White Paper Series

An Overview and Recommendations of High-Visibility Crosswalk Marking Styles

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Executive Summary

As policymakers continue to encourage active transportation in the United States, there is increasing importance by all road users to understand right-of-way laws. Also, engineers and planners should implement the most effective crosswalk marking patterns. The effect of various crosswalk marking patterns should also be understood, in terms of which ones are most effective at causing motorists to yield the right-of-way to pedestrians. The purpose of this paper is to examine the past and current research on crosswalk marking design and to come to conclusions about the best types of marking patterns under various traffic and roadway conditions.

General crosswalk information is given in the paper, such as guidelines supplied by the *Uniform Vehicle Code* and the *Manual on Uniform Traffic Control Devices*, which provides a background of current recommendations in the United States for crosswalk design and installation. This paper also includes a brief description of the decades-long debate about whether uncontrolled crosswalks are safest for pedestrians when they are marked or unmarked. The paper then examines the current research about effective marking patterns. Different patterns' effects on pedestrian collisions and their relative visibility are discussed, as well as best practices from across the country and abroad.

We conclude that, because high-visibility markings are more easily detected by motorists and have been shown to lead to a reduction in pedestrian-vehicle collisions when compared to transverse line crosswalks, transportation agencies should install high-visibility markings at uncontrolled crossing locations whenever a determination is made to provide marked crosswalks. Installing the most visible crosswalk marking styles is important to increase the likelihood that approaching motorists will see marked crosswalks in time to become aware of the possibility of pedestrians crossing the street ahead. At crossing locations controlled by traffic signals or stop signs, the key recommendation is to mark all legs of the intersection with a crosswalk in order to indicate to pedestrians and motorists the preferred locations for pedestrians to cross. More broadly, policymakers in the United States need to come to a consensus on right-of-way laws for crosswalks. If all states are consistent in how they enforce crossing areas, pedestrian and motorist compliance with the rules of the road should also be more consistent, and improve.

Introduction

Pedestrians have the right to adequate opportunities to safely and conveniently cross roads. However, general lack of knowledge of pedestrian right-of-way by motorists and pedestrians can endanger pedestrians who try to accomplish this simple task. As policy makers attempt to encourage more Americans to walk as a way of increasing regular physical activity (*1*), pedestrians should have a safe and supportive environment in which to do so. This goal is especially important because pedestrians continue to be overrepresented in roadway injuries and deaths when compared to their overall exposure. Marking crosswalks at intersections or other roadway crossing sites is one measure that can be used to designate a pedestrian crossing.

The purpose of this white paper is to review national and local guidelines for the implementation of marked crosswalks, to discuss enhancements that can potentially improve crosswalk yielding rates and safety, and to analyze previous crosswalk research to provide agencies with the current standards of practice and recommendations as they relate to crosswalk marking designs.

General Crosswalk Information

A number of attempts have been made to establish guidelines regarding when, how, and in what situations to mark a crosswalk. In this section, the *Uniform Vehicle Code*, research on marked versus unmarked pedestrian crossings, and the guidelines provided by the *Manual on Uniform Traffic Control Devices* are discussed.

Vehicle Codes

The *Uniform Vehicle Code* (UVC) provides guidance for traffic laws with a goal of creating national consistency. Many states have modeled their traffic laws on the UVC; however, state laws still vary significantly regarding right-of-way and yielding requirements for vehicle-pedestrian interactions in crosswalks.

Crosswalks, as defined by the UVC, are:

> (a) That part of a roadway at an intersection included within the connections of the lateral lines of the sidewalks on opposite sides of the highway measured from the curbs or, in the absence of curbs, from the edges of the traversable roadway; and in the absence of a sidewalk on one side of the roadway, that part of a roadway included within the extension of the lateral lines of the existing sidewalk at right angles to the centerline.

(b) Any portion of a roadway at an intersection or elsewhere distinctly indicated for pedestrian crossing by lines or other markings on the surface (*2*).

In other words, according to the UVC, crosswalks exist at the intersection of roadways regardless of whether they are marked or unmarked. At locations that are not intersections, pavement markings establish the crosswalk. Motorists should yield the right-of-way to pedestrians in cases "when the pedestrian is upon the half of the roadway upon which the vehicle is traveling, or when the pedestrian is approaching so closely from the opposite half of the roadway as to be in danger (*2*)." The UVC is not specific about whether a crosswalk exists at intersections where no sidewalks are present, and various state and local codes differ somewhat on this issue.

While the UVC requires that motorists yield the right-of-way to pedestrians at marked and unmarked crosswalks, this guidance is not mirrored in all states' vehicle codes. For example, Massachusetts law requires motorists to yield only in cases where pedestrians are in marked crosswalks (*3*). Such discrepancies in how the laws are written, and how states enforce traffic laws, make it difficult for motorists and pedestrians to understand and follow local laws.

Research about Marked and Unmarked Crosswalks

Considering that many localities use an engineer's best judgment when deciding how and where to mark crosswalks, marked crosswalk installation practices vary significantly across the United States. A decades-long debate about the appropriateness of whether to mark crosswalks at uncontrolled locations has contributed to the varied practices.

Collisions

One of the most contentious issues in pedestrian safety design is whether marked or unmarked crosswalks at uncontrolled locations are safer for pedestrians. Several landmark studies on the safety of crosswalks have influenced decisions about whether to mark uncontrolled crossing locations. A 1972 study by Herms collected data from 400 uncontrolled intersections in San Diego, California, and found that marked crosswalks had twice the risk of having a pedestrian-involved collision as unmarked crosswalks (*4*). The results of this study led many state and city departments of transportation to remove crosswalks or to stop installing new ones at locations with high crash rates, believing that this tactic would reduce the danger to pedestrians.

Nearly three decades later, a study completed in Los Angeles by Jones and Tomcheck (2000) attempted to recreate the Herms study to determine whether the City of Los Angeles' crosswalk marking guidelines made sense. They found that pedestrian-vehicle incidents declined by 61% at intersections following the removal of a marked crosswalk, with no corresponding increase in

incidents at nearby intersections (*5*). These results validated the City's belief that marked crosswalks should be very selectively reinstalled following a road repaving. However, this study did not consider the context of the crosswalks, such as traffic volume levels, speeds, or number of lanes. Also, since many pedestrians and motorists recognize only marked crosswalks as legal crossings, these studies and policies did not balance mobility needs with safety considerations.

A 2001 study by Zegeer, et al. attempted to clarify the results of the Herms study and resolve previous studies' research design flaws by controlling for site context factors. Zegeer analyzed data from 1,000 marked and 1,000 matching unmarked crosswalks sites in 30 U.S. cities (*6*). The study concluded that site factors related to pedestrian-involved collisions included pedestrian average daily traffic (ADT), vehicle ADT, number of lanes, and presence of a raised median.. At uncontrolled locations on two-lane roads and multi-lane roads with ADT below 12,000 vehicles, Zegeer found that the presence of a marked crosswalk alone, compared with an unmarked crosswalk, made no statistically significant difference in the pedestrian crash rate. However, on multi-lane roads with an ADT of greater than 12,000 vehicles (without a raised median) and 15,000 vehicles (with a raised median) the presence of a marked crosswalk alone, without other improvements was associated with a statistically significant higher rate of pedestrian crashes compared to sites with an unmarked crosswalk (*6*).

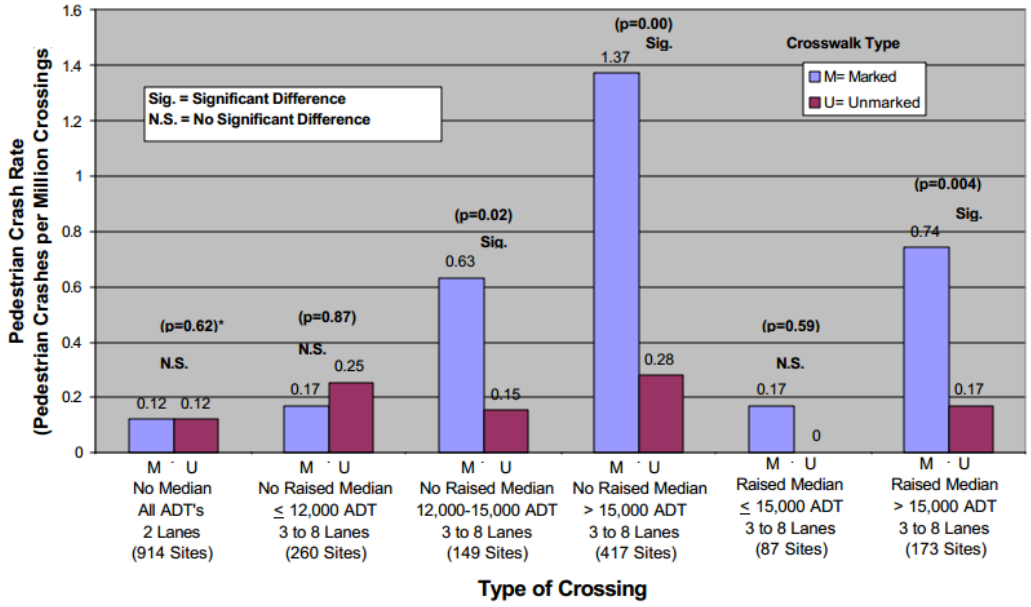


Figure 1 – Pedestrian crash rate versus type of crossing. Results from the Zegeer et al. (2001) study of marked versus unmarked crosswalks (*6*).

Zegeer stressed that the results of the study should not encourage city officials to simply remove (or fail to install) marked crosswalks. Rather, he suggested adding crosswalk enhancements to the marked crosswalks to balance mobility needs with safety needs. These improvements include providing raised medians on multi-lane roads, installing traffic and pedestrian signals where warranted, adding curb extensions, providing adequate lighting, and designing intersections with tighter turn radii, etc. (*6*).

In the Zegeer study, about 70 percent of the pedestrian crashes occurred at marked crosswalks on multi-lane roads. Of the pedestrian crashes at marked crosswalks, 17.6 percent were classified as multiple-threat crashes (*6*). Multiple-threat crashes occur when a pedestrian attempts to cross a multi-lane road and the motorist nearest to the pedestrian stops, but the motorist traveling in the same direction in the farther lane does not stop and hits the pedestrian. The slowing vehicle blocks the sight line of both the pedestrian and the second motorist, leading to the pedestrian-vehicle incident. The multi-lane roadways where multiple-threat crashes occur are not well-served by unmarked or marked crosswalks alone. At these sites, the study concluded, engineers should consider countermeasures that provide additional safety to pedestrians and alert motorists to upcoming crosswalks. Such countermeasures could include advance stop or yield lines with corresponding signs informing motorists where to stop or yield (see Figure 2). Other more substantial measures may also be considered, such as signalization, nighttime illumination, or raised median islands.

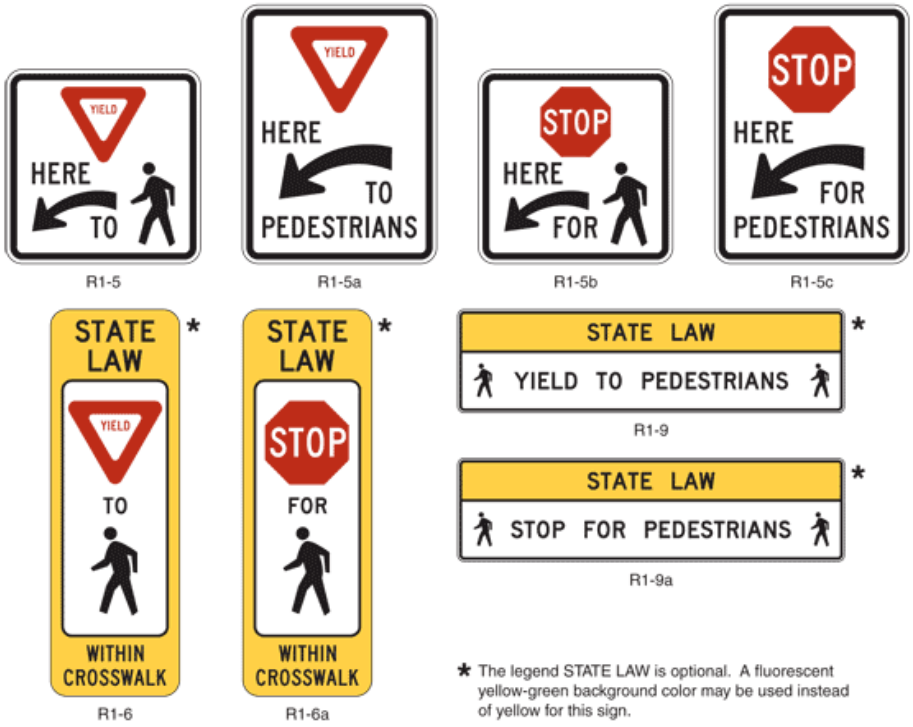


Figure 2 - MUTCD-Approved Unsignalized Pedestrian Crosswalk Signs (*12*)

Motorist Behavior

Researchers have also examined the safety effects of marked and unmarked crossings by observing motorist behavior and vehicle speeds. Knoblauch and Raymond (2000) conducted a before-after study of sites in Maryland, Virginia, and Arizona. They looked at uncontrolled intersections with stop control on the minor leg. Crosswalks were installed after a road repaving, so the before condition had no crosswalks and the after condition had crosswalks. Knoblauch and Raymond analyzed motorist speed during three conditions before and after the marked crosswalk was installed: at a crosswalk with no pedestrians present, at a crosswalk with the pedestrian looking at approaching traffic, and at a crosswalk with the pedestrian not looking at approaching traffic. The researchers did not control for number of lanes on the roadway (*7*). The results of the study found a statistically significant 2.06 mi/h reduction in average speed for crosswalks with no pedestrians. The presence of a crosswalk with a pedestrian not looking at approaching traffic also produced a significant 1.62 mi/h reduction in vehicle speed. No significant reductions occurred in the crosswalk with the pedestrian looking scenario (*7*).

A subsequent study by Knoblauch et al. (2001) looked at motorist and pedestrian behavior when markings were added to previously unmarked crosswalks. The study evaluated four cities: Sacramento, CA; Richmond, VA; Buffalo, NY; and Stillwater, MN. Using before-after experimental

design, the researchers found that motorists appeared to respond differently to crosswalks when they were marked. The motorists decreased their speed, which the researchers believed to indicate increased motorist awareness of pedestrians. Knoblauch, et al. also found that crosswalk usage increased after the installation of markings, although this increase came mostly from pedestrians walking alone, as pedestrians in groups did not tend to use the marked crosswalks (*8*).

One explanation for inconsistent motorist yielding could be a lack of knowledge of right-of-way laws, specifically in regards to marked and unmarked crosswalks. Mitman and Ragland assessed motorist and pedestrian knowledge of the vehicle code in their 2007 study and concluded that much confusion about pedestrian right-of-way at crosswalks exists (*9*). Respondents from the study's focus groups and intercept surveys had trouble determining who had the right-of-way in complex scenarios that did not involve an intersection with four marked crosswalks. Due to these findings, the authors argue that education and enforcement efforts need to be made in addition to engineering changes. They believe that "a change in societal norms may be required before meaningful and sustainable improvements in pedestrian safety can occur" (*9*).

Pedestrian Behavior

Some studies have noted pedestrian behavioral changes as a result of crosswalk markings. Knoblauch et al. (2001) considered whether pedestrians acted more aggressively in marked crosswalks, as had been suggested in the 1972 Herms study. They defined aggressive behavior as crossing behavior that forced the motorist to slow or stop to avoid a collision. However, the research team found no statistically significant difference in aggressive pedestrian behavior following the installation of marked crosswalks (*8*). Mitman, Ragland, and Zegeer (2008) found that pedestrians at an unmarked crosswalk were more likely than those at a marked crosswalk to wait for a larger gap in traffic before crossing (*10*). The authors suggest that this caution could be attributed to another finding of the study, which was that motorists were statistically more likely to yield right-of-way to pedestrians in a marked crosswalk than an unmarked crosswalk. The authors suggested that past experience and unfamiliarity with right-of-way laws may lead pedestrians to be wary of vehicles when crossing at unmarked locations (*10*). The increased yielding behavior at marked crosswalks may also help to explain the higher rate of multiple-threat collisions, as these only occur if the first motorist that encounters a pedestrian yields (a key finding of the Zegeer FHWA study) (*6*).

Additionally, a study of a high-visibility zebra crossing in Edinburgh, United Kingdom found that the installation of a high-visibility crosswalk resulted in pedestrians spending significantly less time waiting to cross the road, being less likely to wait in the center median, and walking more slowly across the road (*11*). The slower pace crossing the street would indicate that pedestrians felt more comfortable in the road when a crosswalk indicated the pedestrians' right to be in the roadway. Based on surveys of nearby residents, the researchers found that pedestrians felt much safer crossing the roadway after the markings were installed.

MUTCD Requirements

The 2009 *Manual on Uniform Traffic Control Devices* (MUTCD) states that marked crosswalks "provide guidance for pedestrians who are crossing roadways by defining and delineating paths on approaches to and within signalized intersections, and on approaches to other intersections where traffic stops (*12*)." Like the *Uniform Vehicle Code*, the MUTCD notes that the presence of markings at a non-intersection location legally establishes the crosswalk.

The MUTCD offers the following guidance on how to decide where to mark crosswalks:

> "Crosswalk lines should not be used indiscriminately. An engineering study should be performed before a marked crosswalk is installed at a location away from a traffic control signal or an approach controlled by a STOP or YIELD sign. The engineering study should consider the number of lanes, the presence of a median, the distance from adjacent signalized intersections, the pedestrian volumes and delays, the average daily traffic (ADT), the posted or statutory speed limit or 85th-percentile speed, the geometry of the location, the possible consolidation of multiple crossing points, the availability of street lighting, and other appropriate factors.
>
> New marked crosswalks alone, without other measures designed to reduce traffic speeds, shorten crossing distances, enhance motorist awareness of the crossing, and/or provide active warning of pedestrian presence, should not be installed across uncontrolled roadways where the speed limit exceeds 40 mph and either:
>
> a) The roadway has four or more lanes of travel without a raised median or pedestrian refuge island and an ADT of 12,000 vehicles per day or greater; or
> b) The roadway has four or more lanes of travel with a raised median or pedestrian refuge island and an ADT of 15,000 vehicles per day or greater" (*12*).

It should be noted that to be consistent with the findings of the FHWA crosswalk study (by Zegeer, et. al.),and the Traffic Control Devices Handbook (Chapter 13- Pedestrians), the above wording

would need to be changed slightly; that is, the word AND would need to change to OR in the phrase which indicates "New marked crosswalks alone, without other measures……where the speed limit exceeds 40 mph AND either….". In other words, the wording in the TCD Handbook would recommend not using a marked crosswalk alone where the approach roadway had a speed limit of 40 mph or greater OR where there is a high- volume road (above 12,000 ADT without a raised median, or above 15,000 ADT with a raised median). Recent recommendations by the National Committee on Uniform Traffic Control Devices (NCUTCD) in 2012 has recommended a revision to the 2009 MUTCD wording on this issue to be more consistent with the TCD Handbook and the FHWA crosswalk study. (13)

The MUTCD also provides basic design guidance for crosswalks, stating, "When crosswalk lines are used, they shall consist of solid white lines that mark the crosswalk. They shall not be less than 6 inches or greater than 24 inches in width" (*12*). These guidelines serve as the basis for states' guidelines, but crosswalk design among the states varies, as noted in results from a nationwide survey by the Institute of Transportation Engineers on pavement marking patterns (*13*). Due to the propensity of many agencies to use an engineer's best judgment when deciding how to mark crosswalks, the authors of the ITE report stress that standards should exist to prevent knowledge gaps resulting from staff turnover.

Marking Patterns

Many options emerge once a locality decides to install a marked crosswalk. A variety of pavement markings patterns are used throughout the United States for marked crosswalks. The type of marking chosen is often based on the local transportation engineer's judgment or cost considerations. Typical patterns, as shown in Figure 3, include transverse lines, ladder, continental, and diagonal (zebra) markings. Bar pairs and triple-four markings, shown in Figures 4 and 5, are high-visibility marking patterns that are becoming popular due to their durability.

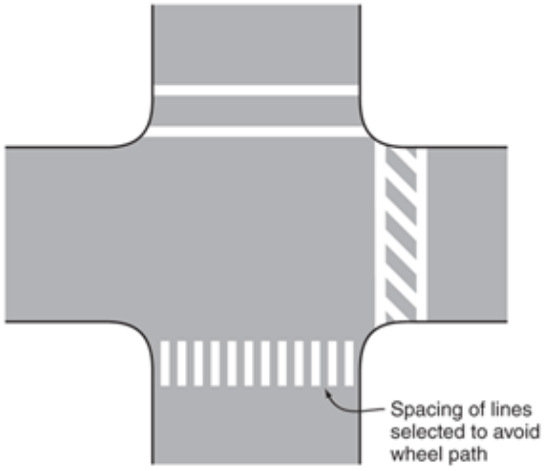


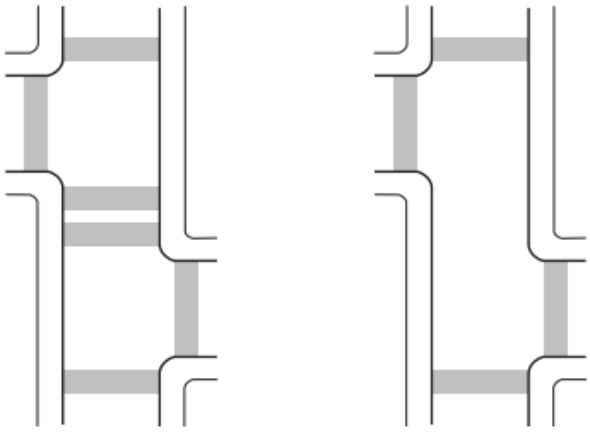
Figure 3 - (clockwise from top) Transverse lines, diagonal (zebra) markings, and continental markings (*12*).

Figure 4 – A bar pair crosswalk that is spaced so as to avoid the wheel path of automobiles. (Source: Dan Burden, 2006. www.pedbikeimages.org)

Transverse lines are sometimes considered the standard crosswalk marking pattern, with ladder and continental markings reserved for uncontrolled intersections or midblock crossings that would benefit from a more high-visibility marking. A key recommendation for ladder, continental, bar pair, and triple-four markings is to space the lines to avoid the wheel path of automobiles, since making this minor adjustment increases the durability of the markings.

Figure 5 – A triple-four crosswalk pattern, which is the standard crosswalk style in Sacramento, CA. This pattern is high-visibility, has a center channel that is less slippery, and has bars spaced so as to reduce maintenance costs. (Source: City of Sacramento, http://www.cityofsacramento.org/transportation/dot_media/engineer_media/traffictriplefourcrosswalk.jpg)

Marked crosswalks also have the potential to provide guidance to pedestrians at skewed or offset intersections, or where heavy pedestrian-motorist conflicts may exist. By marking particular crosswalks, an agency can show recommended pedestrian travel lines (as shown in Figure 6 from the Virginia Department of Transportation).



Typical Offset Intersection Showing All Legal Crosswalks (left) and a More Practical and Effective Crosswalk Application (right).

Figure 6 – Crosswalk application recommendation from the State of Virginia (*15*). http://www.vdot.virginia.gov/vtrc/main/online_reports/pdf/05-r18.pdf

Crosswalk Marking Pattern and Style Research

The MUTCD offers only minimal design guidance for crosswalk marking patterns and does not clarify when specific types of markings should be used. The variety of styles can be confusing to motorists and pedestrians, exacerbating the uncertainty that already exists regarding pedestrian right-of-way in the United States. For these reasons, several recent studies have attempted to provide stakeholders with an answer to the question, "What is the best type of marked crosswalk?"

Collisions

While the marked versus unmarked crosswalk debate has produced the most studies on collisions in crosswalks, other studies have focused on whether high-visibility crosswalks improve pedestrian safety. A study by Feldman, Manzi, and Mitman (2010) analyzed the effect that yellow, high-visibility school crosswalks had on the pedestrian crash rate. In San Francisco, school crosswalks are already painted yellow, so this study focused on the switch from transverse lines to high-visibility (continental) markings. By analyzing 54 treated intersections and 54 control intersections, the researchers found that a statistically significant reduction in collisions occurred at intersections that had high-visibility crosswalks installed (*16*). Feldman estimated a 37% increase in safety at the intersections with high-visibility markings.

A study by Chen et al. (2012) further supported the safety benefits of high-visibility crosswalk markings. The researchers examined the effects of thirteen countermeasures in New York City, one of which was high-visibility crosswalks. Using a two group pretest-posttest design, the researchers studied 72 crosswalk locations as well as reportable crashes in the city from 1989 to 2008. They found that the presence of a high-visibility crosswalk reduced pedestrian-vehicle collisions by a statistically significant 48 percent (*17*).

Visibility

Visibility is another concern in crosswalk design. One limitation of crosswalk markings is they are often much less visible to motorists approaching at a fast speed than to pedestrians about to cross the roadway. Transverse lines are particularly difficult for motorists to see, and for this reason, many agencies are beginning to change crosswalk markings to patterns that provide greater visibility. In 2010, the ITE Traffic Engineering Council Committee analyzed a 1970 study by Bruce Herms that looked at the apparent width of a crosswalk as viewed from an approaching vehicle (*14*). Using current standards for motorist eye height and perception-reaction time, the committee determined

that transverse crosswalks were "essentially not visible" because the apparent width of a 10 foot crosswalk was often below a quarter inch when viewed in the windshield pane (see Figure 7) (*14*).

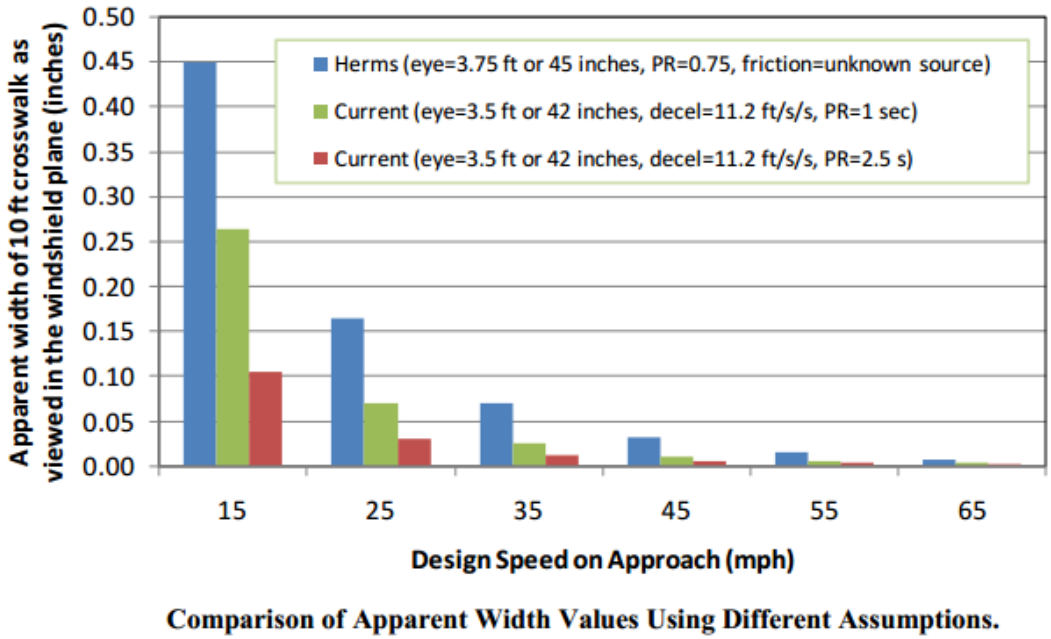


Figure 7 (Source: ITE TENC Technical Committee 109-01. Pavement Marking Patterns Used at Uncontrolled Pedestrian Crossings, Publication No. IR-131. Institute of Traffic Engineers, Washington, DC, 2010)

Due to visibility concerns, many states have guidelines for the minimum width of crosswalks, the width of the specific lines, and the spacing between the lines. For example, in most states the minimum width for a crosswalk is 6 feet. However, agencies in more urban areas tend to establish the minimum width of a crosswalk at around 10 feet due to higher levels of pedestrian traffic (*14*). Most states use continental or ladder crosswalk markings when a high-visibility crosswalk is deemed necessary. A more detailed description of states' guidelines is available in the ITE report (*14*).

In 2001, Nitzburg and Knoblauch completed a study that looked at the effect of a high-visibility crosswalk paired with an illuminated overhead crosswalk sign at unsignalized intersections in Clearwater, Florida. By comparing two high-visibility crosswalk locations with two control sites, Nitzburg and Knoblauch analyzed motorist yielding behavior during the daytime and the nighttime. They found a statistically significant increase in motorists yielding at the locations with high-visibility crosswalks and illuminated overhead crosswalk signs during the daytime (2.8 percent and 20.0 percent yielding at control sites compared to 43.2 percent and 40.3 percent at high-visibility crosswalk sites). The yielding rate at nighttime was not found to be statistically significant. These results implied that high-visibility crosswalks were more visible to motorists and led to an improved

yielding rate. However, separating the impact of the high-visibility crosswalk compared to the illuminated overhead crosswalk sign is not possible (*18*).

Fitzpatrick, et al. (2011) investigated the daytime and nighttime visibility of transverse lines, continental markings, and bar pairs to determine whether one of the three types of markings had better visibility (*19*). Each of the three patterns was installed at a mid-block location, and study participants were asked to drive along a predetermined route and identify when they first saw a crosswalk. The site, vehicle type, and amount of traffic were variables that were considered as possibly affecting detection distance. The study found that the marking type of the crosswalk was statistically significant, with detection distances for bar pairs and continental markings much longer than for transverse lines. As expected, viewing crosswalk markings during the daytime was easier than nighttime. As a result of the findings, Fitzpatrick, et al. recommended adding bar pairs to the MUTCD as a usable crosswalk pattern and using high-visibility markings (bar pairs and continental) for all crosswalks across uncontrolled approaches (*19*).

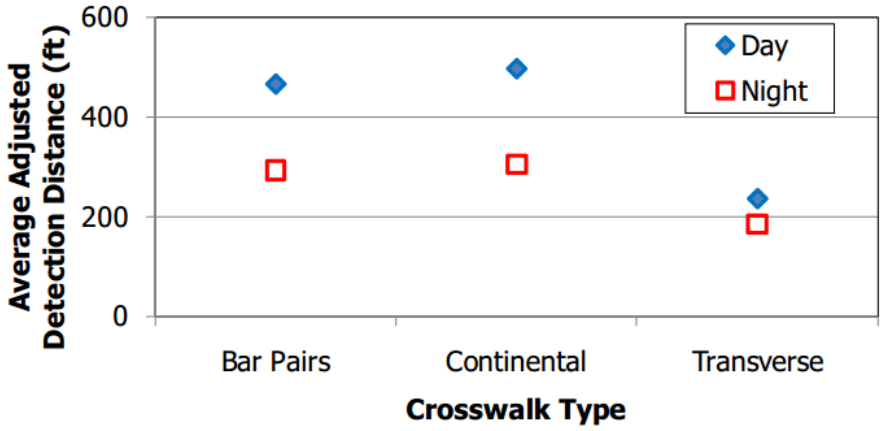


Figure 8 – Average adjusted detection distance results from the Fitzpatrick et al. (2011) study (*19*).

In 2012, Pulugurtha, et al. conducted a study of infrastructure-based countermeasures in Las Vegas, Nevada. The researchers conducted before and after field observations of motorist and pedestrian behavior at eight sites with high-visibility crosswalks installed. The field observations looked at various safety factors, such as whether pedestrians were trapped in the street, whether motorists yielded the right-of-way to pedestrians, and the motorist yielding or stopping distance. The authors found a statistically significant improvement in the percentage of motorists who yielded to

pedestrians in crosswalks with high-visibility striping, as well as an increase in the yielding or stopping distance prior to a high-visibility crosswalk (*20*).

Another key aspect of crosswalk marking design is how the paint performs in low-light conditions. In Arizona and California, state law requires school crosswalks to be painted yellow instead of white (*14*). However, little evidence shows that yellow crosswalks are more visible than the standard white crosswalks. A study of strong yellow/green (SYG) pavement markings around schools in Chicago found that the color produced no noticeable decrease in the 85th percentile speed of motorists traveling along the road. Because of this study, the Federal Highway Administration (FHWA) recommended that SYG crosswalk markings not be applied (*21*).

When decorative pavers are used to create crosswalks, agencies should carefully consider whether the pavers will create a slippery condition for pedestrians. Materials such as brick, granite, and cobblestone become slippery when wet and should be used with caution at pedestrian crossings. Maintenance problems can also be associated with brick, granite, and cobblestone crosswalks. Crossing striping (white or yellow) should always be applied in addition to such decorative treatment, if they are used.

In August 2013, the FHWA issued an "Official Interpretation of Chapter 3G of the *Manual on Uniform Traffic Control Devices for Streets and Highways* (MUTCD)" on the approved uses of colored pavement. The document notes that colored or textured pavement is considered a traffic control device when it attempts to communicate with any roadway user or when it incorporates retroreflective properties. This type of crosswalk treatment is not acceptable as it is considered contrary to the goal of increased safety and the FHWA warns it may lead to a false sense of security. Purely aesthetic colored or textured crosswalks, however, are permissible (defined as subdued-colored, devoid of retroreflective properties, and not diminishing the effectiveness of legally-required transverse white or yellow pavement markings). (*26*)

Crosswalk Enhancements

While high-visibility crosswalk markings can improve the overall visibility of a crosswalk, they are most effective when implemented with a variety of crosswalk enhancements, as discussed in the Zegeer study (*6*). The committee that wrote NCHRP Report 562, *Improving Pedestrian Safety at Unsignalized Crossings*, was tasked with recommending pedestrian safety treatments for high-volume, high-speed roadways at unsignalized intersections (*22*). The authors of the report concluded that a

combination of treatments, including warning beacons or signals, signage and striping, and geometric enhancements, was most effective at improving pedestrian safety because multiple treatments may be necessary to achieve all of the desired characteristics of a pedestrian crossing. These desired goals for pedestrian crossings include good visibility, low vehicle speeds, motorist awareness of crosswalks, and pedestrian compliance with legal crossing locations (*22*).

Discussion

Previous studies have shown that high-visibility markings are more easily detected by motorists (*18*) and lead to a reduction in collisions at intersections (*16*). Based on the aforementioned research, the following considerations are recommended for uncontrolled crosswalks and controlled crosswalks.

Considerations for Uncontrolled Crosswalks

Marked crosswalks at uncontrolled locations (intersections or midblock) may pose greater safety concerns for pedestrians because motorists often do not expect pedestrians to be crossing. As a result, many states require or recommend high-visibility crosswalk markings at all uncontrolled marked crosswalks, especially at midblock locations.

Uncontrolled marked crosswalks on multi-lane roadways require special attention due to the prevalence of multiple-threat crashes. One way to mitigate this issue is to install advance yield markings and pedestrian crossing signs. With advance yield markings, motorists are more likely to yield or stop at a greater distance from the crosswalk, which prevents the vehicle from shielding the view of the pedestrian as he or she crosses the road. Pedestrian crossing signs alert motorists to the possible presence of pedestrians, increasing awareness.

On roadways with higher traffic volumes, speeds, or number of lanes, a combination of signs, markings, and other enhancements may help create an environment in which the pedestrian feels comfortable crossing the road. Small changes such as raised medians, advance yield markings, removal of parking near the crosswalk, and pedestrian crossing signs can dramatically improve the visibility of the pedestrian crossing (*22*). The pedestrian hybrid beacon (HAWK) and rectangular rapid flash beacons (RRFBs) have also been found to help pedestrians safely cross wide, busy roadways. For additional information, refer to *PEDSAFE: Pedestrian Safety Guide and Countermeasure Selection System,* which is a detailed resource on crosswalk enhancements that improve pedestrian safety (*23*).

Considerations for Controlled Crosswalks

At controlled crosswalks, best practice calls for all legs of the intersection to be marked with a crosswalk to reduce pedestrian delay and enhance mobility. Pedestrians are unlikely to travel extra distances to cross a roadway, so leaving one or more legs of an intersection unmarked would only make that crossing choice less visible to motorists. A leg should be left unmarked only when a significant safety reason exists to forbid pedestrians from crossing. However, a much better option

is to make geometric or other physical enhancements to the intersection (e.g., reduce the turning radius for right-turn motorists or provide a crossing island for pedestrians) to improve the safety of the crossing for pedestrians.

Advance stop bars at stop or signal-controlled intersections show the motorist the proper place to stop so that the vehicle does not encroach upon the pedestrian crossing. Pedestrians have a better view of the vehicles in the roadway when vehicles are prevented from stopping too close to the crosswalk. Parking restrictions, also known as daylighting, similarly improve intersection sight lines for pedestrians by ensuring that pedestrians' sight lines are not blocked by large vehicles.

In general, high visibility crosswalk striping should be reserved for uncontrolled locations with higher approach speeds, where the visibility benefits of the striping enhancements is most needed.

Lessons Learned Overseas

European countries are more consistent at marking and enforcing pedestrian crossings. In Germany, controlled crossings with zebra crosswalks are required to have illumination and can only be installed at locations with more than 350 cars per hour and more than 50 pedestrians per hour (*24*). Officials in Sweden strengthened their vehicle code in 2000 by giving pedestrians who were about to enter or who had entered a crosswalk the right-of-way. Before 2000, the motorists had to yield the right-of-way only when they could reasonably do so (*25*). In the Netherlands, motorists are supposed to stop and yield to pedestrians crossing the road when a zebra crossing is present. If a zebra crossing is not present, vehicles do not have to yield the right-of-way (*24*). The different marking styles are intended to clearly communicate to motorists to yield to pedestrians when safe. The type of marking lets motorists know the location of pedestrian crossing zones, but it also specifies whether motorists are legally obligated to stop. The consistency of the markings within different European countries, such as Sweden or the Netherlands, allows motorists and pedestrians in each country to confidently know the right-of-way laws.

Conclusion

High-visibility crosswalks are recommended in place of transverse lines at uncontrolled crossings because they are more visible to approaching motorists and better emphasize pedestrian crossing areas. Based on Fitzpatrick's conclusions, either bar pairs or continental markings would be appropriate high-visibility markings (*19*). Research regarding whether consistency in crosswalk markings has an effect on motorist yielding and pedestrian safety would also help to provide increased understanding of how crosswalk marking patterns affect motorist and pedestrian behavior.

Works Cited

1) Healthy People 2020. *Physical Activity*. U.S. Department of Health and Human Services. http://www.healthypeople.gov/2020/topicsobjectives2020/overview.aspx?topicid=33. Accessed Feb. 1, 2013.

2) *Uniform Vehicle Code 2000*. National Committee on Uniform Traffic Laws and Ordinances, Alexandria, VA, 2000.

3) *General Laws: Public Ways and Works*. Commonwealth of Massachusetts, Boston, MA. http://www.malegislature.gov/Laws/GeneralLaws/PartI/TitleXIV/Chapter89/Section11. Accessed Dec. 2012.

4) Herms, B. Pedestrian Crosswalk Study: Crashes in Painted and Unpainted Crosswalks. *Record No. 406*, Transportation Research Board, Washington, DC, 1972.

5) Jones, T.L. and P. Tomcheck. Pedestrian Accidents in Marked and Unmarked Crosswalks: A Quantitative Study. *ITE Journal*, 2000, pp. 42-46.

6) Zeeger, C., J. Stewart, and H. Huang. *Safety Effects of Marked Versus Unmarked Crosswalks at Uncontrolled Locations*. Publication FHWA-RD-01-142, FHWA, U.S. Department of Transportation, 2001.

7) Knoblauch, R., and P. Raymond. *The Effect of Crosswalk Markings on Vehicle Speeds in Maryland, Virginia, and Arizona.* Publication FHWA-RD-00-101. Federal Highway Administration, McLean, VA, 2000.

8) Knoblauch, R., M. Nitzburg, and R. Seifert. *Pedestrian Crosswalk Case Studies: Sacramento, CA; Richmond, VA; Buffalo, NY; Stillwater, MN*. Publication FHWA-RD-00-103. Federal Highway Administration, McLean, VA, 2001.

9) Mitman, M.F. and D.R. Ragland. More Evidence Why Pedestrian and Driver Knowledge of the Vehicle Code Should Not Be Assumed. *Transportation Research Record: Journal of the Transportation Research Board, No. 2002*. Transportation Research Board of the National Academies, Washington, DC, 2007, pp. 55-63.

10) Mitman, M.F., Ragland, D.R., and C.V. Zegeer. The Marked Crosswalk Dilemma: Uncovering Some Missing Links in a 35-Year Debate. Presented at the 87th Annual Meeting of the Transportation Research Board, Washington, D.C., 2008.

11) Havard, C. and A. Willis. Effects of Installing a Marked Crosswalk on Road Crossing Behaviour and Perceptions of the Environment. *Transportation Research Part F*, Vol. 15, No. 3, 2012, pp. 249-260.

12) 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

13) Institute of Transportation Engineers, Traffic Control Devices Handbook, Chapter 13- Pedestrians, Final Draft, December, 2011.

14) ITE TENC Technical Committee 109-01. *Pavement Marking Patterns Used at Uncontrolled Pedestrian Crossings*. Publication No. IR-131. Institute of Traffic Engineers, Washington, DC, 2010.

15) Dougald, L.E. *Development of Guidelines for the Installation of Marked Crosswalks*. Report VTRC 05-R18. Virginia Transportation Research Council, Charlottesville, VA, 2004.

16) Feldman, M., Manzi, J.G., and M.F. Mitman. Empirical Bayesian Evaluation of Safety Effects of High-Visibility School (Yellow) Crosswalks in San Francisco, California. *Transportation Research Record: Journal of the Transportation Research Board, No. 2198.* Transportation Research Board of the National Academies, Washington, DC, 2010.

17) 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

18) 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

19) Fitzpatrick, K., S. Chrysler, V. Iragavarapu, and E.S. Park. Detection Distances to Crosswalk Markings: Transverse Lines, Continental Markings, and Bar Pairs. *Transportation Research Record: Journal of the Transportation Research Board, No. 2250*. Transportation Research Board of the National Academies, Washington, DC, 2011.

20) 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.

21) Chicago Department of Transportation. Evaluation of School Traffic Safety Program Traffic Control Measure Effectiveness. Chicago, Il., 2005. http://mutcd.fhwa.dot.gov/resources/policy/ygcrosswalkmarking/chicagostudy/index.htm

22) Fitzpatrick, K., N. Lalani, and D. Lord. *Improving Pedestrian Safety at Unsignalized Crossings*, TCRP Report 112/NCHRP Report 562. Transportation Research Board, Washington, DC, 2006.

23) Harkey, D.L. and C.V. Zegeer. *PEDSAFE: Pedestrian Safety Guide and Countermeasure Selection System*. Publication FHWA-SA-04-033, FHWA, U.S. Department of Transportation, 2004. http://www.walkinginfo.org/pedsafe/

24) Zegeer, C.V., M. Cynecki, J. Fegan, B. Gilleran, P. Lagerwey, C. Tan, and B. Works, *FHWA Study Tour for Pedestrian and Bicyclist Safety in England, Germany, and The Netherlands,* Publication No. FHWA–PL–95–006, FHWA, October 1994, available online at http://ntl.bts.gov/DOCS/bikeped.html.

25) Johansson, C., P. Garder, and L. Leden. Toward Vision Zero at Zebra Crossings: Case Study of Traffic Safety and Mobility for Children and the Elderly, Malmo, Sweden. *Transportation Research Record: Journal of the Transportation Research Board, No. 1828*. Transportation Research Board of the National Academies, Washington, DC, 2003, pp. 67-74.

26) Federal Highway Administration (FHWA). *Memorandum: Interpretation Letter 3(09)-24(I) – Application of Colored Pavement*. US Department of Transportation, Washington, DC, 2013. Available online at http://mutcd.fhwa.dot.gov/resources/interpretations/3_09_24.htm.

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