedestrians yielding the right-of-way to turning vehicles. They also concluded that the signal phasing made it easier for pedestrians to cross the street (2).

A 2008 article in the *ITE Journal* by Hubbard, Bullock, and Thai evaluated the trial implementation of a leading pedestrian interval at one crosswalk in an intersection in Anaheim, California. The researchers collected data using video for the periods before and after the LPI implementation. Three thousand pedestrian crossings were categorized into non-conflicting (the pedestrian was able to cross the street without any impact from turning traffic) or compromised (the pedestrian was either delayed by turning cars or had to change path or speed due to a turning vehicle). The table below gives a summary of the results of data analysis (3).

Table 6: Summary of evaluation of leading pedestrian interval

	Number of Pedestrians	Percentage of pedestrians compromised on curb at beginning of walk	Significantly different at 0.10?	Percentage of pedestrians compromised in crosswalk	Significantly different at 0.10?
Low Right-Turn Demand (1-5 vehicles in queue at beginning of cycle					
Concurrent service (no LPI)	432	18	Yes, significant at 4 percent	2	Yes, significant at 0.6 percent
With LPI	622	21		4	
High Right-Turn Demand (5+ vehicles in queue at beginning of cycle)					
Concurrent service (no LPI)	1037	23	Yes, significant at <0.1 percent	6	Yes, significant at <0.1 percent
With LPI	728	44		2	
All					
Concurrent service (no LPI)	1469	22	Yes, significant at <0.1 percent	5	Yes, significant at <0.1 percent
With LPI	1350	33		3	

Table 1 from the Hubbard, Bullock, and Thai article showing the summary of pedestrian outcomes before and after the implementation of the leading pedestrian interval (3).

As shown in the table, results of the analysis were mixed with respect to pedestrian compromise when pedestrians began crossing, as well as once they were in the crosswalk. The authors hypothesized that some of the advantages reported in other studies where an LPI was used at a downtown intersection at the same time that there was an RTOR restriction may not have carried over to the suburban environment where they carried out their study. The authors concluded by recommending field evaluation of the LPI prior to its implementation in new sites (3).

A 2009 report by Pecheux, Bauer, and McLeod assessed the effectiveness of the LPI on pedestrian and driver behavior at two intersections in Miami, Florida. The researchers compared driver and pedestrian behavior pre-and post-treatment and used the following measures of effectiveness (MOEs) to study the pedestrian safety benefits of the treatment: percentage of drivers yielding to pedestrians, percentage of pedestrians in the crosswalk after the all-red phase, the percentage of cycles in which the call button was pressed, the percentage of cycles in which there were pedestrian-vehicle conflicts, and the percentage of pedestrians crossing during the first 4 seconds of the walk phase. At both of the intersections, a statistically significant increase in the percentage of drivers turning left was measured following the implementation of the LPI when compared to baseline. There was no change in the percentage of right-turning drivers who yielded at the one intersection where that behavior was measured. At both intersections, there was a statistically significant increase in the percentage of pedestrians who pushed the call button and the percentage of pedestrians who crossed during the first four seconds of the walk phase. The researchers considered the LPI as a highly effective countermeasure for impacting behaviors related to pedestrian safety (4).

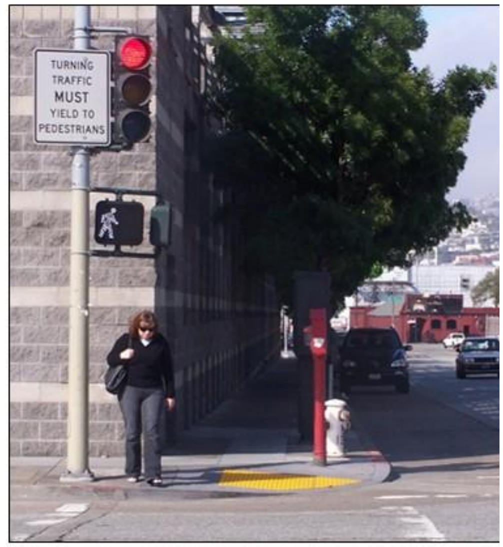

Figure 25: A pedestrian crossing in a location with leading pedestrian interval signal timing.

Figure 34 from the report showing a signal programmed to give a leading pedestrian interval (4). http://safety.fhwa.dot.gov/ped_bike/tools_solve/ped_scdproj/sys_impact_rpt/chap_2.cfm

Table 7: Summary of pedestrian behaviors before and after the installation of a Leading Pedestrian Interval.

Site	MOE	Before	After	Percent Change	p-value
Percent of Left-Turning Drivers Yielding During WALK	Alton & Lincoln	40 (n=46)	58 (n=194)	+18	0.01
	Collins & 16th	22 (n=59)	31 (n=18)	+9	0.05
Percent if Right-Turning Drivers Yielding During WALK	Alton & Lincoln	15 (n=15)	15 (n=15)	0	NA
Percent of Cycles Call Button Pressed	Alton & Lincoln	69 (n=169)	76 (n=431)	+7	0.05
	Collins & 16th	36 (n=781)	51 (n=185)	+15	0.01
Pedestrians Crossing During Beginning of WALK Cycle	Alton & Lincoln	45.3 (n=858)	76.5 (n=1121)	+31.2	0.01
	Collins & 16th	38 (n=300)	59 (n=109)	+21	0.01

Summary of results from the report by Pecheux, Bauer, and McLeod showing changes in pedestrian and driver behavior following the implementation of the LPI (4).

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. Four second pedestrian head starts (leading pedestrian interval) were implemented at 4 intersections, which led to a significant reduction in the percent of vehicles turning in front of pedestrians, from 6.2 percent pre-treatment to 4 percent post-treatment on average over the four sites. Of the 13 countermeasures tested in the study, pedestrian head starts were among the six countermeasures that were considered the most effective in increasing pedestrian safety (5).

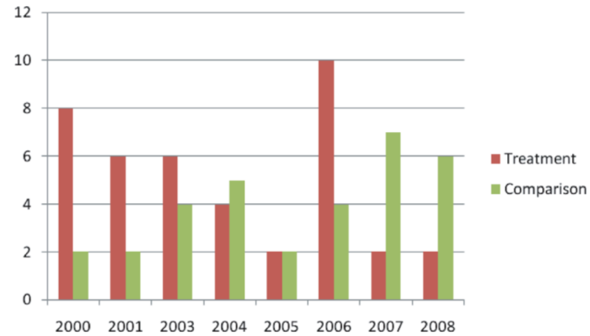

Figure 26: Graph showing pedestrian-vehicle crashes at leading pedestrian interval sites and comparison sites.

Graph caption: Graph from the Fayish and Gross article showing pedestrian-vehicle crashes per year at LPI and comparison sites (6).

A 2010 article by Fayish and Gross studied the safety effectiveness of leading pedestrian intervals (LPIs) implemented at 10 intersections in State College, Pennsylvania. To quantify the differences in collision statistics, the researchers used pre- and post-treatment data and comparison data from 14 study area intersections that were similar in terms of site characteristics, traffic and pedestrian volumes, and crash data. Their results suggested a reduction of 58.7 percent in pedestrian/vehicle crashes at the 10 treated intersections (significant at the 95 percent confidence level). The researchers concluded that implementing LPIs at intersections is a cost-effective strategy to improve pedestrian safety at intersections (6).

References

1. King, M.R. *Calming New York City Intersections*. Transportation Research Board Circular E-CO19: Urban Street Symposium, Issue Number 501, Dallas, Texas, 1999.
2. Van Houten, R., A. R. Retting, C. M. Farmer, and J. Van Houten. Field Evaluation of a Leading Pedestrian Interval Signal Phase at Three Urban Intersections. In *Transportation Research Record: Journal of the Transportation Research Board*, No. 1734, Transportation Research Board of the National Academies, Washington, D.C., 2000, pp. 86-92.
3. Hubbard, S., D. Bullock, and J. Thai. Trial Implementation of a Leading Pedestrian Interval: Lessons Learned. *ITE Journal*, Vol. 78, No. 10, 2008, pp 32, 37-41.
4. Pecheux, K., J. Bauer, and P. McLeod. *Pedestrian Safety Engineering and ITS-Based Countermeasures Program for Reducing Pedestrian Fatalies, Injury Conflicts, and Other Surrogate Measures Final System Impact Report*. Federal Highway Administration, U.S. Department of Transportation, 2009.
5. Hua, J., N. Gutierrez, I. Banerjee, F. Markowitz, and D. R. Ragland. San Francisco Pedsafe II Project Outcomes and Lessons Learned. Presented at the 88th Annual Meeting of the Transportation Research Board, Washington, D.C., 2009.
6. Fayish, A. C. and F. Gross. Safety Effectiveness of Leading Pedestrian Intervals Evaluated by a Before–After Study with Comparison Groups. In *Transportation Research Record: Journal of the Transportation Research Board*, No. 2198, Transportation Research Board of the National Academies, Washington, D.C., 2010, pp. 15-22.

Section 2.11: Advanced Stop Lines & Yield Markings

See section 8.6 for a discussion of advanced yield markings.

Section 3: Transit

While very few studies have analyzed the effect of transit on pedestrian safety, a 2012 article by Chen, Chen, Ewing, McKnight, Srinivasan, and Roe highlighted some of the challenges to pedestrian safety posed by the installation of bus lanes in New York City. As one of the first articles to evaluate the effects of installing curbside bus lanes specifically on pedestrian safety, the authors found that adding bus lanes in the absence of other countermeasures led to an increase in pedestrian collisions at treatment sites. The researchers used two-group pretest-protest research design to analyze total, pedestrian, injury, and fatal collision occurrence at 396 total roadway segment and intersection bus lane installation sites throughout New York City. Collision data were collected for the treatment and comparison sites for the five years preceding bus lane installation as well as for the two years following it. The authors used ANCOVA analysis in order to account for potential regression-to-the-mean effects. Analysis of their results indicated that the observed pedestrian crash rate on roadway segments increased by 20.56 percent at treatment sites and decreased by 19.34 percent at comparison sites. At intersections, pedestrian collisions increased by 4.62 percent at treatment sites, but decreased by 0.85 percent at comparison sites. This resulted in an ANCOVA-adjusted increase in pedestrian collisions of 155 percent on roadway segments and an increase of 33 percent at intersection sites, results which were significant at the 0.05 level (1). The results are summarized in the table below:

Table 8: Summary of the effects of bus lane installation on pedestrian safety in New York City

Location of bus lane installation	Group	Number of Intersections	Percent Change in Pedestrian Crash Rates	Adjusted Percent Change (ANCOVA analysis)	Significant at 0.05?
Roadway segment	Treatment	210	+20.56	+155	Yes
	Comparison	1652	-19.34		
Intersection	Treatment	186	+4.62	+33	Yes
	Comparison	1038	+0.85		

Table with data from the Chen et al. article summarizing the effect of bus lane installation evaluated in the article (1).

The authors of the article concluded that bus lanes had a negative impact on not just pedestrian collisions, but all types of vehicle crashes, including multi-vehicle and injurious and fatal crashes. Since the time of the study, new safety measures have been implemented to better manage conflicts between busses, vehicles, and pedestrians, including automated, camera-based bus lane enforcement and pavement treatments to better demarcate the bus-only zone. The authors suggest empirical study of these new safety countermeasures to determine their effectiveness in reducing collisions caused by adding bus lanes.

References

1. Chen, L., C. Chen, R. Ewing, C. McKnight, R. Srinivasan, and M. Roe. Safety Countermeasures and Crash Reduction in New York City—Experience and Lessons Learned. *Accident Analysis and Prevention*. In print, 2012. Retrieved July 23, 2012.

Section 3.1: Transit Stop Improvements

No information for this section.

Section 3.2: Access to Transit

No information for this section.

Section 3.3: Bus Bulbouts

No information for this section.

Section 4: Roadway Design

Section 4.1: Bicycle Facilities

No information for this section.

A 2012 article by Chen, Chen, Ewing, McKnight, Srinivasan, and Roe was one of the first to evaluate the effects of installing bicycle lanes specifically on pedestrian safety. The researchers used two-group pretest-protest research design to analyze total, pedestrian, injury, and fatal collision occurrence at 1329 total roadway segment and intersection bicycle lane installation sites in New York City. Collision data were collected for the treatment and comparison sites for the five years before bicycle lane installation and the two years following it. The authors used ANCOVA analysis in order to account for potential regression-to-the-mean effects. Analysis of their results indicated that the observed pedestrian crash rate on roadway segments decreased by 40.53 percent at treatment sites and by 35.82 percent at comparison sites. At intersections, pedestrian collisions increased by 6.2 percent at treatment sites, but decreased by 3.25 percent at comparison sites. This resulted in an ANCOVA-adjusted increase in pedestrian collisions of 5 percent on roadway segments and an increase at intersection sites of 7 percent, results which were not significant at the 0.05 level (1). The results are summarized in the table below:

Table 9: Summary of the effects of bicycle lane installation on pedestrian safety.

Location of bicycle lane installation	Group	Number of Intersections	Percent Change in Pedestrian Crash Rates	Adjusted Percent Change (ANCOVA analysis)	Significant at 0.05?
Roadway segment	Treatment	660	-40.53	+5	No
	Control	2227	-35.82		
Intersection	Treatment	669	6.20	+7	No
	Control	1768	-3.25		

Table with data from the Chen et al. article summarizing the effect of bicycle lane installation evaluated in the article (1).

References

1. Chen, L., C. Chen, R. Ewing, C. McKnight, R. Srinivasan, and M. Roe. Safety Countermeasures and Crash Reduction in New York City—Experience and Lessons Learned. *Accident Analysis and Prevention*. In print, 2012. Retrieved July 23, 2012.

Section 4.2: Lane Narrowing (Lane Diets)

No information for this section.

Section 4.3: Lane Reduction (Road Diets)

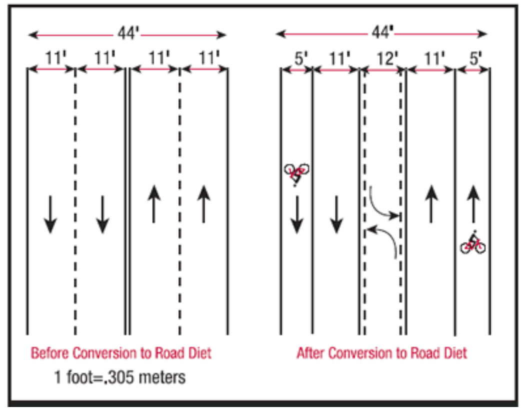

Figure 27: A typical road diet conversion.

Graphic caption: A drawing showing a typical road diet treatment in which a four lane roadway segment is reduced to three lanes (4).

A road diet is a type of traffic calming project that involves reducing the number of lanes in a street, often in conjunction with increasing pedestrian and bicycle access. The most common type of road diet involves converting a four-lane, undivided road into a three-lane road with two through lanes and a center turn lane. The space from the fourth lane can be repurposed to a bike lane, sidewalk, or parking lane. While recent studies have evaluated the effect of road diets on vehicle collisions (Huang, Stewart, and Zegeer 2004, Pawlovich, Wen, Carriquary, and Welch 2006), few to date have directly examined the pedestrian safety impacts. However, many of the components of road diet projects have been shown to have pedestrian safety benefits. The Federal Highway Administration lists the following benefits of a four- to three-lane road diet in their document Proven Safety Countermeasures: "Road Diet" (Roadway Reconfiguration):

1. "Decreasing vehicle travel lanes for pedestrians to cross, therefore reducing the multiple-threat crash" (1). Further evidence of the benefits of reducing roads with four or more lanes can be found in a 2001 study by Zegeer, et al., which found that two- and three-lane roads were associated with reduced pedestrian crash risk when compared to roads with four or more lanes (2).
2. "Providing room for a pedestrian crossing island" (1). Pedestrian islands have been demonstrated to increase pedestrian safety on roadways. Evaluation studies regarding the use of pedestrian crossing islands can be found in Section 2.4.
3. "Improving speed limit compliance and decreasing crash severity when crashes do occur" (1). Reducing vehicle speeds decreases vehicle stopping distance as well as decreases the likelihood of a pedestrian-vehicle collision resulting in a fatality. A 1987 U.K. Department of Transportation study found that the risk of pedestrian death is 5 percent at impacts of 20 mi/h, 45 percent at impacts of 30 mi/h, and 85 percent at impacts of 40 mi/h (3), indicating that decreasing average vehicle speed decreases injury severity and the probability of pedestrian fatality in the event of a collision.
4. Creating a buffer between pedestrians and traffic through the addition of bike lines and on-street parking (1). Such buffers increase safety by leading to lower vehicle speeds as well as an increase the perception of safety for pedestrians traveling on adjacent sidewalks, leading to greater pedestrian mobility.

Figure 28: Before and after pictures of a road diet project in California.

Photo source: http://www.catsip.berkeley.edu/road_diet_before_and_after

A 2012 article by Chen, Chen, Ewing, McKnight, Srinivasan, and Roe was one of the first to evaluate the effects of road diet projects specifically on pedestrian safety. The researchers used two-group pretest-protest research design to analyze total, pedestrian, injury, and fatal collision occurrence at 784 total roadway segment and intersection road diet sites in New York City. Collision data were collected for the treatment and comparison sites for the five years before road diet projects and the two years following them (5). The authors used ANCOVA analysis in order to account for potential regression-to-the-mean effects. Analysis of their results indicated that the average pedestrian crash rate on roadway segments decreased by 52.83 percent at treatment sites and by 3.67 percent at comparison sites. At intersections, pedestrian collisions increased by 3.48 percent at treatment sites, but decreased by 17.86 percent at comparison sites. This resulted in an ANCOVA-adjusted decrease in pedestrian collisions of 41 percent on roadway segments and an increase at intersection sites of 5 percent, results which were not significant at the 0.05 level (5). The results are summarized in the table below:

Table 10: Summary of the effects of road diet projects on pedestrian safety.

Location of road diet project	Group	Number of Intersections	Percent Change in Pedestrian Crash Rates	Adjusted Percent Change (ANCOVA analysis)	Significant at 0.05?
Roadway segment	Treatment	460	-52.83	-41	No
	Control	3362	-3.67		
Intersection	Treatment	324	3.48	+5	No
	Control	2346	-17.86		

Table with data from the Chen et al. article summarizing the effect of road diet projects evaluated in the article (0).

Figure 29: Before and after pictures of a road diet project in Illinois.

The picture on the left shows four lanes without a center turn lane, while the picture on the right shows three lanes with a center turn lane, bike lanes, and a pedestrian refuge island at the bus stop. http://www.vtpi.org/tdm/tdm122.htm

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References

1. Federal Highway Administration. *Proven Safety Countermeasures: "Road Diet" (Roadway Reconfiguration)*. Publication FHWA-SA-12-013, FHWA, U.S. Department of Transportation, year needed.
2. Zegeer, C. V., R. Stewart, H. Huang, and P. Lagerwey. *Safety Effects of Marked Versus Unmarked Crosswalks at Uncontrolled Locations: Executive Summary and Recommended Guidelines*. Publication FHWA-RD-01-075, FHWA, U.S. Department of Transportation, 2002.
3. U.K. Department of Transportation. *Killing Speed and Saving Lives*, U.K. Department of Transportation, London, 1987.
4. Highway Safety Information System. *Summary report: Evaluation of lane reduction "road diet" measures and their effects on crashes and injuries*. Publication FHWA-HRT-04-082, FHWA, U.S. Department of Transportation, 2006. http://www.fhwa.dot.gov/publications/research/safety/humanfac/04082/index.cfm
5. Chen, L., C. Chen, R. Ewing, C. McKnight, R. Srinivasan, and M. Roe. Safety Countermeasures and Crash Reduction in New York City—Experience and Lessons Learned. *Accident Analysis and Prevention*. In print, 2012. Retrieved July 23, 2012.

Section 4.4: Driveway Improvements

No information for this section.

Section 4.5: Raised Medians

See section 2.4 Crossing Islands

Section 4.6: One-Way/Two-Way Street Conversions

No information for this section.

Section 4.7: Access Management Design Solutions

No information for this section.

Section 4.8: Improved Right-Turn Slip Lane Design

No information for this section.

Section 5: Intersection Design

Section 5.1: Roundabouts

Modern roundabouts are a device to control the flow of traffic at intersections without the use of traffic signals or stop signs. The use of roundabouts in the United States dates back to 1905, but safety and efficiency concerns led to a limited use of roundabouts from the 1950s to the 1990s, with increasing use since then (*1*). Design speed differentiates older roundabouts from newer (known as "modern") roundabouts. Older roundabouts, built according to design standards from the 1940s or before, were designed to accommodate 35 mi/h entry speeds and 25 mi/h circulating speeds, while modern roundabouts are designed for 15-25 mi/h entry speeds in urban areas and 25-30 mi/h entry speeds in rural areas (2). While it has been demonstrated that roundabouts are safer for motorists than signalized intersections, the impact of roundabouts on pedestrian safety, especially for visually-impaired pedestrians, has been a subject of debate. One factor that complicates the ability to analyze roundabout performance is the low number of pedestrian crashes at any given intersection before and after roundabout conversion.

Figure 30: A modern roundabout.

An aerial photo of a modern roundabout. Photo by Dan Burden. http://safety.transportation.org/htmlguides/peds/description_of_strat.htm

In 1999-2000, the small town of Storuman, Sweden reconstructed an arterial road that passed through the its center, adding various traffic calming measures, including a roundabout. 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 roundabout treatment had significant effects on pedestrian safety, significantly changing both pedestrian and driver behavior. At the roundabout, drivers yielded to children 72 percent of the time, compared to 32 percent pre-treatment. Additionally, only 10 percent of children ran across the road following treatment, compared to 25 percent pre-treatment. Seventy-eight percent of pedestrians surveyed at the roundabout felt that it was safer to cross the arterial road at the roundabout than before (3).

A 2006 report by Harkey and Carter (4) whose results also appeared in the 2007 NCHRP Report (1) analyzed pedestrian safety as part of a broader analysis of roundabout safety. Using cameras mounted at roundabout sites, researchers collected data for 769 pedestrian crossings at 7 roundabouts. The study produced a number of observations of pedestrian and bicyclist behavior at roundabouts. Because there were no pre-treatment data available, it was unclear how pedestrians or motorists altered their behavior or travel patterns on account of the roundabouts. The data did not show any substantial safety concerns for pedestrians at roundabouts. Only 4 conflicts were observed between motorists and pedestrians, and no collisions were observed. Motorists did not yield to pedestrians upon entry of the roundabout 23 percent of the time, whereas upon exiting, they failed to yield 38 percent of the time, making the exit lane of the roundabout a greater safety concern for pedestrians. Similarly, motorists on two-lane roundabouts failed to yield 43 percent of the time, much higher than motorists on one-lane roundabouts, who yielded 17 percent of the time, making safety a greater concern at multiple-lane roundabouts. The authors also concluded that the safety of pedestrians may be compromised further at greater volumes of pedestrian and motorist traffic than that of the roundabouts they studied (4).

A 2012 Transportation Research Board presentation by Hourdos, Shauer and Davis discussed the results of an ongoing investigation into the effects of two urban roundabouts in Minneapolis and St. Paul, Minnesota on pedestrian accessibility. Researchers collected observational data on pedestrian/vehicle interactions at each of the roundabouts, which were used to quantify the types of crossing problems that pedestrians were having. The second phase of analysis involved studying the traffic conditions for drivers within the roundabout previous to the pedestrian/vehicle conflict. Logistic regression was used to analyze the probability that a driver would yield to a pedestrian, given different variables. Results showed that a majority of drivers failed to yield to pedestrians at both roundabouts, and that direction of traffic, vehicle entrance/exit, pedestrian position, level of traffic, number of lanes, and general design are factors which can influence driver yielding behavior within a roundabout (5).

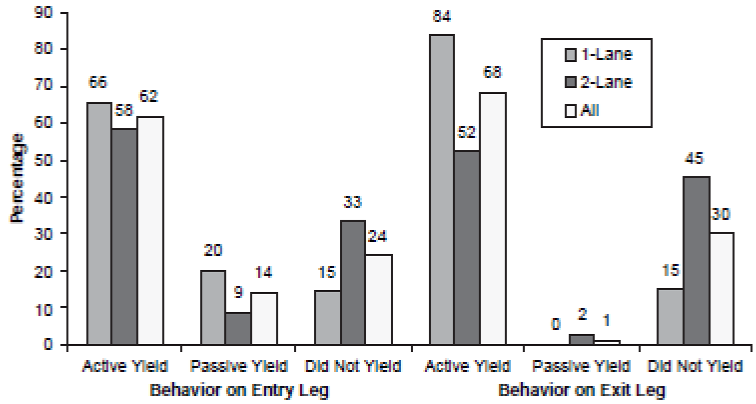

FIGURE 4 Yielding behaviors of motorists when pedestrian crossing began on entry leg.

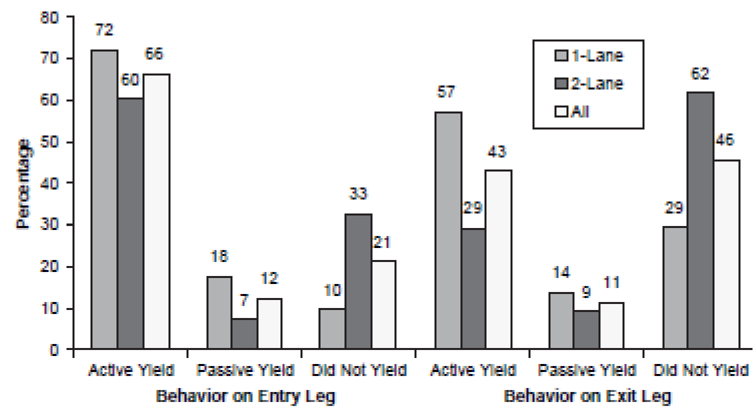

FIGURE 5 Yielding behaviors of motorists when pedestrian crossing began on exit leg.

Figure 31: Bar graphs showing data collected about motorist behavior at a roundabout.

Two graphs from the Harkey and Carter report showing the percentages of motorists who yielded to pedestrians crossing from the entry leg (Figure 4) and exit leg (Figure 5) (4).

Visually-Impaired Pedestrians at Roundabouts

Because roundabouts have relatively free-flowing traffic patterns and lack the more predictable pattern of traffic movement that is associated with signalized intersections, it can be much more difficult for visually-impaired pedestrians to judge gaps in traffic that allow crossing or determine that vehicles have yielded just upstream of the crosswalk using audible cues alone. A second challenge for roundabouts is that they often carry higher volumes than typical stopped controlled intersections (6). Visually-impaired pedestrians experience longer delays, greater assumption of risk, difficulty in locating the crosswalk, and difficulty in detecting yielding drivers.

A 2000 Access Board report by Guth, Long, Ponchillia, Ashmead and Wall evaluated the ability of blind pedestrians to detect safe crossing gaps at three Baltimore, Maryland roundabouts. At each of the roundabouts, blind and sighted participants were instructed to push a button whenever they thought they could complete a crossing before a vehicle arrived during a two-minute trial. Another sighted observer used a button to record the arrival of vehicles at the crosswalk, and the researchers calculated whether the blind participants would have had sufficient time to reach the splitter island before the vehicle arrived. The researchers found that the blind participants were twice as likely to make risky crossing judgements (crossings that might lead to vehicle-pedestrian conflicts) than were sighted participants. Blind participants also detected acceptable crossing gaps approximately 3 seconds later than the sighted participants. More highly-trafficked roundabouts were more problematic for blind pedestrians, leading to higher levels of ambient noise and higher numbers of entering, exiting, and circulating vehicles to monitor. The researchers concluded that there are important differences in the abilities of sighted and blind participants to safely navigate roundabouts which have practical implications for the design of safe roundabouts for all pedestrians (7).

A 2005 article by Geruschat and Hassan evaluated motorist yielding to blind and sighted pedestrians at roundabouts under six different conditions at two sites in Annapolis, Maryland. The researchers acted as decoy pedestrians, and three different pedestrian behaviors were tested: waiting one foot from the curb, waiting at the curb, and waiting with both ft in the crosswalk. The pedestrians tested all three behaviors with and without the white cane and crossing technique taught to blind pedestrians, for a total of six crossing conditions. The experiment involved 960 trials: 40 crossings at the entry and exit leg of each roundabout under the six crossing conditions. Each crossing was timed to give the driver adequate time and distance to yield (35 ft for roundabout 1 and 50 ft for roundabout 2) (8).

A second component of the experiment was recording vehicle speed to study its impact on driver yielding. It was found that approximately 75 percent of drivers yielded at less than 15 mi/h, while less than 50 percent yielded at speeds greater than 20 mi/h. In this experiment, it was found that 52 percent of yielding behavior was accounted for by vehicle speed. The researchers observed that drivers who were entering the roundabout were 6.4 times as likely to yield to pedestrians as drivers who were exiting the roundabouts. Regarding pedestrian behavior, across all trials, drivers yielded 45 percent of the time for pedestrians 1 foot from the curb, 52 percent of the time for pedestrians at the curb, and 60 percent of the time for pedestrians standing in the crosswalk, and the differences between yield percentages were statistically significant. There was also a statistically significant difference in yielding between pedestrians who used or did not use a cane. Drivers yielded 52 percent of the time for pedestrians without a cane, and 63 percent of the time for pedestrians with a cane. The authors concluded that various factors determined motorist yielding at roundabouts, including speed, entry versus exit, pedestrian behavior, and motorist perception of pedestrian impairment (8).

A 2005 *Journal of Transportation Engineering* article by Ashmead, Guth, Wall, Long, and Ponchillia gave a report of observations regarding both sighted and visually-impaired pedestrians making crossings at a roundabout in the United States. Given the low rates of pedestrian crashes at roundabouts in general, as well as the low number of visually-impaired pedestrians in the population, measures of effectiveness were used to gauge the safety effects of roundabouts on pedestrians in this study. Six blind and six sighted adults participated in the study. During one high-traffic and one low-traffic session, each participant performed six crossing trials at the two-lane roundabout. It was found that, compared to sighted pedestrians, blind pedestrians experienced delays that were three times as long in beginning to cross, failure to perceive driver yielding, and failure to gauge crossing opportunities as well as greater risk exposure from higher incidence of risky crossing attempts. Even though the blind study participants were able to use auditory cues to cross the roundabout, none felt comfortable navigating the intersection. The authors concluded by calling for further development of roundabout modifications that would make roundabout crossings safer for visually-impaired pedestrians (9).

A 2006 report by Inman, Davis, and Sauerburger described the results of two studies meant to assess the accessibility of double-lane roundabouts for visually impaired pedestrians. The first study evaluated the use of rumble strip-like treatments placed on the roadway in order to provide an auditory signal of driver yielding. The experiment took place on a closed course with treatment and control conditions. The researchers carried out an analysis of the participants' ability to detect stopping or departing vehicles, and found that the sound strips did increase the probability of detecting stopped vehicles and decrease the time needed to detect vehicle by one second. However, there was no reduction in the number of false detections, undermining the use of the treatment to create safer crossing conditions for visually impaired pedestrians at double-lane roundabouts. The second study was conducted at an existing double-lane roundabout site to examine driver yielding behavior in addition to the effectiveness of the rumble strips. An in-roadway yield to pedestrians sign was placed in the roundabout as well as a more specific sign on the side of the road indicating the crosswalk and the requirement to yield. Observations were made during control and treatment phases of the experiment. In the second study, the rumble strip treatment was not effective in alerting visually impaired pedestrians of vehicle movements. While the in-roadway yield to pedestrians sign led to an increase in driver yielding from 11 percent in the control condition to 16 percent in the treatment condition, overall yielding rates remained low. The authors concluded that the treatments did not appear promising to enhance safety for visually impaired pedestrians at double-lane roundabouts, although they might be more useful at single-lane crossings (10).

Figure 32: A roundabout treated with sound strips.

Photos showing the roundabout evaluated in the Inman, Davis, and Sauerburger article showing the roundabout pre-treatment (left) and post-treatment with sound strips and street sign (right) (10).

A 2009 article by Schroeder, Rouphail, and Hughes presents the results of the development of an analysis framework and performance measure for quantifying the accessibility of crossings at roundabouts for blind pedestrians. The four accessibility components identified by the researchers were the existence of crossing opportunities, the ability of pedestrians to use those opportunities, duration of delay in initiating crossing, and the overall assumption of risk when crossing. The researchers tested their analytical framework at two North Carolina roundabouts with the help of blind study participants. While the authors hypothesized that pedestrian and driver behavior would play a greater role in pedestrian safety than traffic volumes and site geometry, they found safety in crossing to be due to a number of variables. They found that the higher-volume roundabout they studied was more usable from a delay perspective, while the lower-volume roundabout was safer. They concluded that their framework provided a starting point for quantifying roundabout features in order to study how they pertain to roundabout safety for blind pedestrians (11).

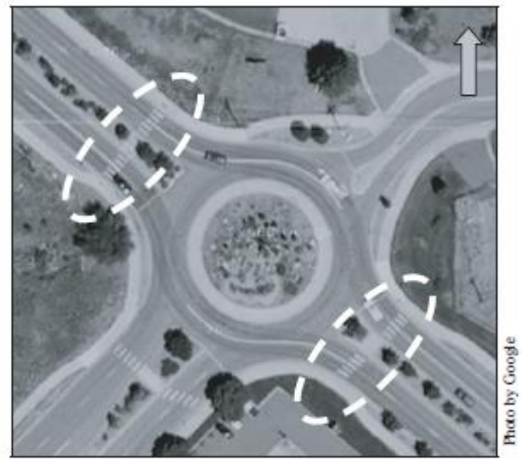

Figure 33: Aerial photograph of a roundabout site, showing study locations.

A photograph from the report showing the two study locations on the double-lane roundabout in Golden, Colorado (12).

A 2011 NCHRP report by Schroeder et al. studied various roundabouts from a visually-impaired pedestrian safety perspective. The research team summarized the results of the above trial and explored the safety effectiveness of raised crosswalks and HAWK beacons at a two-lane roundabout in Golden, Colorado. The researchers used quasi-experimental research design, collecting pre- and post-treatment data regarding pedestrian and motorist data for blind pedestrian crossings. To evaluate the raised crosswalk, a temporary raised crosswalk was installed on one approach of the roundabout. Following the installation of the raised crosswalk, opportunities for blind pedestrians to cross both lanes of traffic increased from 56 percent to 76.9 percent, utilization of those opportunities increased from 88.3 percent to 98.1 percent, and average crossing delay decreased from 17 seconds to 8 seconds, all of which were statistically significant at the 0.05 level. Following the installation of the HAWK beacon, which was installed on the opposite approach of the roundabout, opportunities for pedestrians to cross both lanes of traffic increased from 55.5 percent to 89.3 percent, utilization of those opportunities increased from 91.6 percent to 98.3 percent, and average crossing delay decreased from 16 seconds to 5.8 seconds, all of which were statistically significant at the 0.05 level (12).

Table 11 : Results from a performance study of a roundabout enhanced with raised crosswalks.

Performance Measures	Raised Crosswalk			
	Pre	**Post**	**Difference**	**p-value**
Percent Dual Opportunities	56.0	76.9	20.9	0.0003
Percent Single Opportunities	12.5	7.8	-4.7	0.0842
Percent No Opportunities	31.5	15.3	-16.2	0.0016
Percent Dual Utilization	88.3	98.1	9.8	0.0062
Percent Single Utilization	12.9	15.2	2.3	0.7980
Percent No Utilization	2.0	7.6	5.7	0.3257
Average Delay (s)	17.0	8.0	-9.0	0.0434
Delay>Min (s)	3.4	2.3	-1.1	0.2117
85th Percentile Delay (s)	29.8	12.9	-16.9	--
Percent O & M Interventions	2.8	0.0	-2.8	0.0230

Table 7 from the report, showing the crossing performance summary for the raised crosswalk (RCW) pre- and post-treatment (12).

Table 12: Results from a performance study of a roundabout enhanced with pedestrian hybrid beacons.

Performance Measures	Pedestrian Hybrid Beacon			
	Pre	**Post**	**Difference**	**p-value**
Percent Dual Opportunities	55.5	89.3	33.8	<.0001
Percent Single Opportunities	15.0	4.1	-10.9	0.0001
Percent No Opportunities	29.5	6.6	-23.0	<.0001
Percent Dual Utilization	91.6	98.3	6.7	0.0062
Percent Single Utilization	8.8	8.3	-0.5	0.9468
Percent No Utilization	0.0	0.0	0.0	--
Average Delay (s)	16.0	5.8	-10.2	0.0007
Delay>Min (s)	3.2	1.4	-1.8	0.0044
85th Percentile Delay (s)	29.5	7.7	-21.8	0.0001
Percent O & M Interventions	2.4	0.0	-2.4	0.0112

Table 8 from the report, showing the crossing performance summary for the HAWK or pedestrian hybrid beacon (PHB) pre- and post-treatment (12).

References

1. Rodegerdts, L, M. Blogg, E. Wemple, E. Myers, M. Kyte, M. Dixon, G. List, A. Flannery, R. Troutbeck, W. Brilon, N. Wu, B. Persaud, C. Lyon, D. Harkey, and D. Carter. *Roundabouts in the United States*. NCHRP Report 572. Transportation Research Board, Washington, D.C., 2007.
2. Persaud, B.N., Retting, R.A., Garder, P.E., and Lord, D. Safety Effect of Roundabout Conversions in the United States: Empirical Bayes Observational Before-After Study. In *Transportation Research Record: Journal of the Transportation Research Board*, No. 1751, Transportation Research Board of the National Academies, Washington, DC, 2001, pp. 1-8.
3. Leden, L., P. E. Wikstrom, P. Garder, and P. Rosander. Safety and Accessibility Effects of Code Modifications and Traffic Calming of an Arterial Road. *Accident Analysis and Prevention*, Vol. 38, No. 3, 2006, pp. 455-461.
4. Harkey, D. L., and D. L. Carter. Observational Analysis of Pedestrian, Bicyclist, and Motorist Behaviors at Roundabouts in the United States. In *Transportation Research Record: Journal of the Transportation Research Board*, No. 1982, Transportation Research Board of the National Academies, Washington, DC, 2006, pp. 155-165.
5. Hourdos, J., M. Shauer and G. A. Davis. An Observational Study of Pedestrian and Bicycle Crossing Experience in Two Modern Urban Roundabouts. Presented at the 91st Annual Meeting of the Transportation Research Board, Washington, DC, 2012.
6. Schroeder, B., et al. *Crossing Solutions at Roundabouts and Channelized Turn Lanes for Pedestrians with Vision Disabilities*. NCHRP Report 674. Transportation Research Board, Washington, D.C., 2011.
7. Guth, Long, Ponchillia, Ashmead, and Wall. *Non-Visual Gap Detection at Roundabouts by Pedestrians who are Blind: A Summary of the Baltimore Roundabouts Study*. United States Access Board, Washington, D.C., 2000.
8. Geruschat, D. R. and S. E. Hassan. Driver Behavior in Yielding to Sighted and Blind Pedestrians at Roundabouts. *Journal of Visual Impairment and Blindness*. Vol. 99, No. 5, 2005.
9. Ashmead, D. H., D. Guth, R. S. Wall, R. G. Long, and P. E. Ponchillia. Street Crossing by Sighted and Blind Pedestrians at a Modern Roundabout. *Journal of Transportation Engineering*. Vol. 131, No. 11, 2005, pp. 812-821.
10. Inman, V. W., G. W. Davis and D. Sauerburger. *Pedestrian Access to Roundabouts: Assessment of Motorists' Yielding to Visually Impaired Pedestrian and Potential Treatments to Improve Access*. Federal Highway Administration, Washington, D.C., 2006.
11. Schroeder, B. J., N. M. Rouphail, and R. G. Hughes. A Working Concept of Accessibility - Performance Measures for the Usability of Crosswalks for Pedestrians with Vision Impairments. In *Transportation*

Research Record: Journal of the Transportation Research Board, No. 2140, Transportation Research Board of the National Academies, Washington, D.C., 2009, pp. 103-110.

12. Schroeder, B., R. Hughes, N. Rouphail, C. Cunningham, K. Salamati, R. Long, D. Guth, R. W. Emerson, D. Kim, J. Barlow, B.L. Bentzen, L. Rodegerdts, and E. Myers. *NCHRP Report 674: Crossing Solutions at Roundabouts and Channelized Turn Lanes for Pedestrians with Vision Disabilities*. Transportation Research Board of the National Academies, Washington, D.C., 2011.

Section 5.2: Modified T-Intersections

No information for this section.

Section 5.3: Intersection Median Barriers

No information for this section.

Section 5.4: Curb Radius Reduction

No information for this section.

Section 5.5: Skewed Intersections

No information for this section.

Section 5.6: Pedestrian Accommodations at Complex Intersections

No information for this section.

Section 6: Traffic Calming

Section 6.0: Comprehensive Traffic Calming

The objective of traffic calming is usually to reduce traffic speed or volume, reduce conflicts between local traffic and through traffic, make it easier for pedestrians to cross the road, and reduce traffic noise. Traffic calming can be applied both in residential areas and on roads that have commercial roadside development. A 2001 meta-analysis of 33 studies of traffic calming by Elvik concluded that area-wide traffic calming schemes reduced the number of injury collisions for all road users by about 15 percent, with greater effects on residential streets (a reduction of about 25 percent) than main roads (about 10 percent) (1).

Measures that are part of traffic calming include:

- Narrowing driving lanes, often by widening sidewalks
- Installing chokers or curb bulbs
- Using cobblestone in short sections of the road
- Providing raised crosswalks or speed humps
- Installing transverse rumble strips, usually at the start of the treated roadway segment
- Providing parking bays

Applying traffic calming measures on residential streets

The purpose of traffic calming is to reduce vehicular volumes and speeds on residential streets, which, in turn promotes a more pedestrian-friendly environment. Thirteen types of traffic-calming measures were listed in a 1994 ITE document. Those measures included street closures, cul-de-sacs, diverters, traffic circles, shared street design, chicanes, flares/chokers, speed humps, speed limit signs and speed zones, enforcement programs, walkways, parking controls, and other signage (2).

Ewing's 1999 report *Traffic Calming: State of the Practice* gives an overview of pre-1999 traffic calming project evaluations carried out in the United States. Since sample size, research design, data collection methods and durations were not standardized, Ewing cautions that the statistics should be used as ballpark estimates of impact. The table below summarizes the effects of various traffic calming measures on downstream vehicle speeds. More detailed information regarding study sites and individual site results can be found in Appendix A of the document (3).

Table 13: Speed impacts downstream of various traffic calming measures

Speed Impacts Downstream of Traffic Calming Measures				
		85th Percentile Speed (mi/h)		
Sample Measure	**Sample Size**	**Average After Calming**	**Average Change After Calming**	**Percentage Change**
12-foot humps	179	27.4 (4.0)	-7.6 (3.5)	-22 (9)
14-foot humps	15	25.6 (2.1)	-7.7 (2.1)	-23 (6)
22-foot tables	58	30.1 (2.7)	-6.6 (3.2)	-18 (8)
Longer tables	10	31.6 (2.8)	-3.2 (2.4)	-9 (7)
Raised intersections	3	34.3 (6.0)	-0.3 (3.8)	-1 (10)
Circles	45	30.3 (4.4)	-3.9 (3.2)	-11 (10)
Narrowings	7	32.3 (2.8)	-2.6 (5.5)	-4 (22)
One-lane slow points	5	28.6 (3.1)	-4.8 (1.3)	-14 (4)
Half closures	16	26.3 (5.2)	-6.0 (5.2)	-19 (11)
Diagonal diverters	7	27.9 (5.2)	-1.4 (4.7)	-4 (17)

*** Measures within parentheses represent the standard deviation from the average.**

Table from Traffic Calming: State of the Practice giving a summary of the effects of different traffic calming measures on downstream vehicle speeds (3).

A 2001 Federal Highway Administration report by Huang and Cynecki looked at how various traffic-calming techniques (bulbouts, raised intersections, and raised crosswalks) affected the behavior of pedestrians and drivers at midblock and intersection locations in seven states in the U.S. Traffic-calming devices resulted in lower overall vehicle speeds. Combining a raised crosswalk with an overhead flasher increased motorist yielding behavior, although it was not possible to separate the relative effect of the two aspects of this modification. No other treatments significantly changed the percentage of pedestrians for who the drivers yielded. The various traffic-calming measures did not produce a statistically significant effect on average pedestrian waiting time. It was found that refuge islands

Figure 34: Dynamic Striping along Vermont Route 30.

channelized people into marked crosswalks and that a raised intersection in one location had the same effect (4).

A 2007 report published by the Vermont Agency of Transportation evaluated an innovative series of pavement markings called "Dynamic Striping," intended to call attention to speed limit decreases at four town limits along Vermont Route 30. Researchers collected pre- and post-treatment traffic speeds, finding an average decrease in speed of 0.1 mi/h one week following treatment, and an average decrease of 1.0 mi/h four months after treatment. Research indicated that the markings may have had a greater impact on drivers who used the roads on a daily basis than those that did not (5).

A 2009 article by Grundy et al. used 20 years of police-reported pedestrian collisions to examine the effect of implementing 20 mi/h zones throughout London. Injury counts were compared in the before- and after-intervention periods, as well as between streets with and without the intervention. Information about the dates, locations, and types of collisions from 1986-2006 were geocoded using a geographic information system (GIS), and each roadway segment within the planned 20 mi/h zones was given a code of "pre-intervention," "under construction," or " post-implementation" for each year of the study. A conditional fixed effects Poisson model was used to estimate the change in injuries as the 20 mi/h speed zones were implemented. Results of the analysis indicated that all pedestrian injuries decreased by 32.4 percent on roadways that became 20 mi/h speed zones (95% C.I., 27.1% to 37.7%). The number of pedestrians who were killed or seriously injured decreased by 34.8 percent (95% C.I., 22.2% to 47.5%). Decreases were even more pronounced for children (pedestrians age 0-15), with a decrease in 46.2 percent for all injuries (95% C.I., 36.8% to 55.5%), and 43.9 percent for collisions leading to fatalities or serious injuries (26.6% to 61.3%). All reductions were statistically significant at 0.05. An analysis of roadways in areas adjacent to the speed zones indicated that injuries were not being displaced to nearby roads. The researchers estimated that the percentage decrease in risk was equal to 51 prevented pedestrian injury or fatality collisions. The researchers concluded that the 20 mi/h speed zones were effective in reducing pedestrians' risk of injury or death, with the greatest benefits observed for children under age 15. (6)

Figure 35. A sign at the entrance to a 20 mi/h speed zone in Manchester, England.

A 2014 systematic review by Rothman et al. synthesized the results of 50 walking and 35 child pedestrian injury studies to calculate the effect of different built environment characteristics on child pedestrian injury. Studies were restricted to those that were quantitative, in an urban or suburban study area, and from motorized countries and that had built environment characteristics as their predictor variable and had walking or child pedestrian injury as the outcome variable. The results of the systematic review indicated that traffic calming was consistently associated with a greater amount of walking and less pedestrian injury. The researchers concluded that built environment features that slowed traffic down had a positive effect on the safety of child pedestrians. (7)

A 2014 analysis of the relationship between motor vehicle speed and the percentage of motorists yielding to pedestrians found that speed plays an important role in motorist yielding. The 2014 Transportation Research Board paper by Bertulis and Dulaski analyzed the association between motor vehicle speed and motorist yielding rates at nine crosswalk locations in Boston and Brookline, Massachusetts. First, the researchers measured the 85th percentile speed at each site using radar. They then marked the standard stopping distance (SDD), calculated using AASHTO guidelines, with a cone. To measure yielding behavior, the researchers conducted staged crossings at each site, recording yielding behavior only when vehicles approached within two mi/h of the recorded 85th percentile speed. One hundred yielding or no-yielding events were recorded for each of the nine crosswalks. The results of their analysis indicated that speed was inversely correlated with the percentage of yielding vehicles. At the site with the lowest recorded 85th percentile speed of 20 mi/h, motorists yielded to crossing pedestrians 75 percent of the time. At the site with the highest 85th percentile speed of 38 mi/h, motorists yielded to crossing pedestrians 9 percent of the time. The results at each site were statistically significant. A regression analysis of the relationship between vehicle speed and yielding indicated a nearly linear relationship. As a result of their analysis, the researchers noted that the characteristics of the crossing location affected the 85th percentile speed more than the posted speed limit, and that the 85th percentile speed plays a major role in whether motorists yield to pedestrians at crossing locations. Therefore, the types of engineering treatments used in traffic calming would be expected to increase motorist yielding at crosswalk locations. (8)

Figure 36. A Pedestrian conducts a staged crossing.

Table 14. Motorist Yielding Rates and 85th Percentile Speeds Recorded at Nine Massachusetts Sites

Location	85th percentile speed	Number of lanes	On-street parking	Land use	Percent of yielding motorists
Auckland St. at Savin Hill Ave.	20	2	Yes	Mixed use	75%
Gibson St. at Dorchester Ave.	22	2	Yes	Mixed use	73%
St. Paul St. at Sewall Ave.	23	2	Yes	Residential	63%
Dorchester Ave. at Van Winkle St.	27	2	Yes	Residential	52%
Mayfield St. at Pleasant St.	29	2	Yes	Residential	42%
King St. at Adam St.	30	2	No	Residential	40%

Peak Hill Rd. at W Roxbury Pkwy.	37	4	Yes	Residential	19%
Fletcher St. at Centre St.	37	2	Yes	Residential	17%
Hyde Park Ave. at Eldridge Rd.	38	2	No	Mixed use	9%

References

1. Elvik, R. Area-wide Urban Traffic Calming Schemes: A Meta-Analysis of Safety Effects. *Accident Analysis and Prevention*, Vol. 33, No. 3, 2001, pp. 327-336.
2. Kemper, B. and P. Fernandez. *Design and Safety of Pedestrian Facilities*. Institute of Transportation Engineers, Washington, D.C., 1994.
3. Ewing, R. H. *Traffic Calming: State of the Practice*. Publication FHWA-RD-99-135, FHWA, U.S. Department of Transportation, 1999.
4. Huang, H. F. and M. J. Cynecki. *The Effects of Traffic Calming Measures on Pedestrian and Motorist Behavior*. Publication FHWA-RD-00-104, FHWA, U.S. Department of Transportation, 2001.
5. Fitch, J. and N. Crum. *Dynamic Striping in Four Towns Along Vermont Route 30 – Final Report*. Vermont Agency of Transportation, Montpelier, VT, 2007.
6. Grundy, C., R. Steinbach, P. Edwards, J. Green, B. Armstrong, and P. Wilkinson. Effect of 20 mph Traffic Speed Zones on Road Injuries in London, 1986-2006: Controlled Interrupted Time Series Analysis. BMJ, Vol. 339, 2009, pp. 1-6. Doi:10.1136/bmj.b4469
7. Rothman, L., R. Buliung, C. Macarthur, T. To, and A. Howard. Walking and Child Pedestrian Injury: A Systematic Review of Built Environment Correlates of Safe Walking. *Injury Prevention*, Vol. 20, 2014, pp. 41-49.
8. Bertulis, T., and D. M. Dulaski. Driver Approach Speed and its Impact on Driver Yielding to Pedestrian Behavior at Unsignalized Crosswalk. Presented at the 93rd Annual Meeting of the Transportation Research Board, Washington, D.C., 2014.

Section 6.1: Chokers

No information for this section.

Section 6.2: Chicanes

No information for this section.

Section 6.3: Mini Circles

No information for this section.

Section 6.4: Speed Humps

A 2001 article by Huang and Cynecki evaluated a number of traffic calming countermeasures including raised crosswalks and raised intersections (1). In their literature review section, they summarized previous speed hump evaluation studies in different cities. While few examine the direct impact of the treatment on pedestrian safety, they give examples of where speed humps were used successful to encourage slow vehicle speeds:

- A 1993 study by Klik and Faghri looked at pre- and post-treatment vehicle speeds at 10 locations where speed humps were installed in Omaha, Nebraska. Analysis of the results showed a statistically significant reduction in

85th percentile speeds. A review of data collected from 19 locations revealed a decrease in injury accidents at those sites (2).

- A 1994 Federal Highway Administration publication by Clarke and Dornfeld considered the impact of 16 speed humps installed in 5 residential neighborhoods in Bellevue, Washington. Before speed hump installation, 85th percentile speeds ranged from 36 to 39 mi/h, while following speed hump installation, they decreased to 24 to 27 mi/h (3).
- Two evaluation efforts in Maryland showed the effects of speed humps on 85th percentile speeds on roadways. In Montgomery County, a 1998 program evaluation by Loughery and Katzman of speed hump installation indicated that using the treatment led to a decrease in 85th percentile speeds of 4 to 7 mi/h (4). In adjacent Howard County, a 1995 ITE Journal article by Walter reported that 85th percentile speeds decreased by 9 to 23 mi/h (5).
- A 1993 presentation by Cline evaluated the use of 5 speed bumps on a road in Agoura Hills, California. Following their installation, 85th percentile vehicle speeds decreased by 6 to 9 mi/h. Other speed humps were used in Westlake Village, California, leading to a 9 to 14 mi/h reduction in 85th percentile speeds (6).

More recently, a 2012 article by Chen, Chen, Wing, McKnight, Srinivasan, and Roe evaluated the pedestrian safety impact of installing speed humps on roadway segments and at intersections. The researchers used two-group pretest-posttest research design to compare pedestrian collision statistics following the installation of 601 speed humps on roadway segments and 1087 intersection sites throughout New York City. Pedestrian collision statistics were collected for the five years preceding speed hump installation and two years following it, and the authors used ANCOVA in their analysis in order to control for potential regression-to-the-mean effects. Analysis of their results indicated that the average pedestrian crash rate on roadway segments decreased by 41.63 percent at treatment sites and by 7.11 percent at comparison sites. At intersections, pedestrian collisions decreased by 12 percent at treatment sites, but by 13.24 percent at comparison sites. This resulted in an ANCOVA-adjusted increase in pedestrian collisions of 8 percent on roadway segments and 3 percent, results which were not significant at the 0.05 level (7).

References

1. Huang, H. F. and M. J. Cynecki. *The Effects of Traffic Calming Measures on Pedestrian and Motorist Behavior*. Publication FHWA-RD-00-104, FHWA, U.S. Department of Transportation, 2001.
2. Klik, M. and A. Faghri. A Comparative Evaluation of Speed Humps and Deviations. *Transportation Quarterly*, Vol. 47, No. 3, 1993, pp. 457-469.
3. Clarke, A. and M.J. Dornfeld. *Traffic Calming, Auto-Restricted Zones and Other Traffic Management Techniques - Their Effects on Bicycling and Pedestrians, Case Study No. 19, National Bicycling and Walking Study*. Publication No. FHWA-PD-93-028, Federal Highway Administration, Washington, DC, 1994.
4. Loughery, D. A. and M. Katzman. *Montgomery County, Maryland Speed Hump Program Evaluation Report*. Prepared for presentation to the Montgomery County Council, 1998.
5. Walter, C.E. Suburban Residential Traffic Calming. *ITE Journal*, Vol. 65, No. 9, 1995, pp. 44-48.
6. Cline, E. Design of Speed Humps...Or 'The Kinder, Gentler Speed Hump.' Presented at the 45th California Symposium on Transportation Issues, 1993.

7. Chen, L., C. Chen, R. Ewing, C. McKnight, R. Srinivasan, and M. Roe. Safety Countermeasures and Crash Reduction in New York City—Experience and Lessons Learned. *Accident Analysis and Prevention*. In print, 2012. Retrieved July 23, 2012.

Section 6.5: Speed Tables

No information for this section

Section 6.6: Gateways

No information for this section.

Section 6.7: Landscaping

No information for this section.

Section 6.8: Specific Paving Treatments

No information for this section.

Section 6.9: Serpentine Designs

No information for this section.

Section 7: Traffic Diversion

Section 7.1: Diverters

No information for this section.

Section 7.2: Full Street Closure

No information for this section.

Section 7.3: Partial Street Closure

No information for this section.

Section 7.4: Left Turn Prohibitions

No information for this section.

Section 8: Signals and Signs/Traffic Control Devices

Section 8.1: Traffic Signals

A comprehensive study of pedestrian signal heads was performed in 1982 and 1983 by Zegeer et al. The researchers analyzed data from 1,297 urban signalized intersections involving a total of 2,081 pedestrian crashes in 15 U.S. cities (1,2). The four pedestrian timing patterns used at the 1,297 signalized intersections in the study are summarized below. Marked crosswalks existed at nearly all of the intersections. Of the 1,297 intersections, 508 did not have pedestrian signal heads (i.e., WALK – DON'T WALK).

Table 15: Definitions and frequencies of pedestrian signal timing patterns observed in one research study

Pedestrian timing pattern	Study intersections	Description
Concurrent (standard)	658 (50.7percent)	Gives pedestrians a WALK interval at the same time that parallel traffic has a green light. During this phase, vehicles may also turn right or left across the pedestrian's path when safe to do so. Concurrent timing is the type most often used in the U.S.
None	508 (39.2percent)	Pedestrians are expected to comply with the vehicular signal heads.
Exclusive	109 (8.4percent)	Gives pedestrians a phase during each signal cycle where motor traffic is stopped in all directions so that pedestrians may take advantage of the interval to cross the street. A variation of this timing strategy is the "scramble" or "Barnes Dance" phase, which allows pedestrians to cross diagonally through the intersection as well as across the intersecting roadways
Early release or Late release	22 (1.7percent)	Early: Gives pedestrians a head start in each cycle before allowing motorists to make right or left turnsLate: Makes pedestrians wait to cross until after vehicles have turned

Table from Zegeer et al. showing the definitions and frequencies of signal timing patterns studied by the research team (1,2).

The Zegeer team found a statistically significant relationship between increased pedestrian crashes and factors such as higher pedestrian and vehicle volumes, two-way (vs. one-way) roads, wider streets, higher bus use, and greater percentage of turning movements. Compared with traffic signals without pedestrian signal heads, concurrent timing had no statistically significant effect on pedestrian crashes. Exclusive timing produced statistically significant fewer (about half) of the pedestrian crashes as concurrent timing or signals with no pedestrian signals. However, this was only true at locations with pedestrian volumes of more than 1,200 people per day (1, 2). There was insufficient sample size (22 sites) of early release and late release signal timing to determine the safety effect of those timing schemes.

Zegeer et al. controlled for the effects of pedestrian volume, traffic volume, intersection geometrics, etc. The results of the study are summarized below. The researchers suggested the following possible reasons that concurrent signal timing was not found to be effective in reducing pedestrian crashes (1*, 2*):

- Many pedestrians misunderstand the meaning of signal messages such as the flashing DON'T WALK, which is intended to alert pedestrians that they should not enter the street now but should finish crossing if they've already started;
- Some pedestrians have the incorrect assumption that a WALK interval stops traffic in all directions, including turns;
- Many pedestrians do not comply with pedestrian signals (e.g., 65.9 percent of the pedestrians at 64 intersection approaches were observed to begin crossing the street during the flashing or steady DON'T WALK phase);
- Many pedestrians seem reluctant to use the push buttons that activate pedestrian signals (only 51.3 percent of all pedestrians in the study used the button to activate the crossing signal).

Based on their research, Zegeer et al. recommended that highway agencies should not automatically install pedestrian signals at all locations that have traffic signals. Each site should be evaluated in terms of cost versus effectiveness (1*, 2*). However, the authors affirm the need for pedestrian signals at certain types of locations including school crossings, on wide streets, or places where the vehicular traffic signals are not visible to pedestrians.

Research in Israel (3) in 1987 evaluated the safety effects of concurrent and exclusive signal timing, compared to no pedestrian interval. A total of 320 signalized intersections in Tel Aviv, Jerusalem, and Haifa were included in this study, with analysis of 1,310 pedestrian accidents and 5,132 vehicle crashes. Higher rates of pedestrian crashes were found at intersections with the higher pedestrian and vehicle volumes, as well as at more complex intersections, such as those with greater numbers of legs or potential points of conflict. The type of signal timing provided for pedestrians had only a slight effect on pedestrian crashes and no effect on vehicle injury crashes, especially where vehicle volumes were low (less than 18,000 ADT). Intersections with exclusive phases for pedestrians had fewer crashes where vehicle and pedestrian volumes were higher (3). These results concur with the results of Zegeer et al. (1, 2).

Using a literature review, an analysis of pedestrian crashes, a delay analysis, and a benefit-cost analysis, a 1984 study by Robertson and Carter found that pedestrian signal indications reduce pedestrian crashes at some intersections, have little or no effect at others, and may actually increase crashes at yet other sites (4). The presence of pedestrian signals in itself did not have a statistically significant effect on pedestrian and vehicle delay, but the signal timing scheme had a major influence on delay. As a result of this study, the authors suggested further study to identify the types of intersections where pedestrian signals would be most effective.

Table 16: Summary of effects of pedestrian signal timing on pedestrian crashes

Comparison	Dependent Variable (per year)	Adjusted Means (Sample Sizes in Parentheses)	Significant Difference (0.05 level)	Level of Significance
All Ped. Signal Alternatives	Mean Pedestrian Crashes	No Ped. Signal: 0.36 (508) Concurrent: 0.40 (658) Exclusive: 0.22 (109) Other: 0.38 (22)	Yes	0.001
	Mean Pedestrian Turning Crashes	No Ped. Signal: 0.13 (508) Concurrent: 0.17 (658) Exclusive: 0.01 (109) Other: 0.20 (22)	Yes	0.001
No. Ped. Signal Indication vs. Concurrent Ped. Signal Timing	Mean Pedestrian Crashes	No Ped. Signal: 0.36 (508) Concurrent: 0.40 (658)	No	0.130
	Mean Pedestrian Turning Crashes	No Ped. Signal: 0.12 (508) Concurrent: 0.15 (658)	Yes	0.048
No. Ped. Signal Indication vs. Exclusive Ped. Signal Timing	Mean Pedestrian Crashes	No Ped. Signal: 0.33 (508) Exclusive: 0.15 (109)	Yes	0.001
	Mean Pedestrian Turning Crashes	No Ped. Signal: 0.11 (508) Exclusive: 0.00 (109)	Yes	0.001
Concurrent Ped. Signal Timing vs. Exclusive Ped. Signal Timing	Mean Pedestrian Crashes	Concurrent: 0.43 (658) Exclusive: 0.27 (109)	Yes	0.001
	Mean Pedestrian Turning Crashes	Concurrent: 0.17 (658) Exclusive: 0.03 (109)	Yes	0.001

For each comparison, control variables were: Pedestrian Volume (AADT), Total Traffic Volume (AADT), Street Operation (One-Way/Two-Way), Ped. Signal Alternatives

Much more recently, a 2012 article by Chen, Chen, Ewing, McKnight, Srinivasan, and Roe considered the effect on pedestrian safety of installing signals at previously unsignalized intersections. The researchers used a two-group pretest-posttest research design to compare collision statistics following the installation of 447 new traffic signals installed at non-signalized intersections throughout New York City based on MUTCD warrants. Pedestrian collision statistics were collected for the five years preceding signal installation and two years following it, and the authors used ANCOVA in their analysis in order to control for potential regression-to-the-mean effects. Analysis of their results indicated that the average pedestrian crash rate increased by 11.9 percent at treatment sites and by 60 percent at comparison sites. This resulted in an ANCOVA-adjusted increase in pedestrian collisions of 1 percent at signalized sites, results which were not significant at the 0.05 level (5).

Table 17: Summary of the effects of installing traffic signals at previously unsignalized intersections

Measure	Group	Number of Intersections	Percent Change in Pedestrian Crash Rates	Adjusted Percent Change (ANCOVA analysis)	Significant at 0.05?
Signal installation	Treatment	447	11.91	+1	No
	Control	447	59.79		

Table with data from the Chen et al. article summarizing the effect of the four signal-related pedestrian safety countermeasures evaluated in the article (0).

References

1. Zegeer, C. V., K. S. Opiela, and M. J. Cynecki. Effect of Pedestrian Signals and Signal Timing on Pedestrian Accidents. In *Transportation Research Record: Journal of the Transportation Research Board*, No. 847, Transportation Research Board of the National Academies, Washington, D.C., 1982, pp. 62-72.
2. Zegeer, C. V., K. S. Opiela, and M. J. Cynecki. *Pedestrian Signalization Alternatives*. Publication FHWA-RD-83-102, FHWA, U.S. Department of Transportation, 1983.
3. Zaidel, D. M., and I. Hocherman. Safety of Pedestrian Crossings at Signalized Intersections. In *Transportation Research Record: Journal of the Transportation Research Board*, No. 1141, Transportation Research Board of the National Academies, Washington, D.C., 1987.
4. Robertson, H. D., and E. C. Carter. The Safety, Operational, and Cost Impacts of Pedestrian Indications at Signalized Intersections. In *Transportation Research Record: Journal of the Transportation Research Board*, No. 959, Transportation Research Board of the National Academies, Washington, D.C., 1984.
5. Chen, L., C. Chen, R. Ewing, C. McKnight, R. Srinivasan, and M. Roe. Safety Countermeasures and Crash Reduction in New York City—Experience and Lessons Learned. *Accident Analysis and Prevention*. In print, 2012. Retrieved July 23, 2012. http://dx.doi.org/10.1016/j.aap.2012.05.00.

Figure 37: A pedestrian countdown timer.

Pedestrian countdown timer (PCT) showing how much time there is left to cross. Photo by Paul Krueger / www.flickr.com/photos/pwkrueger/5501826824/

Section 8.2: Pedestrian Signals

Pedestrian signals have undergone many changes since they were first introduced in the first half of the 20th century. Since at least the 1960s, researchers have studied the effects of different types of pedestrian signals on motorist and pedestrian behavior. Countdown timers were first included in the MUTCD in 2003, and the most recent 2009 edition of the Manual on Uniform Traffic Control Devices (MUTCD) requires the use of pedestrian countdown signals at signalized intersection where the pedestrian clearance interval exceeds 7 seconds (*1*). These countdown signals are used in conjunction with standard pedestrian signal indications to provide the pedestrian with information about how much time remains to safely cross the street.

In 1999, Leonard, Juckes, and Clement evaluated pedestrian and motorist behavior after the addition of a countdown signal to conventional pedestrian signal heads in Monterey, California. The study took place at two signalized urban intersections, and observations of 760 pedestrians were conducted over a four-day period. Overall, it was found that 83 percent of pedestrians started at the beginning of the pedestrian phase and completed the crossing during the phase. Leonard et al. concluded that pedestrian countdown signals did not pose any significant safety hazards. The study did not review conflicts or accidents (2).

A 2000 report by Zegeer and Huang evaluated the effects of pedestrian countdown signals in Lake Buena Vista, Florida. The researchers measured pedestrian signal compliance and the percentage of pedestrian crossings completed during the Walk and flashing Don't Walk interval at two treatment and three comparison sites after pedestrian countdown signals were installed. Analysis of results indicated that there was a statistically significant difference in Walk signal compliance, with pedestrians less likely to comply with the Walk signal at pedestrian countdown signal sites than at comparison sites. Despite this effect, there was no statistically significant difference in the number of pedestrians who finished crossing before the steady Don't Walk signal. However, there was a statistically significant reduction in the number of pedestrians who began to run at the appearance of the flashing Don't Walk signal at the treatment sites when compared with comparison sites. The researchers concluded that the countdown signals had both positive and negative effects on pedestrian behavior at the treatment sites. While more pedestrians began crossing during the flashing Don't Walk signal when the countdown signal was present, this change in behavior had little effect on the ability of pedestrians to finish crossing in time. The authors recommended further study at greater numbers of intersection, and with the inclusion of pre-treatment measurements for comparison (3).

In an effort to determine the effects of pedestrian countdown signals on both pedestrian and motorist behavior, a before-after study was conducted by Eccles, Tao, and Mangum in 2004 at 20 crosswalks at 5 intersections in Montgomery County, Maryland, where signals were installed. A survey conducted as part of a Maryland study revealed that most pedestrians were aware of the countdown signal and 62.6 percent understood its meaning. Observational data gathered at the five intersections showed that the countdown signals had mixed effects on pedestrian behavior. At 2 of the 20 crosswalks observed, there was a statistically significant decrease in the number of pedestrians who entered on the WALK indication (meaning that more pedestrians began walking during the flashing or solid DON'T WALK indication). However, at 6 of the 20 crosswalks, there was a statistically significant increase in pedestrians correctly entering the intersection on the WALK indication. The researchers also observed the number of phases during which pedestrians were still in the intersection when conflicting traffic was released; there was no statistically significant increase in the number of phases in which a pedestrian was still in the crosswalk when conflicting traffic was released. At 4 of the 5 intersections, there were statistically significantly fewer pedestrian-motor vehicle conflicts after the countdown signals were installed. The authors found that the countdown signals had no effect on vehicle approach speeds during the countdown pedestrian clearance interval (4).

Table 18: Table showing a summary of pedestrian-vehicle conflicts before and following the installation of pedestrian countdown timers at one study site.

Intersection	Conflicts Before	Pedestrians Before	Conflicts After	Pedestrians After	t-statistic	p-value	Significant at 95%?
Georgia and Reedie	10	222	1	342	-3.53	0.0%	Yes
Wisconsin and Montgomery	9	1723	3	1978	-1.98	4.8%	Yes
Wayne and Fenton	9	398	2	455	-2.35	1.9%	Yes
Georgia and Colesville	9	1090	1	1178	-2.66	0.8%	Yes

Table 6 from the Eccles, Tao, and Mangum article showing a comparison of pedestrian-motor vehicle conflicts in the pre- and post-treatment periods (4).

A 2006 *ITE Journal* article by Markowitz, Sciortino, Fleck, and Lee evaluated the use of pedestrian countdown timers (PCTs) in San Francisco. The researchers examined pedestrian injury events during the twenty-one months leading up to the installation of nine pilot countdown signals, and for the twenty-one months following the safety treatment. They compared treatment location statistics with 1266 intersections, about half of which were scheduled to receive countdown timers, while half were not. They also analyzed statistics for locations which experienced higher than average collision rates in the pre-treatment period. Analysis of the results showed that the number of pedestrian collisions declined by a statistically significant (p=0.03) 52 percent following the introduction of PCTs. However, the authors caution that some of the effect may have been due to regression to the mean, given that the pilot intersections were selected based on pedestrian safety-related criteria. The authors concluded by calling the results encouraging and looking forward to further analysis once the 629 planned PCTs were installed (5).

Table 19: Table showing the number of injury events separated by category of intersection

Treatment Group	Number of Intersections		Number of Injury Events	Percent of Injuries After/Before
Group A: Countdown signals installed	9	After	13	48.1 [a]
		Before	27	
Group B: Planned countdown intersections	629	After	740	97.0
		Before	764	
Group C: No signals planned	628	After	423	90.0
		Before	469	
Group D: Countdown signals installed with 2+ crashes pre-installation	7	After	11	42.3 [a,b]
		Before	26	
Group E: Planned countdown signals with 2+ crashes for the same period	185	After	282	55.6 [a,b]
		Before	507	

a = Sample group crash reduction statistically significant, p-value < .05

b = Difference between groups D and E not statistically significant

Table 1 from the ITE Journal article showing the effect of pedestrian countdown signals on pedestrian injury events in San Francisco, California (5). The first row (Group A) shows the nine intersections where countdown signals were installed.

Four years later, in 2008, Schrock and Bundy questioned if pedestrian countdown timers were used by drivers to make better or worse driving decisions. Based on a study in Lawrence, Kansas, continuous speed data was amassed in advance of the intersection. Analysis of this data illustrated that drivers use CDTs to make safer decisions regarding speed when approaching intersections (6).

A 2008 report by Reddy, Datta, McAvoy, Savolainen, Abdel-Aty, and Pinapaka studied the impact of pedestrian countdown timers (PCTs) at eight large intersections in south Florida. In order to determine the PCTs' effectiveness, researchers made pre- and post-treatment comparisons of pedestrian behavior data. They found that there was a statistically significant increase in the percentage of successful crossings for all intersections combined. However, at some locations they also witnessed an increase in pedestrians entering the intersection during the steady "Don't Walk" signal (7).

A 2011 paper by Levasseur and Brisbane evaluated the effectiveness of pedestrian countdown timers (PCTs) that were installed at two Sydney intersections in order to improve pedestrian safety. The researchers used a video survey to collect pre-/post-treatment and treatment/control pedestrian behavioral data, as well as a survey of pedestrians at treatment and control sites to assess pedestrian perception of PCTs. Results pertaining to the effect of PCTs on pedestrian-vehicle conflicts were inconclusive. It was found that pedestrians were more influenced by PCTs at wider crossings than narrower crossings. Although no conclusive change in pedestrian safety behavior was observed, results of the pedestrian survey demonstrated that 53 percent of pedestrians felt "more safe" when crossing with PCTs (8).

A 2011 report by Camden, Buliung, Rothman, Macarthur, and Howard was the first population-based study to evaluate the impact of the installation of pedestrian countdown signals on pedestrian-motor vehicle collisions. The researchers compared the rate of pedestrian-motor vehicle collisions at 1,965 Toronto intersections before and after the installation of pedestrian countdown signals. A total of 9,262 pedestrian-vehicle collisions took place during the ten year study period. In contrast an earlier experiment (Markowitz, et al. 2006), analysis of the results indicated that the pedestrian countdown signals had no statistically significant effect on the number of pedestrian-motor vehicle collisions at the intersections where they were installed. The authors concluded that pedestrian countdown signals should not be considered to offer significant safety benefits when used in the absence of other safety treatments (9).

Table 20: Pedestrian countdown signal analysis of pedestrian-motor vehicle collisions, Toronto, 2000-2009

	Total Number of Collisions**	**No. of collisions pre-PCS**	**Pre-PCS Collision Incidence Rate/1000 intersection months**	**No. of collisions post-PCS**	**Post-PCS collision incidence rate/1000 intersection-months**	**Modeled Relative Risk***	**Modeled 95% Confidence Intervals*****
Total	9262	7522	40.73	1740	41.30	1.014	0.958, 1.073
Age, years							
Children, 0-15	1089	899	4.87	190	4.51	0.941	0.795, 1.119
Adults, 16-59	6482	5227	28.30	1255	29.79	1.038	0.972, 1.108

Figure 38: A pedestrian signal with animated eyes used in Las Vegas, Nevada.

Older people, 60+	1465	1203	6.51	262	6.22	0.967	0.844, 1.108
Injury Severity							
No injury	399	335	1.81	64	1.52	0.838	0.626, 1.121
Minor/minimal	7949	6440	34.87	1509	35.82	1.026	0.965, 1.090
Major	809	661	3.58	148	3.51	0.984	0.826, 1.173
Fatal	105	86	0.47	19	0.45	0.968	0.594, 1.578
Location							
Pre-amalgamated Toronto	3739	2939	53.03	800	49.52	0.943	0.866, 1.027
Inner suburbs	5523	4583	35.46	940	36.18	1.042	0.967, 1.122
*Reference group is pre-pedestrian countdown signal, **Base: n=1965 intersections; location: pre-amalgamated Toronto (n=622 intersections); inner suburbs (n=1343 intersections), ***95% Poisson Confidence Intervals							

Table from the article showing the modeled relative risk for intersections where pedestrian countdown signals were installed when compared to intersections without pedestrian countdown signals. Given that a relative risk of "1" indicates no difference between the two groups and that all of the 95% confidence intervals include one, the researchers concluded that there was no difference in the risk of pedestrian-motor vehicle collisions at treatment and control sites (9).

A 2011 paper by Vasudevan, Pulugurtha, Nambisan, and Dangeti evaluated three signal-based countermeasures tested in Las Vegas, Nevada, including a pedestrian countdown signal with animated eyes. The pedestrian countdown signal with animated eyes was installed at an intersection that already had a high-visibility crosswalk in place. Thirteen pedestrian and driver measures of effectiveness (MOE) were studied by field observers before and after the installation of the pedestrian countdown signal and analyzed using a two-proportion z-test. Of the MOEs studied, there was a significant increase in the percentage of pedestrians who looked for vehicles before beginning to cross and beginning to cross during the "Walk" phase. The researchers concluded that the pedestrian countdown signal with animated eyes had little effect on driver behavior, but that it improved overall pedestrian crossing behavior at the intersection (10).

A 2012 presentation at the Transportation Research Board meeting by Sharma, Schmitz, Khattak, and Singh discussed an evaluation of a pedestrian countdown timer (PCT) at one intersection in Lincoln, Nebraska. Pedestrian crossing data were collected before and after the treatment was installed. An analysis of the results, the authors concluded that the PCTs contributed to faster walking speeds in the crosswalk and an increase in pedestrian compliance. The authors acknowledge that the use of a single intersection was a limitation in their study (12).

A 2014 Transportation Research Board presentation by Huitema, Van Houten, and Manal analyzed the pedestrian safety effects of installing pedestrian countdown timers (PCTs) in Detroit, Michigan. The study was the second to consider the effects of PCTs at the citywide level rather than at particular sites. The researchers used monthly crash data collected from 2001-2010 to compare the effect of introducing PCTs at 362 treatment sites and 87 control sites. The results of their analysis indicated that the installation of PCTs at all of the treatment sites was associated with a 70% reduction in pedestrian crashes, from about seven per month to about two per month. Because the size of the decrease in pedestrian crashes was correlated with the introduction of PCTs, the researchers concluded that PCTs were an effective pedestrian safety countermeasure (13).

References

1. Federal Highway Administration. Section 4E.07 of "2009 Edition Chapter 4E. Pedestrian Control Features." *Manual of Uniform Traffic Control Devices*, 2009. http://mutcd.fhwa.dot.gov/htm/2009/part4/part4e.htm
2. Leonard, J., M. Juckes, and B. Clement. Behavioural Evaluation of Pedestrians and Motorists towards Pedestrian Countdown Signals. Compendium of Papers, Institute of Transportation Engineers 2000, District 6 Annual Meeting. San Diego, CA, 1999.
3. Zegeer, C. and H. Huang. *The Effects of Pedestrian Countdown Signals in Lake Buena Vista*. Florida Department of Transportation, Tallahassee, Florida, 2000.
4. Eccles, K. A., R. Tao, and B. C. Mangum. Evaluation of Pedestrian Countdown Signals in Montgomery County, Maryland. Presented at 83rd Annual Meeting of the Transportation Research Board, Washington, D.C., 2004.
5. Markowitz, F., S. Sciortino, J. L. Fleck, and B. M. Yee. Pedestrian Countdown Signals: Experience with an Extensive Pilot Installation. *ITE Journal*, Vol. 76, No. 1, Institute of Transportation Engineers, 2006, pp. 43-48.
6. Schrock, S.D., and B. Bundy. Pedestrian countdown timers: Do drivers use them to increase safety or increase risk taking? Presented at 87th Annual Meeting of the Transportation Research Board, Washington, D.C., 2008.
7. Reddy, V., T. Datta, D. McAvoy, P. Savolainen, M. Abdel-Aty, S. Pinapaka. *Evaluation of Innovative Safety Treatments*. Florida Department of Transportation, Tallahassee, Florida, 2008.
8. Levasseur, M. and G. Brisbane. *Trial of Pedestrian Countdown Timers in the Sydney CBD*. Final Report. Roads and Traffic Authority of NSW, 2011. http://www.rta.nsw.gov.au/roadsafety/downloads/trial_ped_countdown_timers_sydney_cbd.pdf
9. Camden, A., R. Buliung, L. Rothman, C. Macarthur, A. Howard. The Impact of Pedestrian Countdown Signals on Pedestrian-Motor Vehicle Collisions: A Quasi-Experimental Study. *Injury Prevention*. Vol. 18, 2012, pp. 210-215. Open access copy: http://injuryprevention.bmj.com/content/18/4/210
10. Vasudevan, V., S. Pulugurtha, S. Nambisan, and M. Dangeti. Effectiveness of Signal-Based Countermeasures on Pedestrian Safety: Findings from a Pilot Study. In *Transportation Research Record: Journal of the Transportation Research Board*, No. 2264, Transportation Research Board of the National Academies, Washington, D.C., 2011, pp. 44-53.
11. Nambisan, S. S., and M. R. Dangeti. *Pedestrian Safety Engineering and Intelligent Transportation System-Based Countermeasures Program For Reducing Pedestrian Fatalities, Injuries, Conflicts, and Other Surrogate Measures Phase 2 Final Technical Report*. Federal Highway Administration, U.S. Department of Transportation, 2008.

12. Sharma, A., J. Schmitz, A. Khattak, and V. Singh. The Impact of Microscopic Factors in Evaluating the Effects of Pedestrian Countdown Timers on Pedestrian Decisions. Presented at 91st Annual Meeting of the Transportation Research Board, Washington, D.C., 2012.

13. Huitema, B., R. Van Houten, and H. Manal. An Analysis of the Effects of Installing Pedestrian Countdown Timers on the Incidence of Pedestrian Crashes in the City of Detroit, Michigan. Presented at the 93rd Annual Meeting of the Transportation Research Board, Washington, D.C., 2014.

Section 8.3: Pedestrian Signal Phasing

Adjusting the timing of pedestrian signals is one type of countermeasure with potential pedestrian safety benefits. Pedestrian signal timing includes changes to signal programming at intersections such as split-phase timing and leading pedestrian intervals and scramble timing [link to scramble timing section], and also measures which automatically extend crossing time for pedestrians, such as the Puffin [link to Puffin crossing section here]. The paragraphs below summarize some of the recent research evaluating the effect of pedestrian signal timing on pedestrian safety.

Green signal timing and pedestrian compliance. A 2007 article discussed a study designed to assess the effects of various minimum green signal times on the percentage of pedestrians that waited for a midblock "Walk" signal. To do so, the researchers chose two midblock crosswalks in Miami-Dade County, Florida. The independent variable, vehicle minimum green time, was changed from its baseline configuration to either 30, 60, or 120 seconds for a period of several days, before being changed in random order to another duration. A z-test of dichotomous variables was used to analyze pedestrian behavior variables. The results of the study showed that pedestrian compliance with the "Don't Walk" signal was inversely related to the amount of signal wait time at the crossing; however, short pedestrian wait times often led to longer vehicle wait times, resulting in the need for a compromise between the two (*1*).

An experimental pedestrian signal timing treatment from Australia. A 2007 paper evaluates a traffic signal modification targeted at improving safety for alcohol-affected pedestrians at high-risk time periods and locations in Ballarat, Australia. The treatment, called "Dwell-on-Red," is a type of signal phasing where the default signal configuration is red for all directions until vehicles or pedestrians are detected. A treatment and control site were chosen along the same arterial, and the treatment site used "Dwell-on-Red" phasing from 10 p.m. until 5 a.m. Pre-treatment and post-treatment data were collected at both sites. Results showed a statistically significant reduction in mean vehicle speed at the stop line in the treatment intersection, with an increase in mean speed at the control site for the same time period, resulting in a net decrease in mean speed of around 40percent. The authors concluded that the treatment resulted in a significant decrease in collision risk for pedestrians crossing at the "Dwell-on-Red" intersection (*2*).

Signal Installation, increasing cycle length, left turn phasing, and split phase timing. A 2012 article by Chen, Chen, Ewing, McKnight, Srinivasan, and Roe considered the effectiveness of the exclusive pedestrian phase in increasing pedestrian safety at intersections. The researchers used a two-group pretest-posttest research design to compare collision statistics following the implementation of various signal-based countermeasures, which included split phase timing and increased pedestrian crossing time at intersections throughout New York City. Pedestrian collision statistics were collected for the five years preceding treatment installation and for two years following it, and the authors used ANCOVA analysis in order to control for potential regression-to-the-mean effects. For each of the evaluated countermeasures, the results were as follows:

- At the 30 intersections where split phase timing was implemented, the average pedestrian crash rate decreased by 38.68 percent at treatment sites, while at the control intersections, it decreased by 11.53 percent. These results were not significant at the 0.05 level.
- At the 244 intersections where pedestrian crossing time was increased, the average pedestrian crash rate decreased by 50 percent, while at the control sites, it decreased by 28.94 percent. These results were significant at the 0.05 level (*4*).

Table 21: Summary of the effects of split phase timing implementation and pedestrian crossing time extension

Measure	Group	Number of Intersections	Percent Change in Ped Crash Rates	Adjusted Percent Change (ANCOVA)	Significant at 0.05?
Split phase timing	Treatment	30	-38.68	-26	No
	Control	579	-11.53		
Increase pedestrian crossing time	Treatment	244	-50.00	-51	Yes
	Control	915	-28.94		

Data from Chen et al. summarizing the effect of the signal-related pedestrian safety countermeasures evaluated in the article (0).

References

1. Van Houten, R., R. Ellis, and J.-L. Kim. Effects of Various Minimum Green Times on Percentage of Pedestrians Waiting for Midblock "Walk" Signal. In *Transportation Research Record: Journal of the Transportation Research Board*, No. 2002, Transportation Research Board of the National Academies, Washington, D.C., 2007, pp. 78-83.
2. Lenne, M., B. Corben and K. Stephan. Traffic Signal Phasing at Intersections to Improve Safety for Alcohol-Affected Pedestrians. *Accident Analysis and Prevention*, Vol. 39, No. 4, 2007, pp. 751-756.
3. Chen, L., C. Chen, R. Ewing, C. McKnight, R. Srinivasan, and M. Roe. Safety Countermeasures and Crash Reduction in New York City—Experience and Lessons Learned. *Accident Analysis and Prevention*. In print, 2012. Retrieved July 23, 2012. http://dx.doi.org/10.1016/j.aap.2012.05.009
4. Chen, L., C. Chen and R. Ewing. The Relative Effectiveness of Pedestrian Safety Countermeasures at Urban Intersections: Lessons from a New York City Experience. Presented at 91st Annual Meeting of the Transportation Research Board, Washington, D.C., 2012.

Scramble Timing

Origins of the pedestrian scramble The pedestrian scramble is a type of pedestrian signal timing in which traffic is stopped, giving pedestrians an exclusive phase in which to cross in all directions, including diagonally. Although pedestrian scramble timing is being introduced for the first time at many intersections throughout the United States, the concept has existed since the early days of traffic signal design in the 1930s and 1940s (*1*). The pedestrian scramble is also known as the Barnes Dance in the United States and elsewhere, and intersections where scramble timing are used are known as "X" crossings in the United Kingdom. One of the most heavily travelled and famous scramble timing intersections worldwide can be found at Hachiko Square in Shibuya, Japan.

Figure 39: Pedestrians using the famous scramble intersection in Shibuya, Japan.

Photo showing pedestrians using a scramble intersection in Shibuya, Japan. Photos by Christopher DeWolf at www.urbanphoto.net

Evaluations of pedestrian scramble

A 1985 Federal Highway Administration report by Zegeer, Opiela, and Cynecki evaluated pedestrian signal configurations, including scramble timing. They found that at high-volume intersections with over 1,200 pedestrian crossings per day, there was a statistically significant reduction for collisions at scramble timing intersections, compared to locations that had either no or concurrent (pedestrians cross with parallel vehicle flow) pedestrian signals. However, at volumes under 1,200 pedestrian crossings per day, there was no measureable difference, but that could have been a result of small sample size (*2*).

Figure 40: Pedestrians use the crosswalk at a pedestrian scramble intersection in the Chinatown neighborhood of Oakland, California

The Oakland pedestrian scramble. Photo courtesy of Matthew Roth at http://sf.streetsblog.org/wp-content/uploads/2009/01_15/grandpa_and_kid_2.jpg

More information about this project: http://sf.streetsblog.org/2009/01/13/eyes-on-the-street-history-of-oakland-chinatowns-barnes-dance/

A 2004 *Transportation Research Record* article by Bechtel, MacLeon, and Ragland evaluated pedestrian scramble timing implemented in 2002 at an intersection in the Chinatown neighborhood in Oakland, California. They measured pedestrian-vehicle conflicts and pedestrian violations at the intersection pre- and post-treatment to evaluate whether the new timing led to greater pedestrian safety outcomes. The authors found that there was a statistically significant decrease in pedestrian-vehicle conflicts at the intersection in the post-treatment period, which indicated increased pedestrian safety. They also found that pedestrian violations increased in the same period, potentially decreasing pedestrian safety; however, many of these crossings (at least 25 percent) were "safe-side" crossings, parallel to traffic flow and in absence of pedestrian-vehicle conflicts. They concluded by recommending longer follow up at such intersections to measure injury and collision data (*3*).

A 2009 article by Kattan, Acharjee, and Tay details the evaluation of a pilot test of pedestrian scramble timing at one downtown Calgary intersection. Video data were collected before and after the pedestrian scramble timing was implemented in order to measure pedestrian/vehicle conflicts and pedestrian compliance. The results of analysis indicates that pedestrian scramble timing implementation significantly reduced pedestrian/vehicle conflicts, but also led to a decrease in pedestrian compliance at the intersection. At the time of the article's publication, scramble timing was still being used at the intersection (*4*).

Figure 41: Instructional signs showing pedestrians how to use the scramble intersection in Calgary

Photos from the Calgary scramble intersection. The first photo shows an instructional sign showing pedestrians how to use the new configuration, while the second photo shows the Canadian scramble timing sign. Photos by Christopher DeWolf at http://www.urbanphoto.net/blog/2008/07/31/calgary-scrambles/

A 2012 article by Chen, Chen, Ewing, McKnight, Srinivasan, and Roe considered the effectiveness of the exclusive pedestrian phase in increasing pedestrian safety at intersections. The researchers used a two-group pretest-posttest research design to compare collision statistics following the implementation of pedestrian scramble timing at 37 sites throughout New York City. Pedestrian collision statistics were collected for the five 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 crash rate at the scramble timing intersections decreased by 44 percent, compared to a decrease of 9 percent in the control group, results which were significant at the 0.05 level (*5*).

Table 22: Change in pedestrian crash occurrence following the implementation of scramble timing at 37 New York City intersections

Safety Countermeasure	Group	Number of Intersections	Change in Pedestrian Crashes (Percent)	Adjusted Percent Change (ANCOVA analysis)	Significant at 0.05?
Exclusive Pedestrian Phase	Treatment	37	-44.44	-45	Yes
	Control	4266	-9.10		

Excerpt from Table 4 from the article, showing the change in pedestrian crash occurrence in the treatment and comparison groups (5).

References

1. Weingroff, R. Where was the First Walk/Don't Walk Sign Installed? Federal Highway Administration Highway History, Washington, D.C. http://www.fhwa.dot.gov/infrastructure/walk.cfm Accessed July 3, 2012.
2. Zegeer, C. V., K. S. Opiela, and M. J. Cynecki. Effects of Pedestrian Signals and Signal Timing on Pedestrian Accidents. In *Transportation Research Record: Journal of the Transportation Research Board*, No. 847, Transportation Research Board of the National Academies, Washington, D.C., 1982, pp. 62-71.
3. Bechtel, A., K. MacLeod and D. Ragland. Pedestrian Scramble Signal in Chinatown Neighborhood of Oakland California: An Evaluation. In *Transportation Research Record: Journal of the Transportation Research Board*, No. 1878, Transportation Research Board of the National Academies, Washington, D.C., 2004, pp. 19-26.
4. Kattan, L., S. Acharjee and R. Tay. Pedestrian Scramble Operations: Pilot Study in Calgary, Alberta, Canada. In *Transportation Research Record: Journal of the Transportation Research Board*, No. 2140, Transportation Research Board of the National Academies, Washington, D.C., 2009, pp. 79-84.
5. Chen, L., C. Chen, R. Ewing, C. McKnight, R. Srinivasan, and M. Roe. Safety Countermeasures and Crash Reduction in New York City—Experience and Lessons Learned. *Accident Analysis and Prevention*. In print, 2012. Retrieved July 23, 2012. http://dx.doi.org/10.1016/j.aap.2012.05.009

Section 8.4: Traffic Signal Enhancements

Section 8.5: Advanced Stop Lines

Advance yield 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" sign at three Dartmouth, Nova Scotia crosswalks to analyze the effect of the 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*).

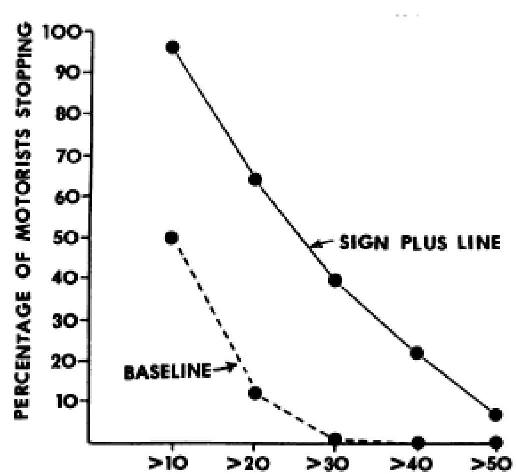

Figure 42: Graph showing the percentage of motorists stopping under two sets of study conditions

Figure 3 from 1988 Van Houten article showing motorist yielding frequency and distance for baseline and treatment phases. The baseline condition, a crosswalk, was enhanced with a "Stop Here for Pedestrians" sign as well as advanced yield markings (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 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 one 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*).

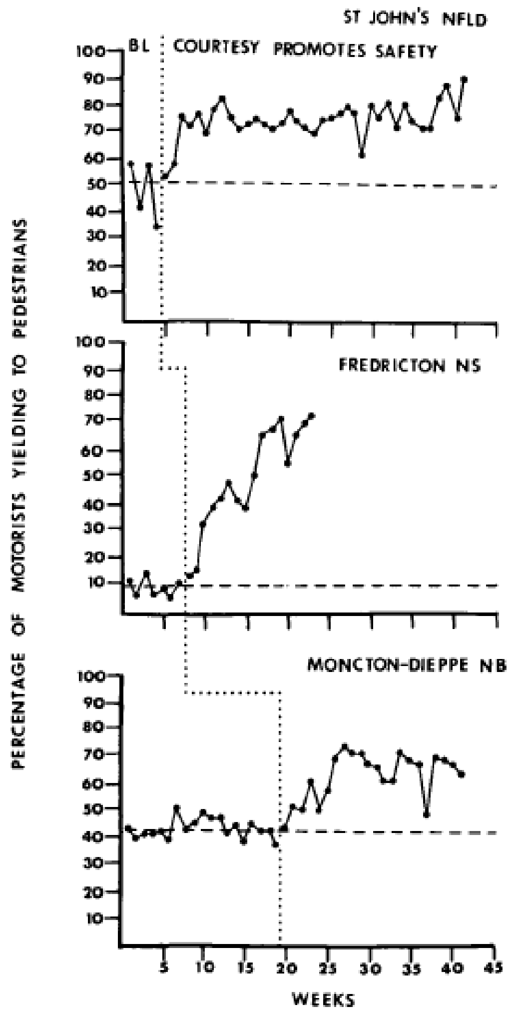

Figure 43: Graph from a 1989 article studying motorist yielding following the implementation of various countermeasures in Canada

Figure 1 from the Malenfant and Van Houten article showing the percentage of motorists yielding to pedestrians during each phase of treatment. The vertical stepped line represents the introduction of the treatments, pedestrian signs and advance stop lines, deployed in conjunction with education and enforcement programs. The horizontal lines represent the mean yielding percentage during baseline (2).

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 (*4*).

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 (*5*).

Figure 45: A pedestrian crosses while a vehicle waits at the advance yield markings.

Figure 1 from the article showing a photograph taken of the Van Houten, McCusker, Huybers, Malenfant, and Rice-Smith study site. A pedestrian crosses in the crosswalk while a motorist waits near the advance yield markings and signs used in this evaluation (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 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 six 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 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 recommended 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*).

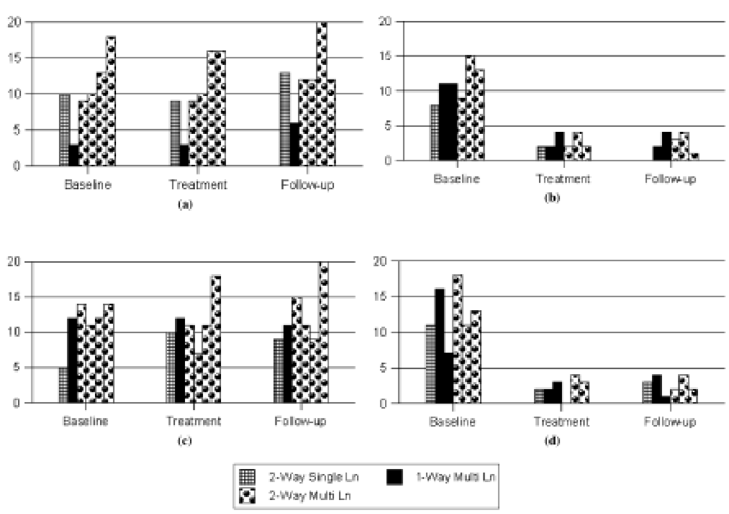

Figure 44: Graph showing the results of a pedestrian sign and advance yield marking evaluation in Nova Scotia.

Figure 4 from the article 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 (6).

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 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 (*7*).

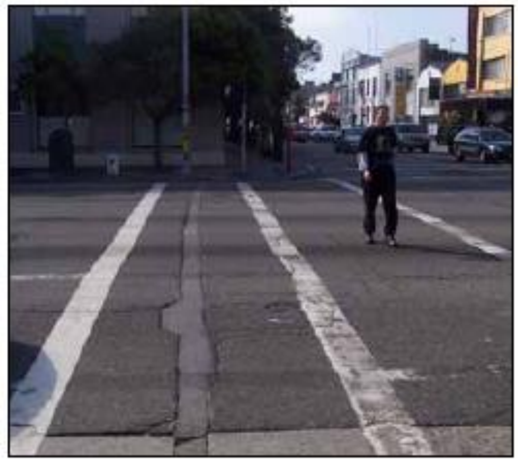

Figure 46: A pedestrian crosses in a crosswalk at an intersection where advance stop lines have been installed

Photo caption: A photo from the Pecheux, Bauer, and McLeod report showing the advance stop lines evaluated in San Francisco to the left of the crosswalk (8). These lines increase the distance between stopped cars and pedestrians, increasing visibility for both.

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 (8).

A 2013 article by Hengel presented the results of a pedestrian safety study of a site in Santa Barbara, California where a curb extension, pedestrian refuge island, and stop bars were installed. The research team studied crossing delay, motorist yielding, and the distance drivers yielded from the crosswalk prior to and following the installation of the countermeasures. Over 200 staged crossings were conducted, and results were analyzed using cross tabulations and analysis of variance (ANOVA). Analysis of data showed that crossing delay decreased by a statistically significant ($p<.05$) average of 4.9 seconds following the installation of the curb extension and refuge island. While no significant difference in yielding before of near lane drivers was observed, a statistically significant increase in yielding was observed for far lane drivers, from 61.5% in the before condition, to 82% in the after condition. There was also a significant increase in motorist yielding distance following the installation of the countermeasures. The author concluded that the combination of treatments was 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 (*9*).

References

1. Van Houten, R. The Effects of Advance Stop Lines and Sign Prompts on Pedestrian Safety in Crosswalk on a Multilane Highway. *Journal of Applied Behavior Analysis*, Vol. 21, 1988, pp. 245–251.
2. Malenfant, L., and R. Van Houten. Increasing the Percentage of Drivers Yielding to Pedestrians in Three Canadian Cities with a Multifaceted Safety Program. *Health Education Research*, Vol. 5, No. 2, 1989, pp. 275-279.
3. Van Houten, R., and L. Malenfant. The Influence of Signs Prompting Motorists to Yield Before Marked Crosswalks on Motor Vehicle-Pedestrian Conflicts at Crosswalks with Pedestrian Activated Flashing Lights. *Accident Analysis and Prevention*, Vol. 24, 1992, pp. 217–225.

4. Cynecki, M. J., J. W. Sparks and J. L. Grote. Rumble Strips and Pedestrian Safety. *ITE Journal*, 1993, pp. 18-24.
5. Van Houten, R., J.E.L. Malenfant, and D. McCusker. Advance Yield Markings: Reducing Motor Vehicle-Pedestrian Conflicts at Multilane Crosswalks with Uncontrolled Approach. In *Transportation Research Record: Journal of the Transportation Research Board*, No. 1773, Transportation Research Board of the National Academies, Washington, D.C., 2001, pp. 69-74.
6. Van Houten, R., D. McCusker, S. Huybers, J. Malenfant, and D. Rice-Smith. Advance Yield Markings and Fluorescent Yellow-Green RA 4 Signs at Crosswalks with Uncontrolled Approaches. In *Transportation Research Record: Journal of the Transportation Research Board*, No. 1818, Transportation Research Board of the National Academies, Washington, D.C., 2002, pp. 119-124.
7. Nambisan, S., V. Vasudevan, M. Dangeti, and V. Virupaksha. Advanced Yield Markings and Pedestrian Safety: Analyses of Use with Danish Offsets and Median Refuge Islands. Presented at 86th Annual Meeting of the Transportation Research Board, Washington, D.C., 2007.
8. Pecheux, K., J. Bauer, P. McLeod. *Pedestrian Safety Engineering and ITS-Based Countermeasures Program for Reducing Pedestrian Fatalies, Injury Conflicts, and Other Surrogate Measures Final System Impact Report*. Federal Highway Administration, U.S. Department of Transportation, 2009.
9. Hengel, D. Build It and They Will Yield: Effects of median and curb extension installations on motorist yield compliance. Presented at the 92nd Annual Meeting of the Transportation Research Board, Washington, D.C., 2013.

Section 8.6: Left Turn Phasing

A 2012 presentation by Pratt, Songchitruska, and Bonneson at the Transportation Research Board annual meeting gave the results of an evaluation of various pedestrian safety countermeasures implemented at four Austin, Texas intersections where pedestrian crossings take place in the path of a signalized left-turn movement. The countermeasures consisted of (1) adding a leading protected-permissive left-turn phase, (2) implementing split phasing, (3) implementing a pedestrian recall, and (4) increasing "Walk" interval duration. Video recordings were taken pre- and post-treatment, and recordings were later reviewed to collect pedestrian/vehicle conflict rates and pedestrian compliance percentages. Based on a comparison of pre- and post-treatment data, it was found that the first three treatments reduced pedestrian/vehicle conflict rates. Implementing a leading protected-permissive left-turn phase led to a reduction in pedestrian compliance percentage, but implementing split phasing led to an increase in pedestrian compliance percentage. Increasing "Walk" interval duration had little effect on pedestrian compliance, and led to an increase in pedestrian/vehicle conflict rate; however, the researchers believed this was due to low pedestrian volumes at the intersection. The researchers concluded that split phasing and pedestrian recalls were viable treatments for reducing pedestrian/left-turning vehicle conflict rates, and protective-permissive left-turn phasing demonstrated preliminary benefits, although they called for further study of the treatment (*1*).

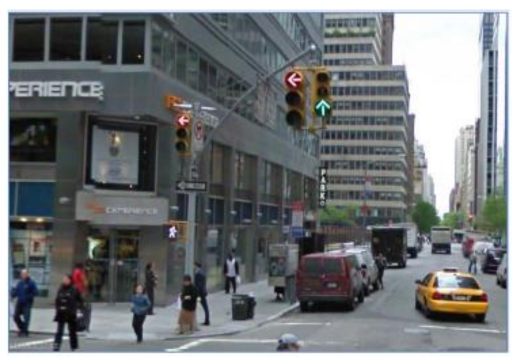

Figure 47: Pedestrians crossing at an intersection where left turn phasing has been implemented in New York City.

Figure 2 from Chen, Chen, and Ewing, showing split phase signal timing as utilized in New York City (3). Pedestrian-vehicle conflicts have been reduced by allowing the pedestrians on the left to cross the street before vehicles are allowed to make a left turn.

Table 23: Changes in conflict rate and pedestrian compliance following the implementation of different signal phasing configurations

Treatment	Conflict Rate		Pedestrian Compliance Percentage		Early Pedestrian Percentage	
	Before	After	Before	After	Before	After
Leading protected left-turn phase	1.00	0.55	86*	62*	3*	12*
Split phasing	0.25*	0.01*	62*	75*	12*	1*
Pedestrian recall	2.13*	0.17*	75	75	3*	8*
Increase Walk interval duration	1.89	2.89	51	52	5	9

*** Statistically significant at the 0.05 level.**

Table from the Pratt, Songchitruska, and Bonneson presentation showing the observed changes in conflict rate and pedestrian compliances following the implementation of a leading protected left-turn phase (top row) (Error! Reference source not found.**).**

A 2012 article by Chen, Chen, Ewing, McKnight, Srinivasan, and Roe considered the effectiveness of implementing a left turn phase in increasing pedestrian safety at intersections. The researchers used a two-group pretest-posttest research design to compare collision statistics following the implementation the countermeasure at 95 intersections in locations throughout New York City. Pedestrian collision statistics were collected for the five years preceding treatment installation and for two years following it, and the authors used ANCOVA analysis in order to control for potential regression-to-the-mean effects. At the 95 intersection where a left turn phase was implemented, there was a 44.85% decrease in the pedestrian crash rate, compared to a decrease of 11.47 percent at comparison sites. These results were significant at the 0.05 level (*2*).

These results are summarized in the table below:

Table 24: Summary of results of left turn phase implementation on pedestrian crash rates, New York City

Measure	Group	Number of Intersections	Percent Change in Pedestrian Crash Rates	Adjusted Percent Change (ANCOVA analysis)	Significant at 0.05?
Left turn phase	Treatment	95	-44.85	-43	Yes
	Comparison	2517	-11.47		

Table with data from the Chen et al. article summarizing the effect of the left turn phase evaluated in the article (2).

References

1. Pratt, M., P. Songchitruska and J. Bonneson. Pedestrians and Left-Turning Vehicles: An Evaluation of Safety Treatments. Presented at 91st Annual Meeting of the Transportation Research Board, Washington, D.C., 2012.
2. Chen, L., C. Chen, R. Ewing, C. McKnight, R. Srinivasan, and M. Roe. Safety Countermeasures and Crash Reduction in New York City—Experience and Lessons Learned. *Accident Analysis and Prevention*. In print, 2012. Retrieved July 23, 2012. http://dx.doi.org/10.1016/j.aap.2012.05.009
3. Chen, L., C. Chen and R. Ewing. The Relative Effectiveness of Pedestrian Safety Countermeasures at Urban Intersections: Lessons from a New York City Experience. Presented at 91st Annual Meeting of the Transportation Research Board, Washington, D.C., 2012.

Section 8.7: Push Buttons and Signal Timing Progression

Responsive push buttons

When pedestrians come to an intersection where a push button is necessary to activate the WALK phase on a crossing signal, they might wonder whether the button has already been pushed and whether or not it is working. If they push the button and there is a delay before the WALK phase illuminates, they might think the system is broken and begin crossing the street while DON'T WALK is still showing. One solution to this problem is the illuminated push button, which has a light that comes on to verify that the WALK phase will soon be displayed.

A 2000 study by Huang and Zegeer looked at the effects of illuminated push buttons on pedestrian behavior. The authors found that illuminated push buttons made no statistically significant difference in crossing behavior, including how often the pedestrian phases were activated and how many people pushed the button or complied with the WALK message. The lighted buttons also had no significant influence on pedestrian behaviors such as running, aborted crossings, and hesitation prior to entering the street. Before the illuminated push buttons were installed, 17 percent of pedestrians pushed the button; afterwards, only 13 percent did so. Both before and after installation of the lighted device, the button was pushed 32 percent of the time by at least one person in each group. Among people who pushed the button when parallel traffic had the red light, the percentage that actually complied with the WALK phase was 67.8 percent with the illuminated type of push button and 72.3 percent without—a majority of pedestrians in either case (1).

A 2006 study by Van Houten, Ellis, Sanda, and Kim studied the effect of visible and audible pedestrian push-button confirmation on pedestrian behavior at two high-traffic Miami Beach, Florida intersections. At the outset of the study, each intersection had a standard, non-confirming pedestrian push button. Data was collected on pedestrian behavior at both intersections prior to treatment, and then the treatment was introduced at one of the intersections. Once the pedestrian behavior data had been collected and evaluated at the first site following treatment, the push-button was installed and evaluated at the second site. Results were analyzed using a two-proportion z-test, and suggested that the push buttons that offered visible and audible feedback can lead to a statistically significant increase in the percentage of cycles in which pedestrians push the button and the percentage of pedestrians who waited for the "Walk" sign, as well as a reduction in the percentage of trapped pedestrians. The author concludes that replacing old, standard call buttons at the end of their life with the newer push buttons that offer confirmation can be a cost-effective method of increasing pedestrian safety at intersections, with specific benefits for visually-impaired pedestrians (2).

A 2009 report by Pecheux, Bauer, and McLeod gave the results of an evaluation of pedestrian push buttons that gave audible and visual confirmation that were tested at two sites in Miami, Florida. The researchers measured several pedestrian behaviors before and after the push button was installed: the percentage of cycles in which the call button was pushed, the frequency of pedestrian signal violation, the percentage of pedestrians crossing during the walk phase, and the percentage of trapped pedestrians. Results of data analysis showed that there was a statistically significant increase in the percent of signal cycles in which the call button was pressed, a statistically significant decrease in the percent of pedestrians violating the signal, a statistically significant increase in the percentage of pedestrians crossing during the walk phase, and a statistically significant decrease in the percentage of pedestrians trapped in the roadway at one of the sites. The table below gives a summary of the results. The study team concluded that the responsive call button was a cost-effective way to increase safe pedestrian behavior (3).

Table 25: Summary of measure of effectiveness observations before and after the installation of responsive push buttons, Miami, Florida

Measure of Effectiveness	Site	Before	After	percent Change	p-value
Percent of Cycles Call Button Pressed	41st St. and Pine Tree Dr.	33.8 (n=420)	58.1 (n=570)	+24.3	0.01
	Alton Rd. and 16th St.	41.8 (n=600)	54.2 (n=810)	+12.4	0.01
Percent of Pedestrians that Began Their Crossing Outside of the Walk Phase	41st St. and Pine Tree Dr.	70.4 (n=879)	52.6 (n=1044)	-17.8	0.01
	Alton Rd. and 16th St.	59.7 (n=1577)	51.7 (n=2490)	-8	0.01
Percent of Pedestrians who Pressed Button that Waited for Walk Phase	41st St. and Pine Tree Dr.	51.2 (n=142)	72.5 (n=331)	+21.3	0.01
	Alton Rd. and 16th St.	82.1 (n=248)	85.9 (n=439)	+3.8	0.05
Percent Cycles Pedestrians Trapped in the Roadway	41st St. and Pine Tree Dr.	3.8 (n=420)	3.1 (n=570)	-0.7	>0.05
	Alton Rd. and 16th St.	4.7 (n=600)	2.4 (n=810)	-2.3	0.025

Table giving a summary of results from the Pecheux, Bauer, and McLeod report (3).

A 2011 paper by Vasudevan, Pulugurtha, Nambisan, and Dangeti evaluates three signal-based countermeasures tested in Las Vegas, Nevada, including illuminated push-button pedestrian call buttons. The illuminated push-button pedestrian call button was installed at an intersection where there was already a portable speed trailer and in-roadway yield to pedestrian sign. Thirteen pedestrian and driver measures of effectiveness (MOE) were studied by field observers before and after the installation of the call button and analyzed using a two-proportion z-test. Of the MOEs studied, there was a significant reduction in the number of pedestrians trapped in the roadway and in pedestrians violating the signal, as well as a significant increase in the percentage of signal cycles in which the call button was used. There was a significant reduction in the number of drivers blocking the crosswalk; however, this countermeasure did not otherwise significantly affect driver behavior at the site (4).

Figure 48: A pedestrian call button that gives audible and visible response when pressed

A photograph of the call button evaluated in Miami, Florida (3).

Accessible pedestrian signals

Wall, Ashmead, Bentzen, and Barlow (2005) conducted studies evaluating the effect of audible pedestrian signals (APS) in providing directional beaconing for pedestrians when crossing the street. Their results indicate that only providing an audible APS on the other side of the street from the pedestrians reduces veering as opposed to providing audible APS on both sides of the street. Providing a push-button locator tone that would activate at the end of the WALK cycle proved to be the most successful strategy (5).

A 2005 study by Scott, Myers, Barlow, and Bentzen studied the ability of visually- and cognitively-impaired pedestrians to navigate an intersection equipped with APS in Portland, Oregon. The researchers recruited 45 visually-impaired participants and forty-five cognitively-impaired participants to test the device features, which consisted of a push-button locator tone, volume which automatically adjusted based on ambient noise, a high-contrast tactile arrow that vibrated during the "Walk" interval, and an audible "Walk" indication. The participants crossed using different configurations of the design features to determine which were the easiest to locate, most effective in indicating the crossing direction accurately, and led to the least amount of crossing delay. The researchers found that mounting each push-button APS on its own pole led to the greater amount of accuracy in identifying the direction of the crossing signal and the least delay in initiating crossing, and that using a fast ticking sound resulted in the fastest and most accurate responses when compared to cuckoo and a "Walk" voice. Ninety-one percent of participants used the vibrating arrows to confirm the direction of the "Walk" signal. As a result of the study, the researchers suggested that

Figure 49: An accessible pedestrian signal, designed to provide cues for visually- and hearing-impaired pedestrians

An accessible pedestrian signal installed in West Hartford, Connecticut. This APS features a locator tone, verbal messages, and vibrating arrow. Photo courtesy of the Town of West Hartford. http://www.westhartford.org/living_here/town_departments/community_services/engineering/new_pedestrian_signals.php

APS be placed on separate poles at least 10 ft apart at intersections, and as close as possible to the curb line and associated crosswalk (6).

Another 2005 study by Williams, Van Houten, Ferraro, and Blasch studied the effects of two types of Accessible Pedestrian Signals (APS) on the street-crossing behavior of 24 blind study participants in Atlanta, Georgia. The first type of signal featured a pedestrian push button enhanced with a sound generator and vibrating hardware. The second device was a portable handheld receiver that received a signal from the pedestrian signal head and transmitted tones indicating "Walk" or "Wait" to the user. Measures of effectiveness included crossing speed, crossing delay, and crossing accuracy. The researchers found that participants were able to initiate crossing and cross the street more quickly when using than handheld device than when using the audible push-button device or in the no APS control condition. The number of missed cycles was significantly lower when using one of the two APS compared to the control condition. Ninety percent of subjects preferred the APS devices to traditional signals. The researchers concluded that the study provided data to support the development and use of APS in order to facilitate street crossing by blind pedestrians (7).

Figure 50: A pedestrian using the tactile surface of an accessible pedestrian signal

A pedestrian uses the tactile surface of an accessible pedestrian signal in order to solicit information about when to cross safely. Such signals provide audible and/or vibrotactile signals to assist visually impaired pedestrians make decisions about crossing the street. Photo by David Harkey.
http://safety.transportation.org/htmlguides/peds/description_of_strat.htm

A 2008 article by Scott, Barlow, Bentzen, Bond, and Gubbe evaluated the effectiveness of accessible pedestrian signals (APS) and innovative APS design features with regards to visually-impaired pedestrians at four complex intersections in Charlotte, North Carolina, and Portland, Oregon. The researchers recruited 54 visually-impaired pedestrians who were unfamiliar with the study crossings. Participants were accompanied by researchers as they navigated intersections, with one group of participants acting as a control group pre-treatment, and a second, mixed group crossing following the installation of APS several months later (there were some, but not all, new participants, due to small recruitment population). Timing and wayfinding measures were compared using t-tests to determine significance. The results suggested that the installation of APS improved timing and wayfinding measures. There was a significant increase in independent crossing initiations, and a significant reduction in starting delay, which resulted in a significant reduction in the number of crossings completed after perpendicular lights changed to green. There were significant improvements to wayfinding measures at only one of the Portland sites: an increase in crossings begun from within the crosswalk, an increase in ability to independently locate the crosswalk, and an increase in percentage of crossings ending within the crosswalk. In Charlotte, a second study was conducted by adding additional beacon features to the treated intersections, including a locator tone from the opposite side of the intersection, as well as additional audible information given when the push button was held down. These improvements led to a statistically significant increase in independence in determining a safe time to cross, a statistically significant increase in starting during "Walk", a statistically significant increase in crossings beginning and ending within the crosswalk, a statistically significant decrease in starting delay, and a statistically significant decrease of crossing following the onset of perpendicular green lights. The authors concluded that APS and innovative APS design features had a significant benefit on pedestrian performance at all installation sites (8).

A 2012 article by Barlow, Scott, Bentzen, Guth, and Graham compared standard accessible pedestrian signals (APS) to two experimental measures, a standard APS with a guidestrip laid along the inside edge of the crosswalk, and a prototype beaconing APS, to measure their effectiveness at guiding visually-impaired pedestrians through large and complex intersections. Experiments took place at three signalized intersection sites, one each in Alpharetta, Georgia, Austin, Texas, and Towson, Maryland. Fifty four visually-impaired pedestrians participated in the study. Data were recorded about each participants' accuracy in locating the crosswalk, their alignment before crossing, their location relative to the crosswalk during crossing, and at which point during the pedestrian signal they initiated and completed their crossing. As shown in the graph below, there was a statistically significant increase in the ability of pedestrians to remain within the crosswalk when crossing for both treatment conditions at all study sites (p<.05), with a further statistically significant increase for the guidestrip as compared to the beaconing APS (p<.05). Similar statistically significant increases of accurate alignment were measured for the two treatment conditions, with participants aligned accurately for 36.3% of crossings with standard APS, 68.1% with the beaconing APS, and 71.0% with the guidestrips. No significant differences were observed for the rate of accuracy in locating the crosswalk, or rate of initiating or completing crossings between the three conditions. As a result of their findings, the research team recommended that prototype beaconing APS and guidestrips be considered when making complex intersections accessible for visually-impaired pedestrians (*9*).

Figure 51: A pedestrian call button that provides audible and visible response when pressed

This APS is located at a midblock signalized crossing. Photo by Mike Cynecki.
http://guide.saferoutesinfo.org/engineering/traffic_signals.cfm

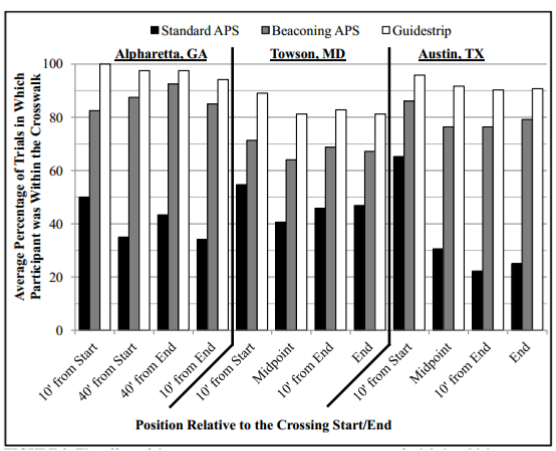

Figure 52: Results of a comparison of three types of accesible pedestrian signals in Georgia, Texas, and Maryland.

Results from Barlow, Scott, Bentzen, Guth, and Graham (2012), showing the difference in percent of accurate crossing with standard APS, beaconing APS, and standard APS with guidestrips (9).

A 2014 presentation at the Transportation Research Board conference by Scott, Bentzen, Barlow, Guth and Graham evaluated the performance of a prototype beaconing APS system at an acoustically complex intersection in Portland, Oregon. The beaconing APS featured loudspeakers at the far end of the crosswalk intended to guide crossing alignment in addition to the ticking that signaled the walk phase, but there was some concern that echoing caused by nearby buildings could confuse visually-impaired pedestrians. Eighteen visually-impaired participants navigated the intersection using either a standard APS, the beaconing APS, or multiple beaconing APS while observers recorded data about their alignment and position throughout the crossing. Results of the analysis indicated that multiple beaconing APS did not result in greater confusion for visually-impaired pedestrians. For all of the measures of wayfinding that were studied (accurate alignment, position within the crosswalk), participant performance was improved when the beaconing APS was used than when the standard APS was used. Additionally, there was no decrease in participant wayfinding ability when multiple beaconing APS were activated. The researchers concluded that beaconing APS could improve wayfinding for visually-impaired pedestrians at intersections, and that the benefit persisted even when multiple APS were activated (10).

References

1. Huang, H. F. and C. V. Zegeer. *An Evaluation of Illuminated Pedestrian Push Buttons in Windsor, Ontario*. Publication FHWA-RD-00-102, FHWA, U.S. Department of Transportation, 2001.
2. Van Houten, R., R. Ellis Jr., J. Sanda, and J.-L. Kim. Pedestrian Push-Button Confirmation Increases Call Button Usage and Compliance. In *Transportation Research Record: Journal of the Transportation Research Board*, No. 1982, Transportation Research Board of the National Academies, Washington, D.C., 2006, pp. 99-103.
3. Pecheux, K., J. Bauer, P. McLeod. *Pedestrian Safety Engineering and ITS-Based Countermeasures Program for Reducing Pedestrian Fatalies, Injury Conflicts, and Other Surrogate Measures Final System Impact Report*. Federal Highway Administration, U.S. Department of Transportation, 2009.
4. Vasudevan, V., S. S. Pulugurtha, S. S. Nambisan, and M. R. Dangeti. Effectiveness of Signal-Based Countermeasures on Pedestrian Safety: Findings from a Pilot Study. In *Transportation Research Record: Journal of the Transportation Research Board*, No. 2264, Transportation Research Board of the National Academies, Washington, D.C., 2011, pp. 44-53.
5. Wall, R., D. Ashmead, B. L. Bentzen, and J. Barlow. Audible Pedestrian Signals as Directional Beacons. International Congress Series, Volume 1282, 2005.
6. Scott, A. C., L. Myers, J. M. Barlow, and B. L. Bentzen. Accessible Pedestrian Signals: The Effect of Push-Button Location and Audible "Walk" Indications on Pedestrian Behavior. In *Transportation Research Record: Journal of the Transportation Research Board*, No. 1939, Transportation Research Board of the National Academies, Washington, D.C., 2005, pp. 69–76.
7. Williams, M. D., R. Van Houten, J. Ferraro, and B. Blasch. Field Comparison of Two Types of Accessible Pedestrian Signals. In *Transportation Research Record: Journal of the Transportation Research Board*, No. 1939, Transportation Research Board of the National Academies, Washington, D.C., 2005, pp. 91–98.
8. Scott, A. C., J.M. Barlow, B.L. Bentzen, T. Bond, and D. Gubbe. Accessible Pedestrian Signals at Complex Intersections: Effects on Blind Pedestrians. In *Transportation Research Record: Journal of the Transportation Research Board*, No. 2073, Transportation Research Board of the National Academies, Washington, D.C., 2008, pp. 94-103.
9. Barlow, J. M., A. C. Scott, B. L. Bentzen, D. Guth, and J. Graham. The Effectiveness of Audible and Tactile Heading Cues for Pedestrians Who are Blind at Complex Intersections. Presented at the 92nd Annual Meeting of the Transportation Research Board, Washington, D.C., 2013.

10. Scott, A. C., B. L. Bentzen, J. M. Barlow, D. Guth, and J. Graham. Far-Side Audible Beaconing of Accessible Pedestrian Signals: Is it Confusing? Presented at the 93rd Annual Meeting of the Transportation Research Board, Washington, D.C., 2014.

Section 8.8: 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 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).

Figure 53: Pedestrians cross at a crosswalk enhanced with a pedestrian hybrid beacon in Phoenix, Arizona

A photo of a pedestrian hybrid beacon in use in Phoenix, Arizona. Photo courtesy of www.pedbikeimages.org / Mike Cynecki. http://www.pedbikeimages.org/pubdetail.cfm?picid=1516

Figure 54: Motorist yielding percentages by countermeasure type

A pedestrian hybrid beacon at NE 41st Ave. and E. Burnside St. in Portland Oregon. Photo courtesy of the Oregon Department of Transportation. http://www.oregon.gov/ODOT/TD/TP_RES/docs/Reports/2012/SPR721pedreport.pdf?ga=t

Evaluation of pedestrian hybrid beacons

A 2006 report by Fitzpatrick, Turner, Brewer, Carlson, Lalani, Ullman, Trout, Park, Lord, and Whitacre, and published by the Federal Transit Administration, *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 5 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 5 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 table below). 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 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. (5)

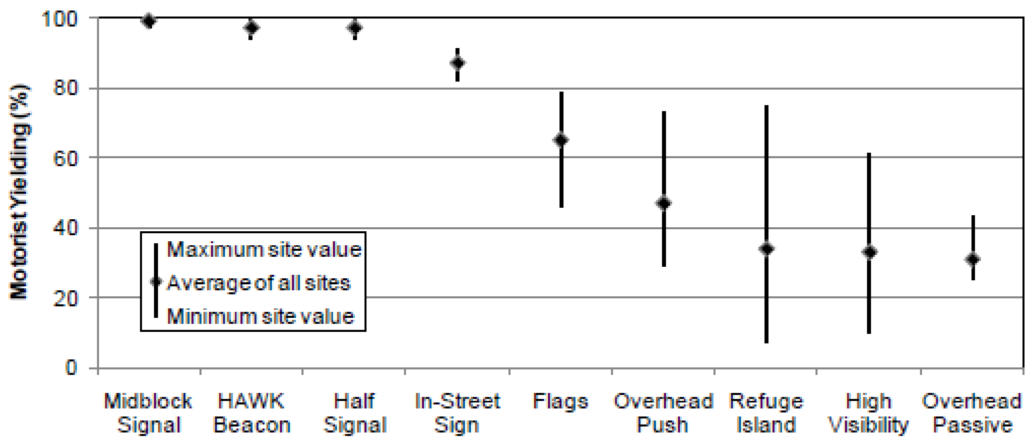

Figure 55: Motorist yielding percentages by countermeasure type

Figure 6 from the report showing the effect of various countermeasures on motorist yielding at study sites. The PHB, or HAWK, beacon is shown second from the left (4). http://www.fhwa.dot.gov/publications/research/safety/10042/10042.pdf

A 2014 article by Pulugurtha and Self 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 one, three, six, and twelve 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 that an increase in the percentage of yielding motorists, a decrease in the percentage of trapped pedestrians, and a decrease in pedestrian-vehicle conflicts were observed at all three sites; however, these results were significant at only one of the three sites. At the same site, a statistically significant increase in average vehicle speed was also observed, while no such increase was observed at the other two sites. An analysis of pre- and post-installation crash data showed no significant change in pedestrian-vehicle crashes, though 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 three months or more. Overall, the PHBs were effective at increasing motorist yielding and reducing trapped pedestrians and pedestrian-vehicle conflicts. Further research could provide more data about these measures of effectiveness as well as the PHBs effect on pedestrian-vehicle collisions in the longer term. (6)

References

1. Fitzpatrick, K. and E. S. Park. *Safety Effectiveness of the HAWK Pedestrian Crossing Treatment*. Publication FHWA-HRT-10-042. FHWA, U.S. Department of Transportation, 2010. This study has also been summarized in Fitzpatrick, K., S. Chrysler, R. Van Houten, W. Hunter, and S. Turner. Evaluation of Pedestrian and Bicycle Engineering Countermeasures: Rectangular Rapid-Flashing Beacons, HAWKs, Sharrows, Crosswalk Markings, and the Development of an Evaluation Methods Report. Publication FHWA-HRT-11-039, FHWA, U.S. Department of Transportation, 2011.
2. Nassi, R.B., and M. J. Barton. New Traffic Control for an Old Pedestrian Crossing Safety Problem. *APWA Reporter*, Vol. 75, No. 6, 2008, pp. 44-49.
3. Chalmers, M. "New Traffic Signals Make It Safer for Pedestrians." USA Today, 8/9/2010
4. Fitzpatrick, K., S. Turner, M. Brewer, P. Carlson, N. Lalani, B. Ullman, N. Trout, E. S. Park, D. Lord, and J. Whitacre. *Improving Pedestrian Safety at Unsignalized Crossings, TCRP/NCHRP Report 112/ 562*. Transportation Research Board, Washington, DC., 2006.
5. Van Houten, R.G., R. D. Ellis Jr, and E. Marmolejo. Stutter Flash LED Beacons to Increase Yielding to Pedestrians at Crosswalks. In *Transportation Research Record: Journal of the Transportation Research Board*, No. 2073, Washington D.C., 2008, pp. 69-78.
6. Pulugurtha, S. S., and D. R. Self. Pedestrian and Motorists' Actions at Pedestrian Hybrid Beacon Sites: Findings from a Pilot Study. *International Journal of Injury Control and Safety Promotion*, 2013.

Section 8.9: Rectangular Rapid Flashing Beacon (RRFB)

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 0percent and 1 percent to 65 percent and 92 percent, respectively. There was also a reduction in the number of vehicle-pedestrian conflicts and 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. The table below gives a summary of the results (3).

Table 26: 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

Table caption: Table of measures of effectiveness observed by the researchers (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 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 0percent 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 six countermeasures from this study that were considered the most effective in increasing pedestrian safety (4).

Figure 56: A pedestrian crosses in a crosswalk where pedestrian crossing signs have been enhanced with RRFBs, Miami, FLorida

The RRFB used at one of the sites in Miami that was evaluated in the 2009 Pecheux, Bauer, and McLeod report. (3)

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).

Table 27: 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)

1Column percent 2Row percent

Table caption: Table 6 from the report showing motorist responses during interactions with bicyclists and pedestrians during the two phases of the evalution (5).

A 2010 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 at 8 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).

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 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 towards 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

Figure 57: RRFB used at a crosswalk in a St. Petersburg, Florida evaluation

Photo from the article showing the RRFB used in the evaluation in St. Petersburg, Florida (5).

Figure 58: Pedestrian sign enhanced with RRFB

Photo from this study showing an RRFB with two forward facing LED flashers and a side-mounted LED flasher (6).

Figure 59: RRFB installation in Bend, Oregon

Photo from the Oregon Department of Transportation report showing one of the RRFB installation sites from the evaluation (7).

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).

A 2014 presentation at the Transportation Research Board conference by Foster, Monsere, and Carlos evaluated the use of RRFBs at two arterial crossings in Portland, Oregon. The researchers videotaped 351 pedestrian crossings at both sites to study motorist yielding, pedestrian activation of the beacon, and use of the crosswalk. At the first site (SW Barbur Boulevard), a crosswalk with median island that crossed five-lane, 35 mi/h arterial, eight RRFBs were placed around the crosswalk (four pointing in each direction of traffic), with six pushbutton-activated RRFBs at the crosswalk site, and two in advance of the crosswalk in each direction. The second site (SW Beaverton-Hillsdale Highway) was a crosswalk with a "Z" crossing (also known as a Danish offset), a type of path in the median that directs pedestrians to face oncoming traffic before completing their crossing, that was enhanced with four RRFBs (two facing each direction of traffic). When the RRFBs were activated, motorists yielded 92 percent of the time at the first site, and 91 percent of the time at the second site. When the RRFBs were not activated, motorist yield rates decreased to 75 percent at the first site, and 45 percent at the second site. The researchers also observed that motorists yielded more frequently to pedestrians in their second half of crossing the road. Pedestrians activated the beacon 94 percent of the time at the first site and 83 percent of the time at the second site. At the second site, 82 percent of pedestrians who crossed the roadway chose to use the crosswalk, which compared favorably to a prior study which found a 71 percent compliance rate for marked midblock crosswalks in general. The researchers concluded that the RRFBs were effective at increasing motorist yield rates, and that pedestrians were attracted to the enhanced crosswalk even with other crossing locations nearby (8).

Figure 60. RRFB installation in Portland, Oregon

A second 2014 presentation at the Transportation Research Board conference by Domarad, Grisak, and Bolger looked at the results of the RRFB Pilot Project in Calgary on motorist yielding. The researchers collected data on motorist yielding before and after the installation of RRFBs through the use of staged crossings at six sites. The table below gives a summary of the characteristics and results at each of the six sites. 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, indicating that the RRFBs were effective at increasing pedestrian safety at these six sites (9).

Table 28. Motorist yielding at six RRFB Sites in Calgary

Location	Type	Traffic volume	Lanes	Speed (km/h)	Percent yielding before	Percent yielding after	Increase in yielding	Statistically significant at 0.05?
Sun Valley Blvd & Sun Harbour Road SE	Multi-lane arterial with median	8,100	5	60	87	98	+11%	Yes
Glenmore Tr. & 18 St. SE	Interchange ramp	10,200	1	50	81	100	+19%	Yes
18 St & Riverview Cl	Multi-lane arterial with median	14,600	5	50	74	100	+26%	Yes
100 Radcliffe Pl & Radcliffe Dr. SE	Collector near school	7,500	2	30	84	99	+15%	Yes
Douglasdale Blvd & Douglas Ridge Cl SE	Collector with median near school	6,100	2	30	94	99	+5%	No
Crowchild Tr. & Shaganappi Tr. NW	Interchange ramp	4,800	1	60	77	90	+13%	Yes

References

1. Federal Highway Administration. *Rectangular Rapid Flash Beacon (RRFB).* Publication FHWA-SA-09-009, FHWA, U.S. Department of Transportation, 2009.
2. Van Houten, R. R. Ellis, and E. Marmolejo. Stutter-Flash Light Emitting-Diode Beacons to Increase Yielding to Pedestrians at Crosswalks. In *Transportation Research Record: Journal of the Transportation Research Board*, No. 2073, Transportation Research Board of the National Academies, Washington D.C., 2008, pp.
3. Pecheux, K., J. Bauer, P. McLeod. *Pedestrian Safety Engineering and ITS-Based Countermeasures Program for Reducing Pedestrian Fatalies, Injury Conflicts, and Other Surrogate Measures Final System Impact Report*. Federal Highway Administration, U.S. Department of Transportation, 2009.
4. Hua, J., N. Gutierrez, I. Banerjee, F. Markowitz, and D. R. Ragland. San Francisco Pedsafe II Project Outcomes and Lessons Learned. Presented at the 88th Annual Meeting of the Transportation Research Board, Washington, D.C., 2009.
5. Hunter, W. W., R. Srinivasan and C. A. Martell. *Evaluation of the Rectangular Rapid Flash Beacon at a Pinellas Trail Crossing in St. Petersburg, Florida*. Florida Department of Transportation, Tallahassee, Florida, 2009.

6. Shurbutt, J. and R. Van Houten. *Effects of Yellow Rectangular Rapid-Flashing Beacons on Yielding at Multilane Uncontrolled Crosswalks*. Publication FHWA-HRT-10-043, FHWA, U.S. Department of Transportation, 2010.
7. Ross, J., D. Serpico, and R. Lewis. *Assessment of Driver Yielding Rates Pre- and Post-RRFB Installation, Bend, Oregon*. Oregon Department of Transportation, Salem, Oregon, 2011.
8. Foster, N., C. M. Monsere, and K. Carlos. Evaluating Driver and Pedestrian Behaviors at Enhanced Multi-lane Midblock Pedestrian Crossings: A Case Study in Portland, Oregon. Presented at the 93rd Annual Meeting of the Transportation Research Board, Washington, D.C., 2014.
9. Domarad, J., P. Grisak, and J. Bolgar. Improving Crosswalk Safety: Rectangular Rapid-Flashing Beacon (RRFB) Trial in Calgary. Institute of Traffic Engineers District 7 Canada, 2013.

Section 8.10: Puffin Crossing

The PUFFIN crossing, short for "Pedestrian User Friendly INtersection," is a type of crossing device in wide use in the United Kingdom. Developed in the United Kingdom in the 1990s, the PUFFIN crossing is an updated version of the older Pelican crossing device. The Pelican crossing is a type of midblock crossing in which pedestrians use a push-button to change two traffic signals facing oncoming traffic in both directions. The pedestrian signal changes to permit crossing once the traffic signal is red. The PUFFIN crossing modifies the crossing signal design so that the pedestrian signal can be found on the near side of the crossing, above the pedestrian push-button and angled so that pedestrians view oncoming traffic while looking at the signal. Additionally, PUFFIN crossings feature a sensor to detect pedestrians waiting to cross and within the crosswalk, giving the possibility of extending the signal if necessary. Advantages of the new design include better accommodation of visually-impaired and slow-crossing pedestrians, as well as reduced delay for pedestrians and vehicles waiting to cross. Throughout its development and beyond, researchers have evaluated the safety benefits of this new type of crossing and found that the new design has measurable pedestrian safety benefits.

Figure 61: Puffin pedestrian signal

Photo by the City of Lambeth, England, showing a Puffin pedestrian signal on the near side of the crosswalk, angled so that pedestrians view oncoming traffic at the same time they view the signal. Source: http://www.lambeth.gov.uk/NR/rdonlyres/69EB9133-7230-4252-91A9-EF81F7AC2B4F/0/PuffinPhoto.jpg

History

A 1999 report by Davies reports that during the 1990's the UK DOT sponsored experiments with signal-controlled midblock crossings such as the Puffin and the Toucan (*1*). The Puffin crossing was developed to replace Pelican crossings for the following reasons:

- Pelican crossings did not allow sufficient time for slow pedestrians to cross;
- The flashing green man phase was stressful and confusing;
- Pelican crossings caused unnecessary delay for vehicles when pedestrians were able to cross quickly; and
- The fixed minimum time between pedestrian phases created excessive delay for people crossing at these locations.

Research on the newly-developed Puffin crossings (Davies, 1992 as cited in (*1*)) provided sufficiently positive feedback to encourage continued development. The Puffin crossings that Davies studied had pressure-sensitive mats near the curb to detect waiting pedestrians as well as infrared sensors to adjust crossing time.

In 1997, Crabtree furthered the research into computer applications at Puffin crossings (as cited in (1)). With some of his modifications, he found that pedestrians were more likely to look at traffic rather than straight ahead (where the green man would be located on a Pelican crossing signal). Crabtree noted fewer serious crossing infringements such as crossing when vehicles had the green light, which he attributed to the reduced delay pedestrians experienced with Puffin crossings. Yet there were more of what Crabtree considered to be slight infringements such as pedestrians crossing when vehicles had the red light but the green man was no longer showing on the pedestrian signal.

Evaluation

When Davies published his report in 1999, there were over 60 Puffin test sites in the United Kingdom. In spite of equipment problems, it seemed clear that the Puffin crossing technology was superior to the Pelican crossing and more amenable to adjustment to suit the needs of various localities. At the end of 1997, regulations were passed in the U.K. which gave local authorities the right to install Puffin crossings without government approval (*1*).

A 2010 article by Maxwell and Kennedy reported on the effects of Puffin crossings on pedestrian safety at 50 crossings in the United Kingdom. The researchers studied accident data from 40 mid-block crossings and 10 intersections, all of which had been converted from either Pelican or farside facilities to Puffin crossings. They used three years of pre- and post-treatment data to compare accident frequencies at the sites. Analysis suggested that the installation of Puffin facilities had statistically significant pedestrian safety benefits. Across all sites, there was a statistically significant reduction (at the 5 percent level) in personal injury accident frequencies of 19 percent. There was a statistically significant reduction (at the 10 percent level) in all pedestrian accidents of 24 percent. The authors concluded that the installation of Puffin facilities had statistically significant pedestrian safety benefits when compared to Pelican and farside crossing facilities (2).

References

1. Davies, D. G. *Research, Development and Implementation of Pedestrian Safety Facilities in the United Kingdom*. Publication FHWA-RD-99-089, FHWA, U.S. Department of Transportation, 1999.
2. Maxwell, A. and J. Kennedy. Study Compares Accident Frequency at Puffins and Crossings Using Farside Facilities. *Traffic Engineering and Control*, Vol. 51, No. 8, 2010, pp. 317-321.

Section 8.11 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 6 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).

Figure 62: Prototype in-street Yield to Pedestrians sign used in the 1990s.

Photo from the report showing the in-street pedestrian sign mounted on a safety cone used in the 2000 Federal Highway Administration evaluation (1).

A 1999 article sponsored by the Federal Highway Administration described the two-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 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). Proportion of driver 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

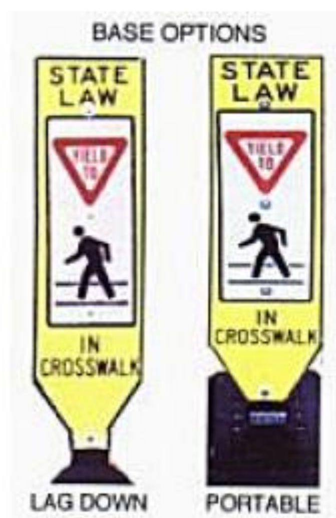

Figure 63: Two types of impactable yield signs

Drawing of the two types of impactable yield signs from the Iowa Department of Transportation report (3).

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 Rapid, 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).

Figure 65: In-roadway pedestrian sign installed mid-crosswalk

Photo caption: In-roadway pedestrian sign. Photo by www.pedbikeimages.org / Peter Speer.

removible median island used in the evaluation in Mahnomen, Minnesota (4).

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).

Table 29: 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

Chart from the article showing the mean speeds measured during each phase of the evaluation (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 4 Pennsylvania cities. The researchers collected pre- and post-treatment driver and pedestrian behavior data at treatment and potential spillover sites. Driver yielding increased by 30-34 percent at intersections and by 17-24 percent at crosswalks at treatment sites. Pedestrian yielding decreased by 11-16 percent at intersections and by 8-13 percent at crosswalks at treatment sites. A statistically significant increase in pedestrians using the crosswalks 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-pedestrians 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. The graph below shows increases in percentages of vehicles which yielded at each of the four sites (6).

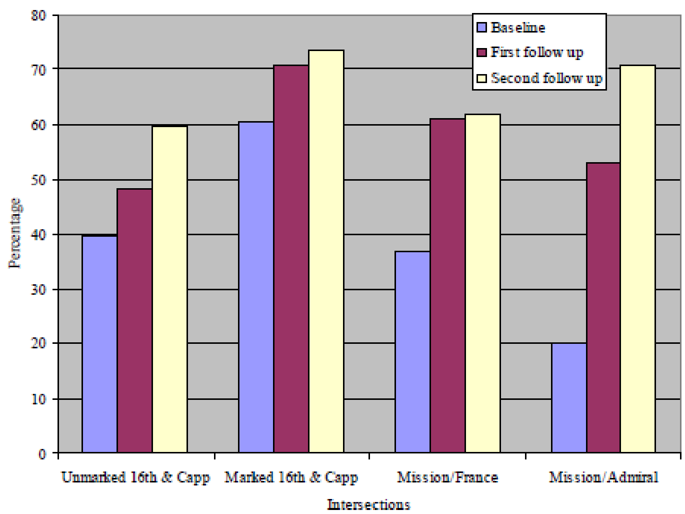

Figure 66: Graph showing the percentage of yielding motorists before and after the installation of impactable yield signs in San Francisco, California.

Figure from the Banerjee and Ragland research study showing the increase in percentage of yielding motorists at before (baseline) and after (first and second follow up) the installation of impactable yield signs in San Francisco, California (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 on a rotating, random order either at the crosswalk itself, 20 ft in advance of the crosswalk, or 40 ft 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 68: Two placements of in-roadway pedestrian signs as tested in a Miami, Florida evaluation study.

In-roadway pedestrian signs as placed in the Ellis, Van Houten, and Kim report. The photo on the left shows a configuration using three signs, while the photo on the right shows a single sign placed 20 ft ahead of the crosswalk. This evaluation study was conducted in Miami, Florida (7).

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 53percent 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 used 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 the first site (Trowbridge Road), 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, and the gateway treatment was associated with motorist yielding of 79 percent. At the second site (Farmington Road), 25 percent

Figure 67: Two pedestrians use a high-visibility yellow crosswalk that has been enhanced with an in-street pedestrian sign in San Francisco, California.

An in-street Pedestrian sign placed at the location of a high-visibility yellow-crosswalk in San Francisco, California (9).

of motorists yielding when there were no signs, 57 percent yielded when one sign was present, and 82 percent of motorists yielded when three signs were present in the gateway configuration (10).

A second experiment compared the effects of in-street signs and the pedestrian hybrid beacon (PHB), used alone or together, at two sites in Detroit, Michigan. At the first site, Livernois Avenue, motorist yielding was 1 percent in the crosswalk-only condition. The addition of one in-street sign was associated with motorist yielding of 37 percent, and the use of the gateway treatment was associated with motorist yielding of 72 percent. This compared favorably to the PHB installed at the site. When the PHB was activated, motorists yielded 62 percent of the time. When one in-street sign was used at this location, motorist yielding increased to 85 percent. At the Cass Road site, an average of 10 percent of motorists yielded at baseline conditions. PHB activation was associated with a motorist yielding rate of 84 percent, and the addition of an on-street sign brought motorist yielding to 94.5 percent. The researchers concluded that the gateway configuration of on-street signs is a promising alternative to the more-expensive PHB, and that the use of on-street signs at PHB locations can also enhance the pedestrian safety benefits at these locations (10).

Figure 69. The gateway configuration of In-Street Yield to Pedestrian Signs

Table 30. Percent of Motorists Yielding by Condition at Study Sites

Site	Baseline (Crosswalk markings only)	Typical configuration (One sign in median)	Gateway configuration (Three signs)	PHB only	PHB and one in-street sign
Trowbridge Road, East Lansing	25	57	79	N/a	N/a
Farmington Road, East Lansing	25	57	82	N/a	N/a
Livernois Avenue, Detroit	1	37	72	62	85
Cass Road, Detroit	10	N/a	N/a	84	94.5

Summary of results from Bennett, Manal, and Van Houten (10).

A 2014 presentation at the Transportation Research Board conference by Gedafa et al. evaluated the pedestrian safety effects of the presence and placement of in-street Yield to Pedestrian signs in Grand Forks, North Dakota.

Research assistants collected data on motorist yielding and speeds at each of the locations under six conditions: no yield sign present, yield sign at the crosswalk, or yield sign at 30 ft, 60 ft, 90 ft, or 120 ft in advance of the crosswalk. At three locations on the University of North Dakota campus where data were collected, there was a statistically significant increase in the percentage of motorists who yielded when the sign was present (between 72 and 98 percent), compared to when the sign was not present (between 62 and 86 percent). There was also a statistically significant increase in the percentage of motorists who yielded when the sign was at the crosswalk (between 97 and 98 percent), compared to when it was placed at advance locations further from the crosswalk (between 72 and 98 percent). Data collected about motorist speed indicated that minimum and maximum motorist speed was higher when no sign was present than when any sign was present at all but one of the eight studied locations. The results of the analysis indicated that the presence of any in-street “Yield to Pedestrians” sign was associated with greater motorist yielding and decreased motorist speeds, and that the increase in yielding was greatest when the sign was placed directly at the crosswalk (11).

References

1. Huang, H., C. Zegeer, R. Nassi, and B. Fairfax. *The Effects of Innovative Pedestrian Signs at Unsignalized Locations: A Tale of Three Treatments*. Publication FHWA-RD- 00-098, FHWA, U.S. Department of Transportation, Washington, D.C., 2000.
2. City of Madison Traffic *Engineering Division. Year 2 Field Evaluation of Experimental 'In-Street' Yield to Pedestrian Signs*. City of Madison Department of Transportation, Madison, Wisconsin, 1999.
3. Kannel, E.J., R. R. Souleyrette, and R. Tenges. *In-Street Yield to Pedestrian Sign Application in Cedar Rapids, Iowa*. Center for Transportation Research and Education, Iowa State University, Ames, Iowa, 2003.
4. Kamyab, A., S. Andrle, D. Kroeger, and D.S. Heyer. Methods to Reduce Traffic Speed in High-Pedestrian Rural Areas. In *Transportation Research Record: Journal of the Transportation Research Board*, No. 1828, Transportation Research Board of the National Academies, Washington, D.C., 2003, pp. 31-37.
5. Strong, C. and M. Kumar. *Safety Evaluation of Yield-to-Pedestrian Channelizing Devices*. Pennsylvania Department of Transportation, Harrisburg, Pennsylvania, 2006.
6. Banerjee, I. and D.R. Ragland. Evaluation of Countermeasures: A Study on the Effect of Impactable Yield Signs Installed at Four Intersections in San Francisco. Presented at the 86th Annual Meeting of the Transportation Research Board, Washington, D.C., 2007.
7. Ellis Jr., R. D., R. Van Houten and J.-L. Kim. In-Roadway 'Yield to Pedestrian' Signs: Placement Distance and Motorist Yielding. In *Transportation Research Record: Journal of the Transportation Research Board*, No. 2002, Transportation Research Board of the National Academies, Washington, D.C., 2007, pp. 84-89.
8. Hua, J., N. Gutierrez, I. Banerjee, F. Markowitz, and D. R. Ragland. San Francisco Pedsafe II Project Outcomes and Lessons Learned. Presented at the 88th Annual Meeting of the Transportation Research Board, Washington, D.C., 2009.
9. Pecheux, K., J. Bauer, P. McLeod. *Pedestrian Safety Engineering and ITS-Based Countermeasures Program for Reducing Pedestrian Fatalities, Injury Conflicts, and Other Surrogate Measures Final System Impact Report*. Federal Highway Administration, U.S. Department of Transportation, 2009.
10. Bennett, M. K., H. Manal, and R. Van Houten. A Comparison of Gateway In-Street Sign Treatment to Other Driver Prompts to Increase Yielding to Pedestrians at Crosswalks. Presented at the 93rd Annual Meeting of the Transportation Research Board, Washington, D.C., 2014.
11. Gedafa, D. S., B. Kaemingk, B. Mager, J. Pape, M. Tupa, and T. Bohan. Impacts of Alternative Yield Sign Placement on Pedestrian Safety. Presented at the 93rd Annual Meeting of the Transportation Research Board, Washington, D.C., 2014.

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 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 (1). The following paragraphs give an overview of some of the sign-related research and evaluation from the past twenty years. More information about in-street pedestrian signs can be found in the section of the same name.

Figure 70: An overhead crosswalk sign used in conjunction with double bar pair crosswalk markings and pedestrian crossing signs in Seattle, Washington.

Figure 7 from the report showing an overhead crosswalk sign used in Seattle, Washington (5).

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).

Figure 71: Pedestrian regulatory signs used in Tucson, Arizona in the 1990s.

Figure 6 from the report showing a pedestrian regulatory sign in Tucson, Arizona (5).

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 which 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 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 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 the photo below. 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 which 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 safety cones 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).

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 six 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 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 recommended 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 mid-block locations, and "Turning Traffic Must Yield to Pedestrians" signs installed at the corners of intersections. At the mid-block 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 reduction 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).

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 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 two years following its installation, BlinkerSign has not required any additional maintenance (9).

Figure 72: A flashing beacon used in conjunction with a pedestrian crossing sign in Austin, Texas

A flashing beacon treatment used to call attention to a pedestrian crossing sign in Austin, Texas (8).

Figure 73: A pedestrian sign with blinking lights installed at a crosswalk.

The BlinkerSign used in the Vermont Department of Transportation evaluation (9).

A 2012 article by Chen, Chen, Wing, McKnight, Srinivasan, and Roe evaluated the pedestrian safety impact of speed limit reductions on roadway segments and at intersections. The researchers used two-group pretest-posttest research design to compare pedestrian collision statistics following the posting of 270 speed reduction signs on roadway segments and 134 signs at intersections throughout New York City. Pedestrian collision statistics were collected for the five years preceding the speed limit reduction and two years following it, and the authors used ANCOVA in their analysis in order to control for potential regression-to-the-mean effects. Analysis of their results indicated that the average pedestrian crash rate on roadway segments decreased by 55.88 percent at treatment sites and increased by 5.77 percent at comparison sites. At intersections, pedestrian collisions decreased by 41.49 percent at treatment sites, but by 15.58 percent at comparison sites. ANCOVA-adjusted decrease in pedestrian collisions were not calculated for roadway segments, but intersection sites experienced a collision decrease of 45 percent, results which were not significant at the 0.05 level (10).

References

1. Fitzpatrick, K., S. Turner, M. Brewer, P. Carlson, N. Lalani, B. Ullman, N. Trout, E.S. Park, D. Lord, and J. Whitacre. *Improving Pedestrian Safety at Unsignalized Crossings, TCRP/NCHRP Report 112/ 562*. Transportation Research Board, Washington, DC., 2006.
2. Clark, K. L., J.E. Hummer, and N. Dutt. Field Evaluation of Fluorescent Strong Yellow-green Pedestrian Warning Signs. In *Transportation Research Record: Journal of the Transportation Research Board*, No. 1538, Transportation Research Board of the National Academies, Washington, D.C., 1996, pp. 86-94.
3. Van Houten, R., K. Healey, J. E. L. Malenfant, and R. Retting. Use of Signs and Symbols to Increase the Efficacy of Pedestrian-Activated Flashing Beacons at Crosswalks. In *Transportation Research Record: Journal of the Transportation Research Board*, No. 1636, Transportation Research Board of the National Academies, Washington, D.C., 1998, pp. 92-95.
4. Nitzburg, M., and R. Knoblauch. *An Evaluation of High-Visibility Crosswalk Treatments—Clearwater, Florida*. Publication FHWA-RD-00-105, FHWA, U.S. Department of Transportation, 2001.

5. Huang, H., C. Zegeer, R. Nassi, and B. Fairfax, B. *The Effects of Innovative Pedestrian Signs at Unsignalized Locations: A Tale of Three Treatments*. Publication FHWA-RD- 00-098, FHWA, U.S. Department of Transportation, 2000.
6. Van Houten, R., D. McCusker, S. Huybers, J. Malenfant, and D. Rice-Smith. Advance Yield Markings and Fluorescent Yellow-Green RA 4 Signs at Crosswalks with Uncontrolled Approaches. In *Transportation Research Record: Journal of the Transportation Research Board*, No. 1818, Transportation Research Board of the National Academies, Washington, D.C., 2002, pp. 119-124.
7. Hua, J., N. Gutierrez, I. Banerjee, F. Markowitz, and D.R. Ragland. San Francisco Pedsafe II Project Outcomes and Lessons Learned. Presented at the 88th Annual Meeting of the Transportation Research Board, Washington, D.C., 2009.
8. Lalani, N. *Alternative Treatments for At-Grade Pedestrian Crossings*. Institute of Transportation Engineers, Washington, D.C., 2001.
9. Kipp, W.M.E. and J. Fitch. *Evaluation of SmartStud In-Pavement Crosswalk Lighting System and BlinkerSign Interim Report*. State of Vermont Agency of Transportation, Montpelier, VT, 2011.
10. Chen, L., C. Chen, R. Ewing, C. McKnight, R. Srinivasan, and M. Roe. Safety Countermeasures and Crash Reduction in New York City—Experience and Lessons Learned. *Accident Analysis and Prevention*. In print, 2012. Retrieved July 23, 2012. http://dx.doi.org/10.1016/j.aap.2012.05.009

Permit/Restrict Right-Turn-On-Red (RTOR)

During the mid-1970's, a number of states in the eastern portion of the United States adopted the "permissive" type of RTOR that was already common in some western states. The "Western" approach allowed RTOR at all locations that were not otherwise marked by a prohibitory sign. Prior to making a RTOR, motorists are required to stop and yield to pedestrians, bicyclists, and oncoming vehicles. A 1982 study by Preusser et al. of several eastern locations revealed statistically significant increases in pedestrian and bicyclist crashes with right-turning vehicles after the Western RTOR was introduced (*1*). Comparison of computerized accident data from the periods before and after implementation of the Western RTOR rule showed the following increases in accident rates:

- 43 percent for pedestrian accidents and 82 percent for bicycles in New York State;
- 107 percent for pedestrians and 72 percent for bicycles in Wisconsin;
- 57 percent for pedestrians and 80 percent for bicycles in Ohio; and
- 82 percent for pedestrians in New Orleans.

However, given the rarity of RTOR-pedestrian crashes, these percentages represented increases in very small numbers.

A second part of this study involved analysis of police crash reports. From this analysis, the authors were able to identify a common crash scenario involving RTOR. Often, a driver who is stopped prior to turning right focuses on traffic coming from the left in order to identify a gap adequate to permit his right turn. Consequently, the motorist does not see a pedestrian or bicyclist on his right and a conflict occurs when the turn is initiated. The Preusser team found that RTOR accidents account for 1 percent to 3 percent of all pedestrian and bicycle accidents (*1*).

In 1986, Zegeer and Cynecki collected observational data on more than 67,000 drivers at 110 intersections in Washington, D.C., Dallas, Austin, Detroit, Lansing, and Grand Rapids, looking for links between motorist violations of NO TURN ON RED (NTOR) signs and the related crashes with pedestrians (*2*). Analysis of the data showed that

3.7percent of all drivers making a right-turn violated the NTOR signs. When given an opportunity to violate the NTOR sign (i.e., being the first car in line at a signalized intersection with no pedestrians in front of them and no cars coming from the left), 21 percent of the drivers ignored the NTOR signs.

Furthermore, according to Zegeer and Cynecki, 23.4 percent of all RTOR violations create a conflict with a pedestrian. Where RTOR is permitted, 56.9 percent of drivers do not come to a complete stop before turning, compared with 68.2percent who fail to do so at STOP-controlled intersections. One suggested reason for the higher violation rate at the latter is that stop-sign intersections may be more conducive to either a rolling stop or no stop at all due to lower side street volumes and pedestrian activity than most signalized locations (*2*).

In a later phase of the study, Zegeer and Cynecki developed 30 potential countermeasures to enhance pedestrian safety at intersections permitting RTOR, where seven of these countermeasures were tested at 34 intersections in six cities in the U.S. Motorist violations and pedestrian-vehicle conflicts related to both RTOR and RTOG (right turn on green) were used as measures of effectiveness (*2*). Results included the following:

- NTOR signs with a red ball were more effective than standard black-and-white ones.
- An offset stop bar increased compliance in making a full stop before turning at RTOR locations and also lessened conflicts with traffic on cross streets.
- The more costly electronic NTOR/black-out sign used only during school crossing periods or other critical times was slightly more effective than the regular NTOR sign.
- Drivers were more likely to comply with the RTOR restriction if it was limited to peak pedestrian periods rather than imposed full-time.
- In areas with moderate or low RTOR volumes, an alternative NTOR WHEN PEDESTRIANS ARE PRESENT sign was effective at intersections with low to moderate volumes of RTOR vehicles.
- In general, the likelihood of a RTOG accident was found to be greater than that of a RTOR accident, based on conflict data.

In 1994, NHTSA (Compton and Milton) reported to Congress that 0.2 percent of all fatal pedestrian and bicycle accidents result from RTOR (*3*).

A study by Lord in 2003 reported that New York City and the Province of Quebec were the only places in North America that did not allow motorists to make a right turn on red (RTOR) at signalized intersections. In the year 2000, Quebec's Ministry of Transportation (MTQ) sponsored a study aimed at finally ending the quarter-century-old debate as to whether or not to permit RTOR. Elements of this study included analysis of crash statistics from Canada and the United States, a literature review, expert survey, and a two-part pilot study described below. One issue mentioned several times in Lord's paper outlining the MTQ study is the lack of adequate data related to RTOR crashes (*4*).

The two-part pilot study was initiated in the spring of 2001. Driver behavior was observed at 26 sites in the Province of Quebec where RTOR was authorized for a period of nine months. The second part of the pilot study involved collecting data from a number of U.S. and Canadian agencies concerning the effect that RTOR had on safety and on traffic operations (*4*). Lord found that, in most cases, RTOR does not pose a danger to motorists, cyclists, or pedestrians. Lord reported that pedestrian crashes involving a RTOR maneuver make up less than 1 percent of all reported accidents in the U.S. and Canada, and the crashes that do occur are usually not severe. Many of the transportation experts and researchers who were surveyed for this study do not consider RTOR to be a safety problem (*4*).

Evaluation of Safety Measures to Restrict Right-Turn-On-Red

An older study conducted in 1983 looked at the safety effects of RTOR in South Carolina and Alabama. In South Carolina, accident data at signalized intersections involving right-turning vehicles were collected for two years before and three years after the RTOR law was implemented to be compared with accidents in the same period that did not involve right-turning vehicles. A similar comparison in Alabama studied three years before and five years after RTOR was instituted. Results showed a statistically significant increase during the after period in South Carolina for right-turning property damage accidents than for accidents not involving right turns. This was not true in Alabama. There was no statistically significant difference in the rate of change in fatality or injury accidents in either state when comparing right-turning vehicles to non-right-turning vehicles. Furthermore, there was no evidence of increased pedestrian accidents resulting from RTOR in either South Carolina or Alabama (5).

A 2002 study by Retting, Nitzburg, Farmer, and Knoblauch conducted in Arlington County, Virginia evaluated the comparative safety benefits of two methods for restricting RTOR movements: traffic signs that limit RTOR during specific time periods and highly visible traffic signs that prohibit RTOR when pedestrians are present. The study took place at 15 signalized intersections targeted by the Department of Public Works for implementation of pedestrian safety measures, due in part to public concern over RTOR conflicts. A third of the intersections (5 sites) served as the control group, while the others were equally divided between the two treatments. At the first group of five treated sites, signs were placed that stated "No Turn on Red, 7 am – 7 pm, Mon – Fri." At the second group of five treated sites, fluorescent yellow-green reflective signs reading "No Turn on Red – When Pedestrians are Present" were implemented (6).

Observations of pedestrian and motorist behavior were conducted at each location during the before and after phases. The researchers found a small but statistically significant increase in the percentage of drivers who actually stopped at painted stop lines prior to turning at the sites with signs related to the presence of pedestrians. Large increases were noted at the intersections where time-specific RTOR restrictions were imposed, whether pedestrians were present or not. During the pre-treatment period, 80percent of all observed vehicles turned right on red at these locations. Following sign installation, there was a small decline in the percentage of motorists who turned right on red at the sites with signs restricting right turns when pedestrians are present, and a large decrease where RTOR was not permitted during specified time periods (*6*).

During the before period, 39 percent of all vehicles observed did not come to a full stop before making a RTOR. This figure decreased greatly when time-specific signs were installed, but there was little change at locations where pedestrian presence was a factor for drivers to consider. In terms of pedestrian behavior, 14percent yielded to drivers making a RTOR during the before period. After installation of the signs, there was a large decrease in those who yielded to vehicles turning right at time-specific locations, with little change at sites that prohibited RTOR in the presence of pedestrians. Overall, the researchers concluded that signs that made RTOR dependent on driver discretion related to the presence or absence of pedestrians were less effective. Therefore, signs that prohibit RTOR during daytime hours, when pedestrians are more numerous, might be a preferable safety treatment (*6*).

A 2009 report by Pecheux, Bauer, and McLeod studied the relative effectiveness of three types of No Turn on Red (NTOR) signs at one site in Miami, Florida. The first two that were used were static signs printed with the messages "No Turn on Red" and "No Turn on Red When Pedestrians in Crosswalk." The third sign was an electric sign that was dark during the protected right turn phase, displayed the message "Yield to Pedestrians" during the green phase, and displayed a "No Turn on Red" message during phases when right turn was prohibited and pedestrians had pushed the call button. Data were collected in four phases. Baseline data were collected with the conditional "No Turn on Red When Pedestrians in Crosswalk" in place. For the next phase, the conditional sign was replaced with the "No Turn on Red" sign. For the second phase, the active sign was used, and for the third phase, the baseline conditional sign was reinstalled. The primary measure of effectiveness (MOE) was the percentage of drivers who violated the NTOR restriction. It was found that violations were lowest when the active sign was used. Of those drivers who violated the turn restriction, there was a significant increase in drivers coming to a full stop before doing so from 29 percent during the baseline phase to 78 percent with the electronic sign. The chart below gives a summary of the percentage of drivers who violated the NTOR restriction during each phase of the study. The authors concluded that the electronic NTOR sign was of medium effectiveness in increasing pedestrian safety, while the two static signs were of low effectiveness (7).

Table 31: Summary of driver RTOR restriction violations during three phases of a Miami, Florida, study

Drivers Violating NTOR					
	Baseline	Percent Drivers Violating the NTOR			
MOEs	**Conditional Statistic**	**Static NTOR (Measure 1)**	**Active NTOR (Measure 2)**	**Static NTOR (Measure 3)**	**p-value**
Percent violations – all	34	41	32	48	0.0008
Percent violations when ped present at curb	90	94	25	92	0.0001
Percent violations when ped present in crosswalk	34	11	6	8	0.0001

Table 14 from the report giving a summary of driver RTOR restriction violations during each phase of the study in Miami, Florida (7).

Figure 74: Three types of No Turn on Red signs

The static and active No Turn on Red (NTOR) signs evaluated in Miami, Florida (7).

A 2010 Transportation Research Board presentation by Dangeti, Pulugurtha, Vasudevan, Nambisan, and White evaluated four Intelligent Transportation Systems (ITS) based countermeasures, including an "ITS No Turn on Red" sign. The sign was installed concurrently with a high-visibility crosswalk at one intersection in Las Vegas, Nevada, and the following measures of effectiveness (MOEs) were observed before and for three weeks following the installation of the sign: (1) the percent of signal cycles in which the call button was pushed, (2) the percent of drivers who came to a complete stop before making a RTOR, (3) the percent of drivers who violated the RTOR when pedestrians were present, and (4) the percent of drivers who violated the RTOR when pedestrians were not present. A comparison of pre- and post-treatment data showed no significant improvement in the percentage of drivers who yielded to pedestrians but did show a significant increase in the percentage of drivers who came to a complete stop before making a RTOR and in the percentage of pedestrians who looked for a vehicle before beginning to stop. The authors concluded that the "ITS No Turn on Red" sign made drivers and pedestrians more cautious at the intersection, and therefore increased pedestrian safety (8).

References

1. Preusser, D. F., W. A. Leaf, K. B. DeBartolo, R. D. Blomberg, and M. M. Levy. The Effect of Right-Turn-on-Red on Pedestrian and Bicyclist Accidents. *Journal of Safety Research*, Vol. 13, No. 2, Oxford, N.Y., Pergamon Press, 1982, pp. 45-55.
2. Zegeer, C. V. and M. J. Cynecki. Evaluation of Countermeasures Related to RTOR Accidents that Involve Pedestrians. In *Transportation Research Record: Journal of the Transportation Research Board*, No. 1059, Transportation Research Board of the National Academies, Washington, D.C., 1986, pp. 24-34.
3. Compton, R. P. and E. V. Milton. *Safety Impact of Permitting Right-Turn-On-Red: A Report to Congress by the National Highway Traffic Safety Administration*. DOT HS 808, National Highway Traffic Safety Administration, Washington, D.C., 1994.
4. Lord, D., Synthesis on the Safety of Right Turn on Red in the United States and Canada. Presented at the 82nd Transportation Research Board Annual Meeting, Washington, D.C., 2003.

5. Clark, J. E., S. Maghsoodloo, and D. B. Brown. Public Good Relative to Right-Turn-on-Red in South Carolina and Alabama. In *Transportation Research Record: Journal of the Transportation Research Board*, No. 926, Transportation Research Board of the National Academies, Washington, D.C., 1983, pp. 24-31.
6. Retting, R. A., M. S. Nitzburg, C. M. Farmer, and R. L. Knoblauch. Field Evaluation of Two Methods for Restricting Right Turn on Red to Promote Pedestrian Safety. *ITE Journal*, Vol. 72, No. 1, Washington, D.C., Institute of Transportation Engineers, 2002, pp. 32-36.
7. Pecheux, K., J. Bauer, P. McLeod. *Pedestrian Safety Engineering and ITS-Based Countermeasures Program for Reducing Pedestrian Fatalies, Injury Conflicts, and Other Surrogate Measures Final System Impact Report*. Federal Highway Administration, U.S. Department of Transportation, 2009.
8. Dangeti, M.R., S.S. Pulugurtha, V. Vasudevan, S. S. Nambisan, and O.C. White Jr. Evaluating ITS-Based Countermeasures – How Effective are they in Enhancing Pedestrian Safety? Presented at 89th Annual Transportation Research Board Meeting, Washington, D.C., 2010.

Section 9: Other Measures

Section 9.1: School Zone Improvements

In 1978, Zegeer and Deen evaluated the "25 MI/H WHEN FLASHING" sign at 48 school zone locations with yellow flashing beacons in Kentucky (as cited in (1)). Speeds ranged from 35 to 45 mi/h (56 to 72 km/h) without the flasher. When the beacons were activated, only 18 percent of all motorists complied with the 25 mi/h speed limit. Overall vehicle speeds averaged just 3.6 mi/h less when the beacon was flashing than when it was off, and only two sites experienced average speed reductions of 10 mi/h or more. The researchers concluded that the regulatory flashing signs in these locations were not effective in reducing vehicle speeds to the mandated 25 mi/h. In rural locations, the beacons increased speed variance, which elevated the potential for rear-end crashes. However, the presence of school crossing guards and police enforcement did promote driver compliance with speed limits (1).

A 2005 article by Boarnet, Day, Anderson, McMillan, and Alfonzo evaluated the impact of California's Safe Routes to School (SR2S) program on walking, bicycling, and pedestrian safety. SR2S originally began in California in 1999. In one community, Marin County, California, there was a 64 percent increase in walking to school by 2003. The researchers evaluated the pedestrian safety impact of 10 traffic improvement programs funded by SR2S by comparing pre- and post-treatment data, as well as by comparing predicted results to measured results. The ten schools selected for analysis were located in nine cities and one unincorporated area in three counties. A successful project was defined as one where the measured outcomes exceeded expected outcomes. At three sites where sidewalk gaps were closed, there was a statistically significant increase in children walking on the sidewalk as well as a statistically significant decrease in children walking in the roadway. At two sites where new sidewalks or pathways were built, there was a significant shift from walking in the roadway to walking on the pathway, but the number of observed pedestrians at both sites was low. At two sites where traffic signals replaced four-way stops, the new signals were considered successful in increase the number of drivers who yielded, but had a mixed effect on reducing driver speeds. At the four sites where crosswalks or crosswalk signals were improved, measured outcomes on vehicle yielding and vehicle speeds did not exceed expected levels. The research team concluded that five of the ten traffic improvement projects were successful according to their strict evaluation criteria (2).

Figure 75: Before and after images of a street segment improved using Safe Routes to School funding in California.

Image from the Boarnet, Day, Anderson, McMillan, and Alfonzo article showing before and after photos of a roadway segment improved using SR2S funding (2).

A 2008 article by Gutierrez et al evaluated the effect of the California Safe Routes to School (SR2S) program on collision statistics at 125 project locations throughout California. Pre-treatment data were collected from the year 1998 until the award date for the project. Post-treatment data were collected for the period between treatment completion and the end of 2005. Intersections were considered to be in the treatment group if they were within ¼ mile of a school entrance, and all other intersections within the city limits were used for control. An analysis of the results showed a 13 percent reduction in the number of injured child pedestrians and bicyclists in the post-treatment period; however, control sites demonstrated a similar decrease. The researchers note that overall numbers of child pedestrians are much higher in treatment zones, meaning that sites are not completely comparable. The 5-12 age group had the largest observed reduction in injuries, with a 27.6 percent decrease. While numbers of minor injuries were reduced, fatal and severe injuries did not show the same reduction; however, as relatively rare events, more data may be needed to study this trend. Based on their analysis, the researchers concluded that the SR2S program appeared to increase pedestrian and bicyclist safety in school zones (3).

Figure 76: Children crossing the street as part of the Safe Routes to School program.

California children participating in a Safe Routes to School Program. Note the yellow crosswalk, used in California to denote school zone crosswalks. Photo by the State of California. Source: http://www.dot.ca.gov/hq/LocalPrograms/saferoutes/saferoutes.htm

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 (4).

Figure 77: A high-visibility yellow crosswalk in Stockton, California

A high-visibility yellow crosswalk in Stockton, California. In California, yellow crosswalks are used to denote crosswalks in school zones. Photo by the City of Stockton, California Source: http://www.stocktongov.com/files/PWProvider_HighVisibilityCrosswalk.jpg

A 2013 article by DiMaggio and Li evaluated the effects of the Safe Routes to School (SR2S) program in New York City. The researchers compiled records from every pedestrian-motor vehicle collision between 2001 and 2010 from the New York City DOT (n = 168,806) and compared annual pedestrian injury rates during school travel hours (7 a.m.--9 a.m. and 2 p.m.--4 p.m.) for different age groups and for census tracts with or without SR2S. A total of 4760 pedestrian injuries were reported for 5-19 year olds during school travel hours between 2001 and 2010. Overall, from 2001 to 2010, the rate of pedestrian injuries in the school-aged group decreased by 33 percent from 40.9 to 27.4 injuries per 10,000 people. The rate of pedestrian injuries during school travel hours decreased in census tracts with SR2S interventions by 44%, from 8.0 per 10,000 population per year in the pre-SR2S period (2001-2008) to 4.4 per 10,000 population per year in the post-SR2S period (2009-2010). In census tracts without SR2S programs, the rate of pedestrian injuries remained at 3.1 per 10,000 population per year during both time periods. Though the researchers could not eliminate the possibility of confounding factors or secular trends, they noted that the results of the analysis indicated that the implementation of SR2S in New York City may have resulted in greater safety for school-aged pedestrians (5).

A 2014 article by Ragland, Pande, Bigham, and Cooper assessed the long-term impact of infrastructure improvements funded by the California Safe Routes to School (SR2S) program on the safety of pedestrians and bicyclists. For the purposes of the analysis, pedestrians and bicyclists were considered as a single group. Data on pedestrian/bicyclist collisions were collected for the pre- and post-construction periods spanning from 1998 to 2009, as well as for treatment areas (within 250 feet of a treatment) and control areas (outside of the 250-foot buffer around treatments but within ¼ mile of a school). Two analyses were conducted. The first, which looked only at collisions involving pedestrians and bicyclists ages 5 to 18, found an incident rate ratio (IRR) of 0.47, representing a reduction in the risk of collisions of about 53% for treatment areas when compared to control areas; however, this effect was not statistically significant. The second analysis looked at collisions involving pedestrians and bicyclists of all ages and found an IRR of 0.26, representing a 74% decrease in the risk of collisions in treatment areas when compared to control areas. This difference was statistically significant, as were the decreases in the subgroups of collision involving minor injury (decrease in risk of 73%), collisions occurring between 3 and 6 p.m. (decrease in risk of 91%), and collisions at high school locations (decrease in risk of 88%). The researchers concluded that, while the primary focus of the SR2S program is to increase safety for students traveling to and from school, engineering treatments to increase safety also improve safety for all pedestrians and bicyclists at treatment locations (6).

References

1. Campbell, B. J., C. V. Zegeer, H. H. Huang, and M. J. Cynecki. *A Review of Pedestrian Safety Research in the United States and Abroad*. Publication FHWA-RD-03-042, FHWA, U.S. Department of Transportation, 2004.
2. Boarnet, M. G., K. Day, C. Anderson, T. McMillan, and M. Alfonzo. California's Safe Routes to School Program. *Journal of the American Planning Association*, Vol. 71, No. 3, 2005, pp. 301-317.
3. Gutierrez, N., M. Orenstein, J. Cooper, T. Rice, D. R. Ragland. Pedestrian and Bicyclist Safety Effects of the California Safe Routes to School Program. Presented at 87th Annual Meeting of the Transportation Research Board, Washington, D.C., 2008.
4. Feldman, M., J. G. Manzi and M. Mitman. An Empirical Bayesian Evaluation of the Safety Effects of High-Visibility School (Yellow) Crosswalks in San Francisco. In *Transportation Research Record: Journal of the Transportation Research Board*, No. 2198, Transportation Research Board of the National Academies, Washington, D.C., 2010, pp. 8-14.
5. DiMaggio, C., and G. Li. Effectiveness of a Safe Routes to School Program in Preventing School-Aged Pedestrian Injury. *Pediatrics*, Vol. 131, No. 2, 2013, pp. 290-296.
6. Ragland, D. R., S. Pande, J. Bigham, and J. F. Cooper. Ten Years Later: Examining the Long-Term Impact of the California Safe Routes to School Program. Presented at the 93rd Annual Meeting of the Transportation Research Board, Washington, D.C., 2014.

Section 9.2: Neighborhood Identity

No information for this section.

Section 9.3: Speed-Monitoring Trailer

A 2009 report by Pecheux, Bauer, and McLeod contained an evaluation of portable speed trailers used at four sites in San Francisco and one midblock location in Miami. The effect of the speed trailers on vehicle speeds is given in the table below. While vehicle speeds decreased at the two San Francisco sites, they increased slightly at the Miami site (16).

The two research teams measured slightly different measures of driver yielding. In Miami, the researchers measured the percentage of drivers who applied the brakes when a pedestrian was crossing outside of the mid-block crosswalk. They observed a 10 percent increase in driver breaking in the post-treatment phase. In San Francisco, the researchers measured the percentage of drivers who yielded to pedestrians, finding an increase of 11 percent and 21.7 percent at the two sites they studied. The San Francisco researchers also measured pedestrian delay, finding a 1.4 percent and 4.1 percent decrease at the two sites. While research teams in both cities measured vehicle-pedestrian conflicts, they found no significant changes in between the pre- and post-test phases. The researchers concluded that speed trailers can have small impacts on vehicle speeds and possibly increase driver awareness of pedestrians at their locations. They gauged the countermeasure to be of medium effectiveness, and found it unlikely that impacts would continue once the speed trailer was removed (16).

Figure 78: A portable speed trailer that displayed driver speed used in a San Francisco, California, evaluation study

The portable speed trailer used in the San Francisco evaluation by Pecheux, Bauer, and McLeod (16).

A 2010 Transportation Research Board presentation by Dangeti, Pulugurtha, Vasudevan, Nambisan, and White evaluated four Intelligent Transportation Systems (ITS) based countermeasures, including a portable speed trailer. The speed trailer was installed two locations in Las Vegas, Nevada, and the following measures of effectiveness (MOEs) were observed before and for three weeks following the installation of the trailer: (1) the percentage of drivers who yielded to pedestrians, (2) pedestrian crossing delay, and (3) vehicle speeds. A comparison of pre- and post-treatment data showed neither a significant increase in driver yielding nor a decrease in pedestrian crossing delay. Overall, vehicle speeds decreased at both sites. The authors concluded that the portable speed trailer was effective; however, the benefits of the speed trailer disappeared when the trailer was removed from its location (2).

Figure 79: A portable speed trailer that displayed driver speed used in a Las Vegas, Nevada, evaluation study.

The sign used in the Las Vegas evaluation (16).

Table 32: Vehicle speeds as measured before and during the use of a portable speed trailer in Miami and San Francisco

Location	Site	Vehicle Speed		% Change	p-value
		Before	After		
Miami	Collins between 38th and 39th	25.9 (n=330)[1]	26.2 (n=300)[1]	+0.30	0.05
San Francisco	Mission &	26	24	-2	<0.01

	France	(n=64)[2]	(n=46)[2]		
	Geary & 11th	29 (n=80)[2]	25 (n=49)[2]	-4	<0.01

1 Number of pedestrian crossings observed

2 Number of vehicle-pedestrian interactions

Table 19 from the report showing vehicle speeds before and after the installation of the portable speed trailer (16).

References

1. Pecheux, K., J. Bauer, P. McLeod. *Pedestrian Safety Engineering and ITS-Based Countermeasures Program for Reducing Pedestrian Fatalies, Injury Conflicts, and Other Surrogate Measures Final System Impact Report*. Federal Highway Administration, U.S. Department of Transportation, 2009.
2. Dangeti, M.R., S.S. Pulugurtha, V. Vasudevan, S. S. Nambisan, and O.C. White Jr. Evaluating ITS-Based Countermeasures – How Effective are they in Enhancing Pedestrian Safety? Presented at 89th Annual Transportation Research Board Meeting, Washington, D.C., 2010.

Section 9.4: On-Street Parking Enhancements

No information for this section.

Section 9.5: Pedestrian/Driver Education

No information for this section.

Section 9.6: Police Enforcement

A 1995 article by Britt, Bergman, and Moffat evaluated the effect of four enforcement campaigns in Seattle on driver compliance with crosswalk laws. The authors explained that crosswalks provided specific target locations for measuring motorist yielding behavior. In 1990, a new Seattle Police Department policy shifted in focus from ticketing jaywalkers to enforcing yielding to pedestrians at marked crosswalks. For the next four years, from 1991-1994, the Police Department conducted four different enforcement campaigns at different locations throughout the city. One hundred vehicle-pedestrian conflicts were observed before and after each campaign. The results indicated that targeting small areas (neighborhoods or specific intersections) may be as effective as citywide campaigns, that short programs may be as effective as longer programs, and enforcement in high-volume corridors may have minimal safety benefits. The authors conclude that altering design features of the roadway to encourage lower speeds may be more effective, although possibly more expensive, than conducting enforcement campaigns (1).

Table 33: Summary of the effects of crosswalk enforcement efforts, Seattle, Washington, 1990-1994

Summary of Crosswalk Enforcement Efforts, 1990 to 1994[a]					
Campaign	**Focus**	**Duration**	**# Citation**	**Before**	**After**
#1	City-wide	1 yr+	3600+ (est)	15%	19%
#2	Neighborhood	3 months	--	11%	18%

#3	Neighborhood (1)	3 months	286	19%	7%
	Neighborhood (2)	3 months	150	9%	30%
#4	Intersection (1)	3 weeks	74	24%	15%
	Intersection (2)	3 weeks	50	30%	45%

a Size of area enforced and sentinel intersections enforced varied with individual campaigns

b Near-side compliance of marked crosswalks was measured in all campaigns. Compliance for Campaigns 1 & 2 represent averages of 12 sentinal crosswalks. Compliance for Campaigns 3 & 4 represent observations at single sentinel marked crosswalks.

Table 5 from the article showing the percentage of vehicles that yielded to pedestrians following each phase of the enforcement campaign (1).

A 2004 *Journal of Applied Behavior Analysis* article by Van Houten and Malenfant evaluated the effects of a 2-week saturation enforcement program carried out in Miami Beach. The program used decoy pedestrians, feedback flyers, verbal and written warnings, and enforcement to catch drivers who failed to yield to pedestrians at crosswalks and remind them of the law that required them to do so. The researchers used a multiple baseline design, measuring yielding behavior and driver-pedestrian conflicts at baseline (pre-enforcement), following the launch of an enforcement program in one corridor (the west corridor), following the launch of a second enforcement program in another corridor (the east corridor), and once a month at the eight sites for one year following the introduction of the treatment program. At baseline, 3.3 percent (west corridor) and 18.2 percent (east corridor) of drivers yielded for pedestrians at each of the four sites in each of the study corridors. At one week following the introduction of the enforcement program in the west corridor, driver yielding increased to 27.6 percent, while no increase was observed in the untreated east corridor. Driver yielding increased to 33.1 percent in the east corridor following the introduction of enforcement. Following the reduction in enforcement, yielding rates were maintained at the treated crosswalks in the course of the year that followed. The researchers also observed increases in motorist yielding at ten of twelve control sites which received no treatment, demonstrating spillover effects. The researchers concluded that enforcement programs produce pedestrian safety benefits, especially when coupled with engineering enhancements (2).

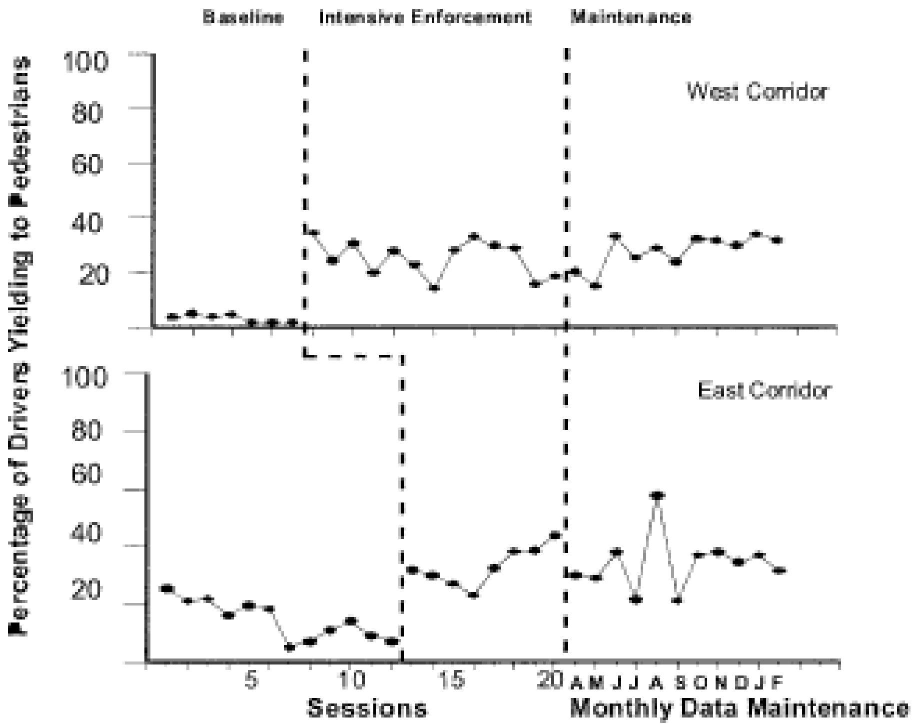

Figure 80: Graph showing the percentage of drivers yielding to pedestrians before, during, and after a motorist yielding enforcement campaign in Miami Beach, Florida.

Graph from the article showing the percentage of yielding pedestrians during each phase of the evaluation. The dashed lines indicate where programs were introduced (2).

A 2011 paper by Savolainen, Gates, and Datta evaluated two citywide pilot enforcement programs intended to improve pedestrian safety in Detroit, Michigan. Each program was conducted twice, for two weeks each, in 2008 and 2009. The first program, Walk Safely to Wayne State, was implemented at three signalized intersections and one signalized midblock crossing. The second program, Share the Road, was implemented at five signalized intersections in 2008 and ten signalized intersections in 2009. Data were collected for one week pre-implementation, followed by a public awareness campaign, pre-enforcement warning period, the enforcement period, and post-implementation data collection. Results from the two programs indicated that targeted enforcement was effective in reducing the rate of pedestrian traffic violations, with results sustainable for some time following the enforcement program. The Walk Safely to Wayne State program led to a 27 percent reduction in violations during the enforcement period, and a 9.8 percent sustained reduction in violations. The Share the Road program led to a 17.1 percent reduction in traffic violations, with a 7.8 percent sustained reduction in the weeks following the program. The authors concluded that targeted enforcement was an effective method of improving pedestrian safety; however, they indicated that infrastructure-based countermeasures enhanced the effectiveness of enforcement programs (3).

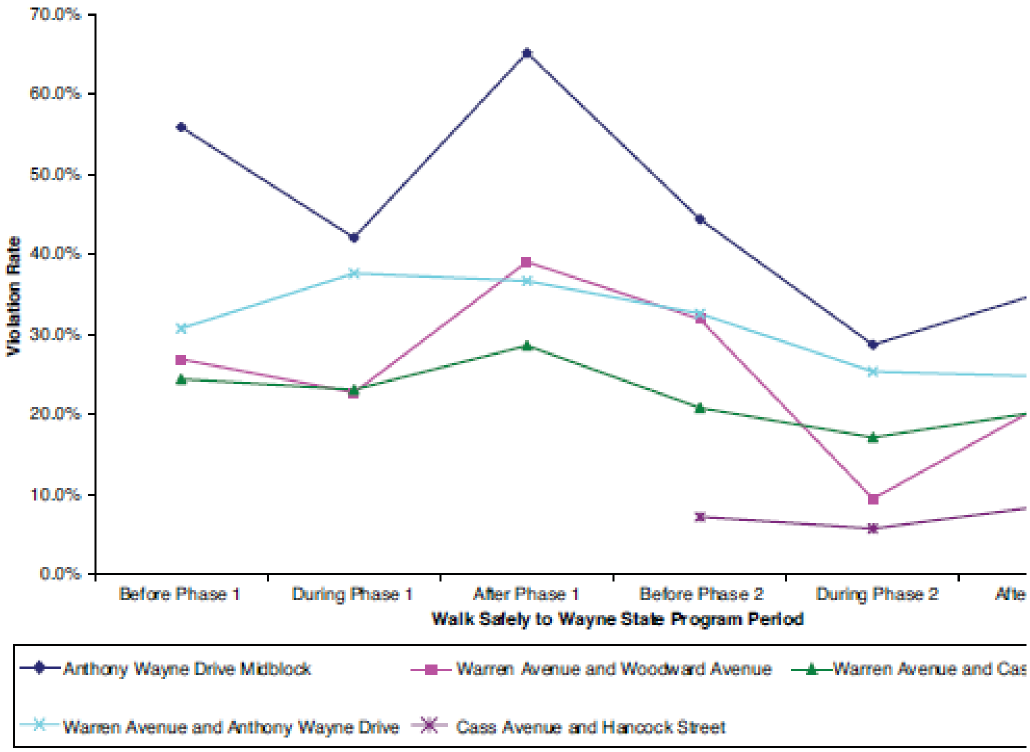

Figure 81: A graph showing motorist yielding violation rates before, during, and after a pedestrian safety program in Detroit, Michigan.

Graph from the article showing violation rate percentage before, during, and after the Walk Safely to Wayne State program.

A 2012 study by Van Houten, Malenfant, Huitema, and Blomberg evaluated the effectiveness of a one-year high-visibility enforcement program to increase motorist yielding to pedestrians at marked, uncontrolled crosswalks (lacking a traffic light or stop sign) in Gainesville, Florida. The researchers chose 12 crosswalk sites near pedestrian generators, and sites were randomized to treatment (high-visibility enforcement) or control conditions, where it was expected that spillover effects may be observed. Prior to the collection of baseline data, all crosswalks were repainted and advanced yield markings were installed. Trained data collectors measured motorist yielding to crossing pedestrians using a mixture of staged and naturally-occurring crossings during five phases of the study: at baseline, during enforcement only, during enforcement and ticketing, during citations and ads, and during enforcement and signs. At the end of the study, 82.7% of motorists yielded to unstaged pedestrians, compared with 45.4% at baseline. Results indicated that

Figure 82: A police officer giving a citation to a motorist

Police enforcement can be used in addition to engineering countermeasures to remind drivers of laws requiring motorists to yield to pedestrians. Photo by Michael Ronkin. Source: http://safety.transportation.org/htmlguides/peds/description_of_strat.htm

enforcement measures were associated with a slow and steady increase in the percentage of yielding motorists over the course of the year and that effects were observed in untreated crosswalks, with the amount of effect observed inversely proportional to their distance from treated crosswalks (*4*).

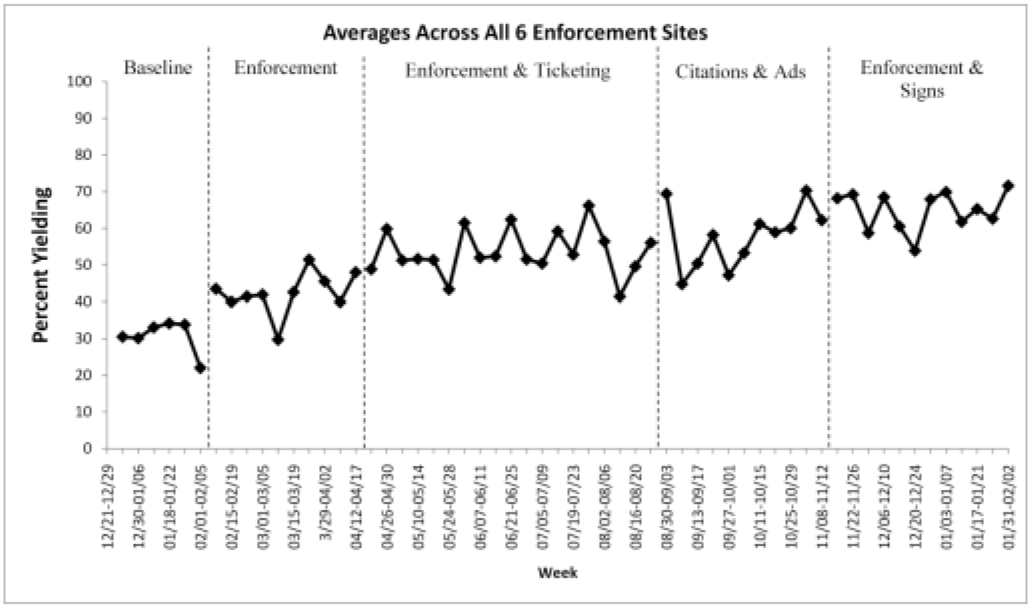

Figure 83: A graph showing mean motorist yielding percentages at 6 treatment sites before and during a yearlong enforcement program in Gainesville, Florida.

Figure 2 from the Van Houten, Malenfant, Huitema, and Blomberg study that shows the mean percentage of motorists yielding to pedestrians at treatment sites during each phase of the experiment (4).

References

1. Britt, J.W., A.B. Bergman, and J. Moffat. Law Enforcement, Pedestrian Safety, and Driver Compliance with Crosswalk Laws: Evaluation of a Four-Year Campaign in Seattle (With Discussion and Closure). In *Transportation Research Record: Journal of the Transportation Research Board*, No. 1485, Transportation Research Board of the National Academies, Washington, D.C., 1995, pp. 160-167.
2. Van Houten, R., and J.E.L. Malenfant. Effects of a Driver Enforcement Program on Yielding to Pedestrians. *Journal of Applied Behavior Analysis*, Vol. 37, 2004, pp. 351-363.
3. Savolainen, P. T., T. J. Gates and T. K. Datta. Implementation of Targeted Pedestrian Traffic Enforcement Programs in an Urban Environment. In *Transportation Research Record: Journal of the Transportation Research Board*, No. 2265, Transportation Research Board of the National Academies, Washington, D.C., 2011, pp. 137-145.
4. Van Houten, R., L. Malenfant, B. Huitema, and R. Blomberg. The Effects of High Visibility Enforcement on Driver Compliance to Pedestrian Yield Right-of-Way Laws. Presented at the 92nd Annual Meeting of the Transportation Research Board, Washington, D.C., 2013.

Section 9.7: Automated Enforcement Systems

No information for this section.

Section 9.8: Pedestrian Streets/Malls

No information for this section.

Section 9.9: Work Zones
No information for this section.

Section 9.10: Pedestrian Safety at Railroad Crossings
No information for this section.

Section 9.11: Shared Streets
No information for this section.

Section 9.12: Streetcar Planning and Design
No information for this section.

Section 10: 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 roadway safety 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*).

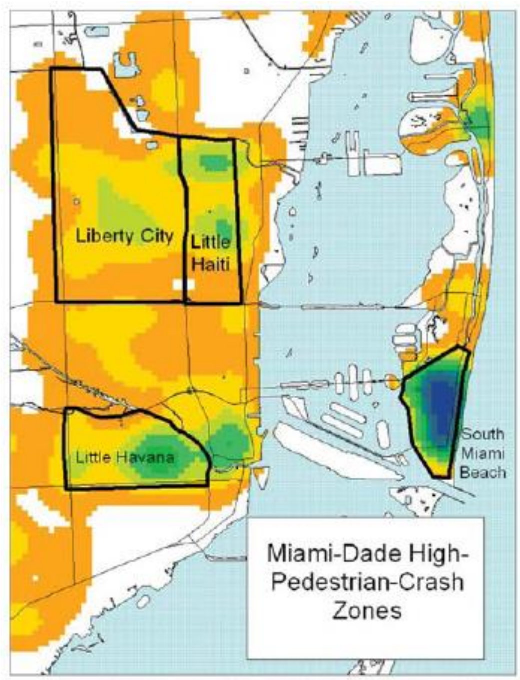

Figure 84: Map of Miami, Florida, showing areas with high frequencies of pedestrian crashes.

Map of high-frequency pedestrian crash zones created by the researchers. As a result, the countermeasure program was concentrated in these four areas (3).

In 1999-2000, the small town of Storuman, 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 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 extended to adjacent roads as well (*2*).

A 2009 report by Zegeer et al evaluated a comprehensive countermeasure program, consisting of 16 education, enforcement, and engineering treatments, deployed at four high-collision zones identified by the researchers throughout Miami-Dade County, Florida. The researchers used pre- and post-treatment collision statistics, as well as three control groups, in order to evaluate the effects of the pedestrian safety program. Collision data from the year 1998 until 2001 were obtained for the pre-treatment period. Post-treatment data were collected upon project implementation in 2002 until 2004. Neighboring counties were used to analyze overall local collision trends. Analysis of results showed a reduction in pedestrian crashes of 13.3 percent in the post-treatment period when compared to nearby Broward County, and a reduction of 8.5 percent when compared to all counties in the state. The researchers estimate that this reduction in pedestrian crashes translates into 180 fewer crashes per year in Miami-Dade County (*3*).

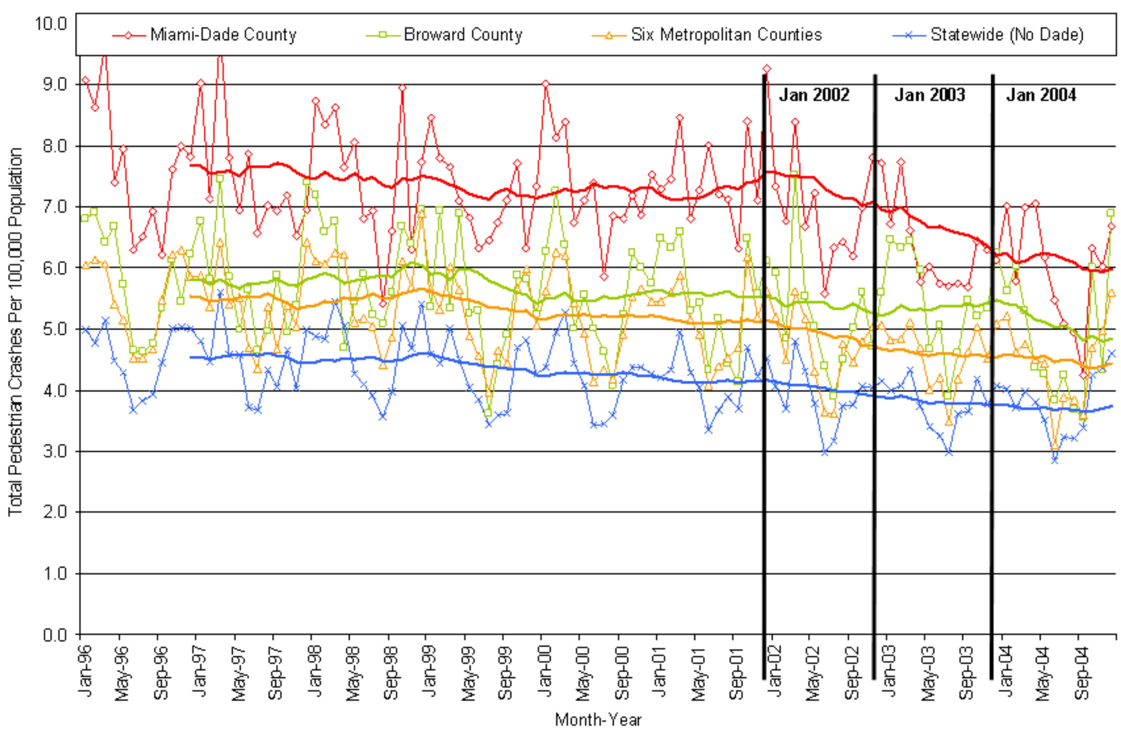

Figure 85: Graph showing monthly pedestrian crashes per 100,000 individuals over a nine-year period in Florida

Graph from the report showing monthly pedestrian crashes per 100,000 individuals in Miami-Dade County, Broward County, Six Combined Metropolitan Counties, and Statewide from 1996-2004. The vertical lines represent the three project intervention points in January 2002, January 2003, and January 2004 (3).

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, 7 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 2004-2007 serving as the pre-treatment phase, and the period from 2008-2009 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) 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 (*4*).

Table 34: 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

Table 2 from article showing pedestrian crash statistics from the pre- and post-intervention periods in the City of Detroit and in the rest of the state of Michigan (4).

A different type of study looked at the role of pedestrian-friendly policies in creating a safer pedestrian environment. The 2013 article by Kerr, Rodriguez, Evenson, and Aytur was the first to study the association between the publication of local pedestrian plans and rates of pedestrian injury. The researchers created a database of North Carolina's 533 municipalities, noting whether or not each municipality had a pedestrian plan during the study time period (1999-2007), and collecting plans from the 130 municipalities that did. They collected injury statistics from the state bicycle and pedestrian crash database and calculated exposure estimates using data from the American Community Survey, U.S. Census, Safe Routes to School 2010 Report, and the 2009 National Household Transportation Survey. Using quasi-experimental, interrupted time series research design, the researchers estimated pedestrian injury risk ratios for municipalities with and without pedestrian plans. Incident rate ratios were adjusted for year, demographic, and land use factors. Overall, nonfatal pedestrian injuries in North Carolina decreased by 25 percent from the pre-plan to post-plan period, and fatal pedestrian injuries decreased by 37 percent. The authors

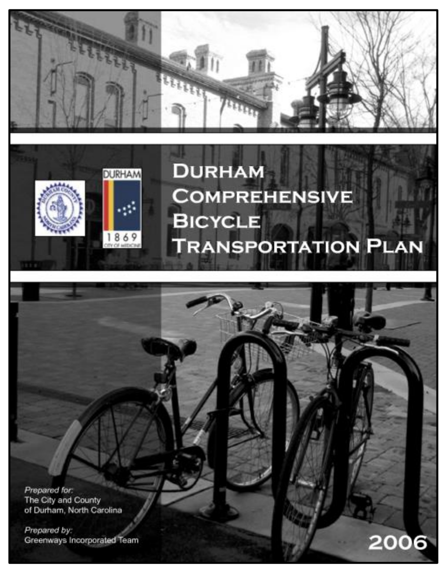

Figure 86. Durham, North Carolina, bicycle plan.

Cover of one of the bicycle plans studied by Kerr, Rodriguez, Evenson, and Aytur (2013) (5)

conclude that further study is needed to understand how changes in injury rates are related to specific safety-related plan content, as well as the extent of implementation of plans and plan quality (5).

A 2013 article by Islam and El-Basyouny considered the safety impacts of an integrated speed management plan implemented on Silverberry Road in Edmonton, Canada. The plan, designed to reduce speeding, involved the painting of a centerline coupled with one month of educational and enforcement activities along the 50 km/h (31 mi/h) road. The educational activities included a voice message sent to Silverberry Road residents, a dynamic messaging sign asking drivers to slow down, and portable speed trailers. Enforcement activities were both manned and unmanned (photo enforcement). The researchers collected pre- and post-intervention vehicle speed data from seven locations along the treatment site (Silverberry Road) and five locations along a comparison site (Woodvale Road). In the short term (the week following the end of intervention activities), mean speed was decreased by nearly 3 km/h (nearly 2 mi/h), a decrease in speed of 5.8 percent. In the long term (one month following the end of the intervention activities), mean speed was decreased by 2.26 km/h (1.4 mi/h), a reduction in speed of 4.5 percent. Results in the short and long term were statistically significant at 0.05. Overall, the greatest decreases in speed were observed on weekend nights. The researchers concluded the integrated speed management plan was an effective, low-cost alternative to the traditional enforcement-only approach to speed management in Edmonton (6).

References

1. Malenfant, L., and R. Van Houten. Increasing the Percentage of Drivers Yielding to Pedestrians in Three Canadian Cities with a Multifaceted Safety Program. *Health Education Research*, Vol. 5, No. 2, 1989, pp. 275-279.
2. Leden, L., P. E. Wikstrom, P. Garder, and P. Rosander. Safety and Accessibility Effects of Code Modifications and Traffic Calming of an Arterial Road. *Accident Analysis and Prevention*, Vol. 38, No. 3, 2006, pp. 455-461.
3. Zegeer, C., D. Henderson, R. Blomberg, L. Marchetti, S. Masten, Y. Fan, L. Sandt, A. Brown, J. Stutts, and L. Thomas. *Evaluation of the Miami-Dade Pedestrian Safety Demonstration Project*. National Highway Traffic Safety Administration. Washington, DC, 2008.
4. Savolainen, P. T., T. J. Gates and T. K. Datta. Evaluation of the Effectiveness of a Comprehensive Pedestrian Safety Program in a Major City. Presented at 90th Annual Meeting of the Transportation Research Board, Washington, D.C., 2011.
5. Kerr, Z., D. Rodriguez, K. Evenson, and S. Aytur. Pedestrian and Bicycle Plans and the Incidence of Crash-Related Injuries. *Accident Analysis and Prevention*, Vol. 50, 2013, pp. 1252-1258.
6. Islam, M. T., and K. El-Basyouny. An Integrated Speed Management Plan to Reduce Vehicle Speeds in Residential Areas: Implementation and Evaluation of the Silverberry Action Plan. *Journal of Safety Research*, Vol. 45, 2013, pp. 85-93.

Pedestrian and Bicycle Information Center

730 Martin Luther King Jr. Blvd., Suite 300
Chapel Hill, North Carolina 27599-3430
pbic@pedbikeinfo.org
888-823-3977