Crosswalk Marking Selection Guide

Photos: Kittelson

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References to the *Manual on Uniform Traffic Control Devices* (MUTCD) are based on the 2009 (10^{th}) edition. At the time of writing, rulemaking was in process for the 11^{th} edition. Readers should verify MUTCD-related information with the contents of the 11^{th} edition once it becomes effective.

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Section 1. Executive Summary

This guide is a decision support tool for transportation professionals and agencies selecting crosswalk marking designs. It provides information about selecting crosswalk marking designs based on overall effectiveness and considerations of materials, maintenance, and cost. This guide presents information related to crosswalk markings—explaining their purpose and documented effects—and provides factors to consider when selecting marking designs. This guide recommends high visibility crosswalks (HVCs) at all uncontrolled crosswalk locations.

Sections 3 and 4 of this guide explain the purpose of marked crosswalks and the types of markings available to practitioners. In most states, crosswalks exist and provide the right of way to pedestrians at intersections even in the absence of markings. Crosswalk markings are traffic control devices and serve several core functions:

- Alert drivers to pedestrians' potential presence and right of way.
- Establish pedestrian right of way at midblock locations.
- In States that follow the UVC definition of an unmarked crosswalk, establish pedestrian right of way at crossings lacking sidewalk connections on both sides.
- Provide wayfinding cues to pedestrians with low vision.

For crosswalk marking designs, lines striped parallel to the direction of pedestrian travel are referred to as transverse lines and those striped in the direction of vehicle travel are referred to as longitudinal lines. This guide refers to the two transverse lines alone as a "basic crossing" and any design that incorporates longitudinal or diagonal lines as an HVC.

Section 5 provides existing and original research findings on the safety effects of crosswalk markings. Existing research offers mixed results on the safety effects of marking crosswalks and using an HVC design but indicates the importance of roadway context. Crash risk appears to improve (i.e., lower) with application of markings on narrower and lower-speed roads but not along wider or higher-speed roads. HVCs have been shown to be more visible from twice the distance of basic markings. Again, site context matters greatly: yielding rates are inversely correlated with speed and are influenced by several factors including roadway characteristics, local driving culture, and roadway and site context. A growing amount of research also shows disparities in yield rates based on perceived race, gender, age, and socioeconomic status of both the driver and the pedestrian that can impact the effectiveness of crosswalk markings. Drivers have been shown to be less likely to yield for pedestrians who are Black (versus white), men (versus women), or different from the driver in age or perceived gender.

Original research conducted for this guide tested yielding rates at uncontrolled intersection crossings. It tested basic versus HVC markings at low volume, low speed, two-lane roads. The results offer strong findings relating driver yielding to site context and treatments:

- HVCs are associated with greater increased driver yielding compared to basic markings.
- Yielding rates showed a robust negative relationship with driver speeds. HVC effectiveness is strongest with lower driver speeds (sites with 85th percentile speeds ≤ 30 mph).
- HVCs show a positive yielding effect with and without supplemental warning signs present. HVC effectiveness is stronger in the absence of warning signs.

Section 6 provides recommendations for where to use HVCs. Based on the existing and original research, this guide recommends using HVCs for all uncontrolled marked crosswalks as well as midblock crossings. However, crosswalk markings are not the only treatments available to engineers attempting to make a pedestrian crossing location safer. Existing research and guidance clearly indicate that supplemental treatments are appropriate in many cases. A combination of treatments improves pedestrian safety, especially at uncontrolled crossings on multilane, higher-speed roads (85th percentile speeds > 30 mph).

Section 7 provides a scan of practice and recommendations regarding materials used for crosswalk markings. A variety of marking materials and application methods are available for marking crosswalks. Many agencies' marking material decisions depend on a combination several factors, including but not limited to traffic volumes, snowplowing activity, lighting conditions, climate, and resurfacing schedule. Most agencies determine marking material based on these factors and do not vary this based on a location's marking type (basic or HVC).

Section 8 provides a scan of practice and recommendation regarding maintenance. Regularly scheduling inspections or using an asset management system are two good options for maintaining crosswalk visibility. Additionally, staff observations and public input are supplemental means of identifying crosswalk markings that require maintenance sooner than expected. However, relying solely on public input or requests can lead to an inequitable distribution of maintenance work. Replacing markings can be as cost effective as refreshing them. HVCs may be designed to place the markings outside typical vehicle paths and therefore improve longevity.

Section 9 describes cost tradeoffs relevant to crosswalk marking types. Agencies are often constrained in their application of traffic control devices—

financially or in available labor. These constraints hinder the ability to mark or re-mark crosswalks as frequently as desired. Incorporating the longevity benefits of HVCs However, HVCs may still be more cost effective on a life cycle basis.

Section 2. Introduction

This guide is a decision support tool for transportation professionals and agencies selecting crosswalk marking designs. It provides information about selecting crosswalk marking designs based on overall effectiveness and considerations of materials, maintenance, and cost. In this report, marking design refers to the pattern, color, width, and arrangement of the marking.

An effective roadway treatment accomplishes its core functions efficiently and cost effectively. Several factors influence a crosswalk marking's effectiveness including safety, visibility, and compliance by drivers and pedestrians. This guide builds on existing research and guidance on these factors, highlights gaps in knowledge, and documents original research conducted in guide development to inform these gaps and aid in marking selection. This guide provides recommendations for agencies on selecting crosswalk marking designs as part of a project or on a systematic basis.

2.1 GUIDE ORGANIZATION

This guide presents information related to crosswalk markings—explaining their purpose and documented benefits—and provides factors to consider when selecting marking designs. The question of *whether* to mark a crosswalk is well studied and is not the intent of this guide. However, the topic is presented as it is relevant to the question of how to mark.

The guide is organized in the form of a series of questions agencies may find relevant when making decisions regarding crosswalk installation, placement, and design:

- Section 3: Why do we have crosswalks?
- Section 4: What are the types of crosswalk markings?
- Section 5: What are the safety effects of crosswalk markings?
- Section 6: When should HVCs be used?
- Section 7: What materials are used for crosswalk markings?
- Section 7: What maintenance considerations apply to crosswalk markings?
- Section 9: What are the cost tradeoffs?

Sections 3 and 4 provide background information on crosswalk markings, including considerations for the marking and placement of crosswalks and definitions of key terms. These sections refer to published guidance for practitioners to select locations for crosswalk markings.

Section 5 presents what is known about the safety effects of crosswalk markings. This section includes a synthesis of background research on the known benefits of crosswalk marking types along with findings from original research comparing driver yielding rates at different crosswalk marking types.

Section 5 provides recommendations for agencies and practitioners selecting crosswalk markings on a project or policy basis. The section refers to the research presented in Section 4 and to existing crosswalk marking guidance as the basis for recommendations. This section provides recommendations for applying crosswalk marking designs on both a location-specific and a systemwide basis and emphasizes that crosswalk markings are one part of a set of crossing treatments.

Section 6 through Section 8 present other factors related to effectiveness that may influence agency decisions: materials, maintenance, and cost. However, the relationship between these factors and marking effectiveness is less studied. These sections discuss existing research, supplement the discussion with findings from original research conducted for the development of this guide, and provide suggestions for further research.

Section 3. Why do we have crosswalks?

3.1 WHAT IS A CROSSWALK?

Crosswalks designate the locations where other road users are required to yield the right of way to pedestrians crossing the street. Traffic laws in most States are based—at least in part—on the *Uniform Vehicle Code* (UVC) (1), which recommends text for traffic laws. While implementation of the UVC varies from State to State and sometimes within jurisdictions in the same State, it still provides a good baseline definition and explanation of crosswalks.

The UVC defines crosswalks as follows (see also Figure 1):

> "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." (§1-118(a)); and,
> "Any portion of a roadway at an intersection or elsewhere distinctly indicated for pedestrian crossing by lines or other markings on the surface." (§1-118(b))

The first case, where a crosswalk exists without the presence of pavement markings, is known as an **unmarked crosswalk.** The second case, where pavement markings are used to highlight or establish the pedestrian crossing location, is known as a **marked crosswalk.** At unsignalized intersections in the United States, pedestrians have the right of way while in the crosswalk, whether or not the crosswalk is marked. The markings simply reinforce and convey the location to drivers. At signalized intersections, pedestrians are generally allowed to cross on all approaches while following the indications of the signal traffic control device, even without any markings present—unless a crossing is explicitly prohibited or closed as indicated by signage and/or physically obstructed barriers.

Markings may also provide a wider area for a pedestrian crossing at an intersection than would otherwise exist based on the definition of an unmarked crosswalk—for example, Washington State defines an unmarked crosswalk as the portion of the roadway between the intersection area and a line 10 feet distant from the intersection (RCW §46.04.160). Markings can denote a wider or differently located crossing area.

By contrast, marked crosswalks at non intersection locations *establish* the right of way for pedestrians and delineate the crossing location. Figure 1 shows these types of crossing configurations and draws the distinction among intersection unmarked crosswalks, intersection marked crosswalks, and midblock crosswalks.

Figure 1: Marked and Unmarked crosswalks at intersections.
Image Source: Google

The six intersections above include legal crossings and curb ramps leading to the crossings. Intersections A and B include marked crosswalks (different patterns, which are explained in Section 3). Intersections C through F are not marked but provide legal unmarked crosswalks where pedestrians have the right of way. Between these intersections, markings would be required to establish crossing locations.

Marked crosswalks can include **transverse** markings, **longitudinal** markings, or both. Transverse markings are striped in the direction of pedestrian travel. **Longitudinal** markings are marked in the direction of vehicle travel. Crosswalk marking types are defined in Section 3.

3.2 IMPLICATIONS FOR ROAD USERS

Motor vehicle operators, bicyclists, and other road users must yield the right of way (or come to a full stop in some States) to pedestrians in crosswalks. For crosswalks without signal control, the UVC clearly describes a driver's duty to yield the right of way but also stipulates that pedestrians should not dash into the roadway when a vehicle "is so close as to constitute an immediate hazard"*(*§11-502, *1).*

At signal-controlled intersections, a pedestrian within a crosswalk likewise is granted the right of way over turning drivers, provided that the pedestrian is "facing any green signal, except when the sole green signal is a turn arrow" or "unless otherwise directed by a pedestrian-control signal"(*(*§11-502(a)(1), *1)*).

Other sections of the UVC define pedestrian responsibilities when crossing at locations other than crosswalks, granting the right of way to motor vehicles outside of marked or unmarked crosswalks and prohibiting pedestrians from crossing between adjacent intersections with traffic signals at any location other than in a marked crosswalk (§11-502(b) and (§11-502(c), *1*).

3.3 DIFFERENCES IN VEHICLE CODE IMPLEMENTATION

The implementation of the UVC varies from State to State as well as by jurisdiction in some States. Each State's vehicle code defines drivers' legal requirements and obligations concerning pedestrians at crosswalks. These requirements can vary considerably, including, for example, whether "yielding the right of way" entails slowing ("yielding") or stopping for pedestrians and whether drivers must yield the right of way when a pedestrian is in the same half of the roadway as the driver or anywhere in the crosswalk (2).

State and local vehicle codes also define pedestrian obligations when crossing the road. These codes typically prohibit pedestrians from stepping into the roadway when an oncoming driver would not have time to stop. These codes occasionally prohibit pedestrians from crossing the street when a traffic signal or marked crosswalk is located within a specified distance. These latter provisions can mean, for example, that a marked crosswalk across one leg of an unsignalized intersection would nullify the existence of an unmarked crosswalk across the opposite leg, as pedestrians would be required to use the adjacent marked crosswalk.

A crosswalk defines the legal crossing area for pedestrians. Turning drivers are typically required to yield to pedestrians, though local definitions vary regarding whether pedestrians may be at the curb or in the road to command the right of way.

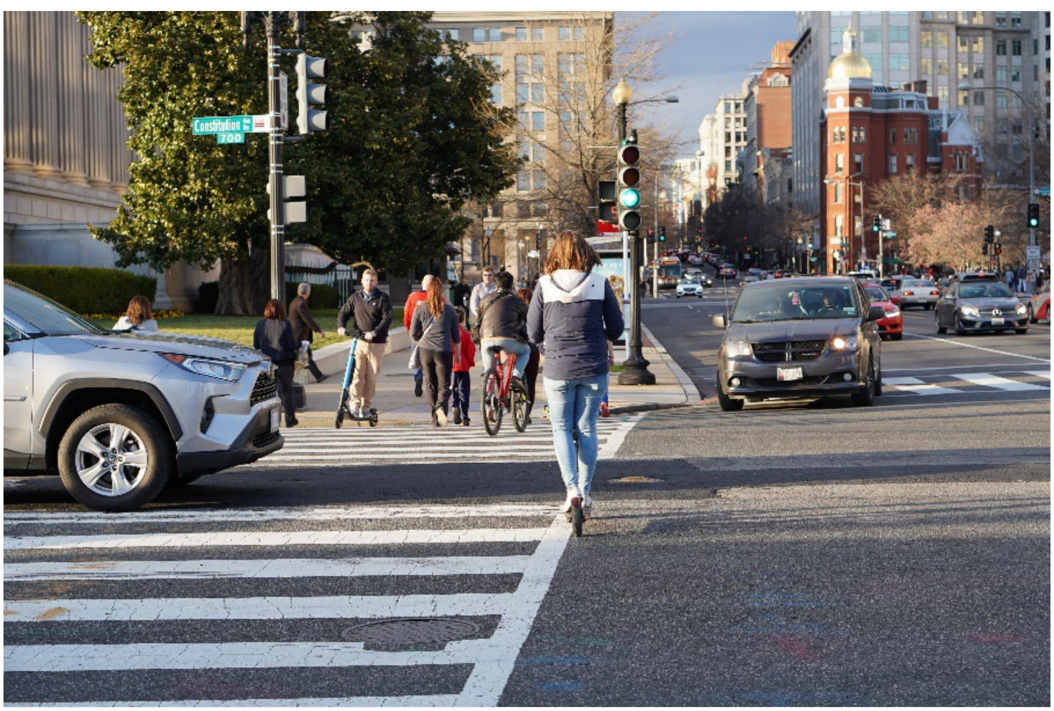


Figure 2: Pedestrians in a crosswalk at a signalized intersection.
Source: Kittelson, 2021.

Based on the UVC definition, an unmarked crosswalk does not exist at an intersection unless a sidewalk continues in the same direction on at least one side of the crossing. In States that follow the UVC definition, an unmarked crossing therefore does not exist at an intersection when neither side of the crossing has a connecting sidewalk. Pedestrians would not have the right of way when crossing at those locations. This stipulation can result in unintuitive circumstances, like the intersection depicted in Figure 3. A street connecting a school and a residential subdivision does not include a sidewalk on one side of the street; therefore, it does not legally include unmarked crossings at the depicted intersections.

A street provides access to a school(bottom) and a residential subdivision (top). Depending on the jurisdiction's laws, the absence of a marked crossing at the tee intersection in the middle of the image and the absence of a sidewalk (in favor of a park path) may result in a crossing location where pedestrians must give right of way to drivers.

Figure 3: Stop-Controlled intersection with no sidewalks.
Image Source: Google

Although the land use patterns (neighborhood with adjacent school/park) are complementary, the infrastructure only provides legal access for motor vehicles, preventing pedestrians from legally accessing the facility. In this example, drivers would not be expected to yield to crossing pedestrians, and a pedestrian may be more likely to be found at fault by a reporting officer in the event of a crash. This is a clear social equity injustice given that the distribution of infrastructure in the United States is uneven across many lines: urban/suburban areas versus rural areas, and higher- versus lower-income communities (including corresponding and race and ethnicity differences) (3). The result is inequitable access and mobility for people walking, with intrinsically discriminatory effects on people and communities less likely to drive (underserved communities, such as low-income, people of color, people with disabilities, and non-car households).[1]

Other States establish unmarked crossings (and requirements for drivers to yield or stop) across all legs of all intersections unless a sign specifically prohibits crossing. In these States, drivers must yield to pedestrians crossing at intersections regardless of the presence or absence of sidewalks. Given these jurisdictional differences in assigning pedestrian right of way and defining unmarked crosswalk locations, this guide recommends that practitioners and agencies weigh the implications of State and local laws when considering marking application and type.

3.4 WHY DO WE MARK CROSSWALKS?

Crosswalk markings are traffic control devices, so the question of whether to mark a crossing location is informed by an understanding of what the marking intends to accomplish. Marked crosswalks serve several core functions:

- Alert drivers to pedestrians' potential presence and right of way.
- Establish pedestrian right of way at midblock locations.
- In States that follow the UVC definition of an unmarked crosswalk, establish pedestrian right of way at crossings lacking sidewalk connections on both sides.
- Provide wayfinding cues to pedestrians with low vision.

This discussion about unmarked versus marked crosswalks highlights that marking a legal crossing area can reduce ambiguity and clearly indicate where crossing pedestrians can be expected to have the right of way, irrespective of State and local laws regarding unmarked crossings.

[1] "Underserved" as defined in E.O. 13985 includes individuals who belong to communities that have been denied such treatment, such as Black, Latino, and Indigenous and Native American persons, Asian Americans and Pacific Islanders and other persons of color; members of religious minorities; lesbian, gay, bisexual, transgender, and queer (LGBTQ+) persons; persons with disabilities; persons who live in rural areas; and persons otherwise adversely affected by persistent poverty or inequality.

A core function of marked crosswalks is to highlight crossing locations for pedestrians and drivers. At this signalized intersection, a wider marked crossing area indicates more designated crossing space than would be assumed if this location were unmarked.

Figure 4: Wide crosswalk at signalized intersection.
Source: pedbikeimages.org / Toole Design Group

3.5 MANUAL ON UNIFORM TRAFFIC CONTROL DEVICES

The *Manual on Uniform Traffic Control Devices* (2009 MUTCD, with 2012 revisions) guides and supports the installation and design of crosswalk markings, including location characteristics suitable for installation. According to the MUTCD, the decision to mark a crosswalk, as with the decision to install any other traffic control device, is made after considering the basic requirements of an effective traffic control device: fulfilling a need; commanding attention; conveying a clear, simple meaning; commanding respect from road users, and giving adequate time for proper response (4).

3.5.1 Controlled Crossing Locations

The 2009 MUTCD indicates that crosswalks at controlled locations should direct pedestrians to appropriate crossing locations:

> "…at locations controlled by traffic control signals or on approaches controlled by STOP or YIELD signs, crosswalk lines should be installed where engineering judgment indicates they are needed to direct pedestrians to the proper crossing path(s)" (Section 3B.18(07), *4*)

3.5.2 Uncontrolled Locations

At uncontrolled locations, the 2009 MUTCD emphasizes the need for an engineering study:

> "[Marked crosswalks] 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" (Section 3B.18(08), *4*)

The 2009 MUTCD lists factors for the study to consider, which include but are not limited to:

- Number of lanes.
- Presence of a median.
- Distance from adjacent signalized intersections.
- Pedestrian volumes and delays.
- Average daily traffic or 85th percentile speed.
- Geometry of the location.
- Possible consolidation of multiple crossing points.
- Availability of street lighting.

Because a marked crosswalk either establishes or reinforces crossing locations for driver and pedestrian benefit, some locations to consider marking include:

- Locations where added visibility of the crosswalk is desired.
- Places where a driver might not expect to see people crossing.

The original research results discussed in Section 5 of this guide indicate how to evaluate what these locations are and help answer the question: where *would* added visibility be desired, if not everywhere? Where may a driver not expect to see people crossing?

The 2009 MUTCD indicates that crosswalk markings alone are not presumed to be sufficient at all locations. Many characteristics that merit marking the crosswalk to reinforce its location (e.g., higher 85th percentile speeds) also make supplemental treatments desirable to enhance its safety. This is a key point that Section 6 discusses further. Many agencies have developed local guidelines for where to mark crosswalks along with providing supplemental treatments. Supplemental treatments could include additional signage, flashing beacons, or geometric modifications to the roadway as discussed later. Once an agency determines where markings are appropriate, some key questions that remain include:

- What marking design should be selected? (Addressed in Section 6.1)
- Does that decision change in the presence of supplemental treatments? (Addressed in Section 6.2.3)
- When is marking not enough on its own? (Addressed in Section 6.2)

3.6 HOW DO MARKED CROSSWALKS HELP PEDESTRIANS WITH LOW VISION?

According to the 2018 National Health Survey, an estimated 32.2 million American adults 18 and older reported experiencing some form of vision loss (5).

No published research compares the effects of different marking designs on street crossing by pedestrians with low vision. However, orientation and mobility experts interviewed during the development of this guide pointed to the benefits of transverse lines as a visual distinction from the pavement (6). The contrast between markings and pavement can assist pedestrians who have low vision with the critical wayfinding tasks of finding the crosswalk, aligning to cross, and maintaining proper alignment during crossing. Of course, the marking must be adequately maintained to assist people with low vision in establishing and maintaining heading during crossing.

In the United States, access to public facilities is a civil right under the Americans with Disabilities Act (ADA) legislation. The implementing regulations for Title II of the ADA specify that any newly constructed or altered public facility shall be "readily accessible to and usable by individuals with disabilities," including those with vision loss, mobility impairments, or other disabilities (7). However, no technical specifications for accessible crosswalk markings have been developed by the U.S. Access Board, the agency responsible for developing accessibility guidelines under the ADA.

In addition to helping position pedestrians within the crosswalk, the 2009 MUTCD states that "crosswalk markings should be located so that the curb ramps are within the extension of the crosswalk markings" *(*Section 3B.18(17), *4).*

Only a few States provide specific guidance on crosswalk markings for pedestrians with disabilities. For example, although the 2009 MUTCD allows the option to omit transverse crosswalk lines when diagonal or longitudinal lines are used to mark a crosswalk, California's supplement to the MUTCD states that "when the factor that determined the need to mark a crosswalk is the clarification of pedestrian routes for sight-impaired pedestrians, the transverse crosswalk lines shall be marked" (8).

A core function of marked crosswalks is to assist in wayfinding, especially for pedestrians with low vision.

Figure 5: Marked crosswalk with lateral and transverse markings.
Source: Kittelson, 2021.

Crosswalk markings do not provide a wayfinding benefit to pedestrians who are blind. Independent of the marking pattern, the material used for marking crosswalks (whether it is paint or thermoplastic material; see Section 7 for more details on materials) is generally *not* reliably detectable underfoot or by use of a long white cane.

3.7 SUMMARY

- Crosswalks are areas where pedestrians are granted the right of way when crossing a roadway.
- Crosswalks may be marked or unmarked, both of which typically have the same legal status. In most cases, crosswalks—marked or unmarked—exist as extensions of the sidewalk network at intersections and grant the right of way to pedestrians crossing the street. Between intersections and—in States following the UVC—at intersection crossings without at least one connecting sidewalk, marked crosswalks establish crossing locations where drivers must yield the right of way to pedestrians.
- Marked crosswalks serve a few core functions:
    - Alert drivers to pedestrians' potential presence and right of way.
    - Establish pedestrian right of way at midblock locations.
    - In some States, establish pedestrian right of way at crossings lacking sidewalk connections on at least one side.
    - Provide wayfinding cues to pedestrians with low vision.
- The 2009 MUTCD recommends an engineering study at uncontrolled locations to determine whether marking a crosswalk is appropriate.
- Crosswalk markings and supplemental treatments are particularly useful at uncontrolled crossings, nonintersection locations, locations where added visibility of the crosswalk is desired, and places where a pedestrian crossing might not be expected.
- Anecdotal evidence from orientation and mobility professionals interviewed during the development of this guide indicates that transverse lines by themselves or as part of a perpendicular crosswalk design may help pedestrians with low vision establish and maintain their heading while crossing.

Section 4. What are the types of crosswalk markings?

4.1 CROSSWALK MARKING DESIGNS

Common crosswalk marking designs include the following, illustrated in Figure 6:

- **Basic:** Two solid transverse lines parallel to the direction of pedestrian travel.
- **Longitudinal Bar:** Wide, evenly-spaced lines parallel to the direction of vehicle travel (also known as a "continental" or "zebra" design).
- **Perpendicular:** A combination of transverse and longitudinal markings (also known as a "ladder" design).
- **Double-Paired:** Closely-spaced pairs of lines parallel to the direction of vehicle travel (also known as a "bar pair" or "piano" design).

The 2009 MUTCD also shows a variation of the perpendicular design that combines transverse and wide diagonal lines; however, at the time of writing, FHWA was proposing to remove this "diagonal" design from the next edition of the MUTCD (10).

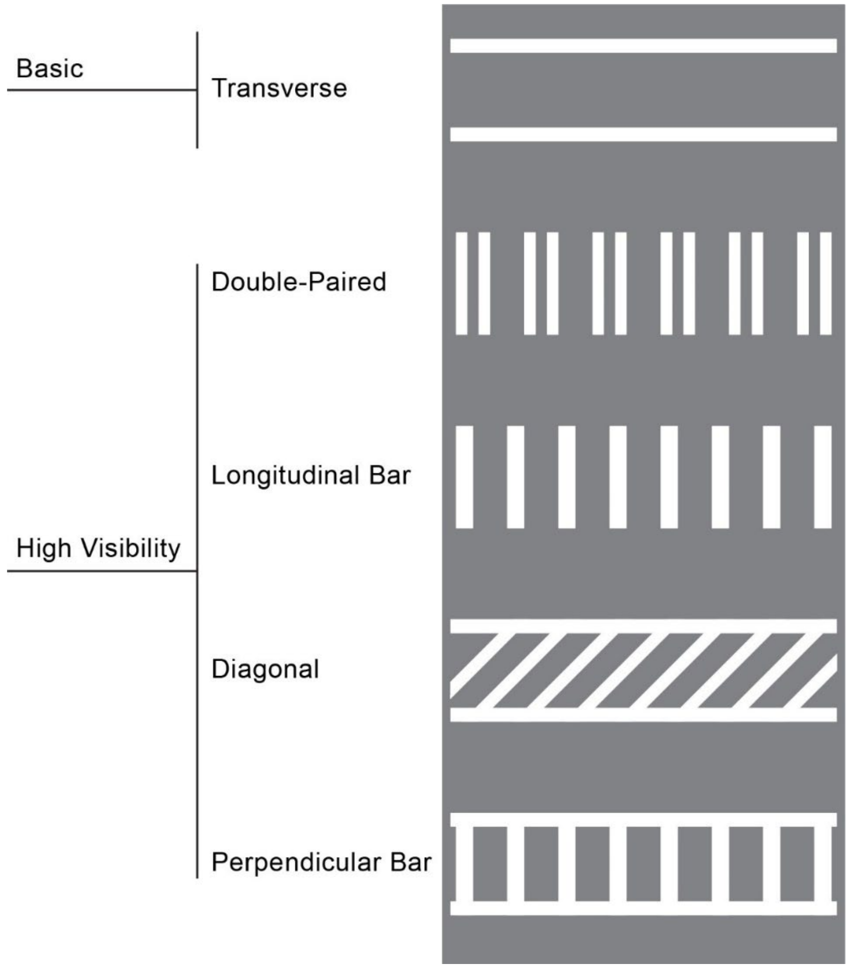


Figure 6. Graphic. Examples of crosswalk markings.
Source: Adapted from Federal Highway Administration. Manual on Uniform Traffic Control Devices for Streets and Highways. Section 3B.18(04). Washington, D.C., 2009.

Lines striped parallel to the direction of vehicle travel are referred to as longitudinal lines, and those parallel to the direction of pedestrian travel are referred to as transverse lines. This guide refers to the two transverse lines alone as a **basic crossing** and any design that incorporates longitudinal or diagonal lines as a **high-visibility crossing** (HVC) (9).

The 2009 MUTCD provides guidance for striping dimensions and parameters (4). At the time of writing, the Notice for Proposed Amendments (NPA) for the 11th edition of the MUTCD has been released. The NPA proposed the following notable crosswalk-related changes to the 2009 MUTCD (9). Practitioners should refer to the current version of the MUTCD for the latest standards and guidance for crosswalk marking designs.

In the absence of Federal requirements on the use of crosswalk marking designs in the 2009 MUTCD, it is left to individual jurisdictions to determine which design(s) to use in which situations. Some jurisdictions use a single design for all marked crosswalks; others use basic crossings in some situations and HVCs in other situations. Further, others leave the decision to engineering judgment related to the specific location. Regardless of the selected design, it is critical that curb ramps providing access to the sidewalk at each end of the crosswalk fall within the crosswalk markings.

4.2 DECORATIVE CROSSWALK MARKINGS

Decorative crosswalk markings are popular in large and small communities across the country, but there does not appear to be any documented before/after, case-controlled, or other published studies evaluating their traffic safety effectiveness or their effect on pedestrians with low vision. At the time of this guide's development, FHWA-sponsored research was investigating decorative crosswalk effects.

Guidance from FHWA maintains that "subdued-colored aesthetic treatments between the legally marked transverse crosswalk lines" (e.g., brick pavers) are permissible but that freeform design within the crosswalk would "degrade the contrast of the white transverse lines against the composition of the pavement beneath it" (11). Generally, two types of decorative crosswalks have been used: those that confine colorful or artistic elements within MUTCD designs (e.g., transverse lines) and those that do not.

FHWA issued an official interpretation further clarifying its position concerning "crosswalk art," stating that:

> "Subdued-colored aesthetic treatments between the legally marked transverse crosswalk lines are permissible provided that they are devoid of retroreflective properties and that they do not diminish the effectiveness of the legally required white transverse pavement markings used to establish the crosswalk.… All elements of pattern and color for these treatments are to be uniform, consistent, repetitive, and expected so as not to be a source of distraction. No element of the aesthetic interior treatment is to be random or unsystematic. No element of the aesthetic interior treatment can implement pictographs, symbols, multiple color arrangements, etc., or can otherwise attempt to communicate with any roadway user." (11)

FHWA has determined that a design giving the illusion of being three-dimensional (3-D) does not comply with the MUTCD (12).

4.3 SUMMARY

- Crosswalk designs include basic (two transverse lines) and high-visibility designs that incorporate longitudinal or diagonal marking elements.
- In the absence of Federal requirements on the use of crosswalk marking designs in the 2009 MUTCD, it is left to individual jurisdictions to determine which design(s) to use in which situations.

- The 2009 MUTCD provides guidance on dimensions and design specifications for each type of crosswalk marking.
- FHWA has defined parameters for appropriate "artistic" crosswalk applications and is sponsoring research investigating decorative crosswalk effects.

Section 5. What are the safety effects of crosswalk markings?

5.1 CROSSWALK MARKING RESEARCH

The two most common outcomes that measure the effect of crosswalk markings are pedestrian–vehicle crashes (a direct measure of safety) and driver yielding or stopping (an indirect measure of safety that also affects perceived safety). It can be difficult to isolate the effect of crosswalk markings from other safety treatments in study design because markings are often installed along with other, supplemental treatments, such as warning signage, beacons, curb extensions, refuge islands, traffic control, or a combination of these. Research explored in this section has given some indication of crosswalk marking safety effects and the effects of HVC markings versus basic markings.

5.1.1 Pedestrian–Vehicle Crashes

The U.S. research on crash effects of marked crosswalks has shown that context matters. Marked crosswalks alone—without other safety countermeasures—were associated with a higher pedestrian crash rate compared to unmarked locations in a few contexts: when installed on multilane roads (1) without raised medians and with annual average daily traffic (AADT) greater than 12,000, and (2) with raised medians and AADT greater than 15,000 (13). The same research showed that when compared with and matched to unmarked crosswalk comparison sites, marked crosswalks showed no significant difference in pedestrian crash rates after accounting for regional effects (13).

International Research

International research provides mixed findings, also highlighting the importance of context. A Norwegian report compiling international experience (including U.S. experience) found diverging effects based on roadway context as well as a worse safety record for marked locations than for unmarked locations. The studies included locations where marked crosswalks had been installed at several locations that would be considered inappropriate under current national guidance in many European countries today; for example, roads wider than 2-to-4 lanes or speed limits greater than 50-to-60 kilometers per hour (30-to-35 miles per hour), depending on the country. The compiled studies showed:

- On 2-lane roads: 8 percent fewer pedestrian crashes at marked crossings compared to unmarked crossings (controlling for differences in traffic and pedestrian volumes).

- On roads with 4 or more lanes: 88 percent more pedestrian crashes at marked crossings than at unmarked locations.
- In aggregate: 44 percent more pedestrian crashes at marked crossings on all types of roads (not statistically significant) and 9 percent more vehicle-only crashes (14).

Any interpretation of these conclusions should account for a few differences:

- In the 84 countries that are parties to the Vienna Convention on Road Traffic, (15) including most countries in Europe, pedestrians only have the right of way at marked crossings, and the concept of an unmarked crosswalk does not exist.
- The longitudinal bar design is used exclusively to mark pedestrian crossings in many European countries, including Denmark, France, Germany, The Netherlands, Norway, and Sweden (16).

In summary, U.S. and international findings point to the variable effectiveness of marked crosswalks in relation to other factors. Safety outcomes appeared to improve with the application of marked crossing locations on narrower roads and lower speed roads but appeared to degrade along wider or higher speed roads.

5.1.2 Driver Yielding

Driver yielding behavior is influenced by several factors, and research has shown a large variance in yielding rates across sites when testing treatments. Yielding rates are affected by traffic speed, roadway geometry, local driving culture, and law enforcement practices, among others. Some U.S. research findings have indicated the following:

- An average yielding rate at uncontrolled crossings with only crosswalk markings (no other supplemental treatments) of 33 percent (across 58 tested sites), with the yielding rate at individual sites ranging from 0 to 95 percent (17).
- A clear inverse relationship exists between speed and driver yielding, with higher speeds resulting in reduced yielding propensity by drivers (18).
- Drivers are more aware of pedestrians, reduce their speeds, and are more likely to yield at marked crosswalks than at unmarked crosswalks (19, 20).

Sociodemographic Effects

A growing amount of research shows disparities in yield rates based on perceived race, gender, age, and socioeconomic status that can impact the effectiveness of crosswalk markings. U.S. studies have been based on staged crossings at a single or matched pair of crosswalks. Studies have demonstrated the following behaviors:

- Black pedestrians waiting to cross were passed by drivers twice as often and waited to cross 32 percent longer than white pedestrians at a marked crosswalk (21).
- The driver of the first car in a platoon was more likely to yield for white pedestrians (57 percent) than for Black pedestrians (44 percent) as well as more likely to yield for women (62 percent) than for men (46 percent) (22).
- The driver in the first car in a platoon yielded at a marked crosswalk in a high-income neighborhood 52 percent of the time but 71 percent in a low-income neighborhood. At the crosswalk in a high-income neighborhood, more drivers passed a Black pedestrian in a crosswalk than a white pedestrian (23).
- Drivers perceived to have a high socioeconomic status (based on their vehicle's make, age, and appearance) were less likely to yield to a pedestrian at a marked crosswalk than other drivers (24).
- Drivers were more likely to yield to pedestrians of similar age or the same gender than to pedestrians outside their age range or gender, as perceived by field researchers (25).

5.2 HIGH VISIBILITY CROSSWALK (HVC) RESEARCH

Several studies have tested the relative effectiveness of HVCs concerning visibility, crashes, and yielding.

5.2.1 Visibility

A rigorous FHWA field visibility study found that HVCs are indeed more visible: drivers detect continental markings at a midblock crossing about "twice the distance upstream as the transverse markings during daytime conditions," and daytime detection distance was longer than nighttime detection distance regardless of location or marking type (26). Figure 7 illustrates this point, providing a driver's view of basic (Site A) and HVC (Site B) markings located along the same roadway. The crosswalks are first shown from approximately 150 feet upstream of the crossing location (View 1) and then shown from the view of a pedestrian beginning to cross (View 2).

Top to bottom, left to right:

Site A, View 1: Basic Crosswalk Marking on Driver Approach (approximately 150 feet upstream).

Site B, View 1: HVC Marking on Driver Approach (approximately 150 feet upstream).

Site A, View 2 (left):Basic Marking from Pedestrian View.

Site B, View 2 (right): HVC Marking from Pedestrian View.

Figure 7: Basic and HVC crosswalk designs along the same street.
Source: Kittelson, 2021

5.2.2 Pedestrian–Vehicle Crashes

Studies have come to different conclusions about crash rates at HVCs versus basic crossings. One study found no significant difference in pedestrian crash rates when comparing sites with a basic design to those with high-visibility designs (13). In contrast, two more recent studies have demonstrated a reduction in pedestrian–vehicle crashes with the use of HVCs at intersections in New York City, New York and within school zones in San Francisco, California, with estimated crash reductions of 48% and 37%, respectively (27,28).

5.2.3 Driver Yielding

A few studies have compared yielding rates at HVC versus basic sites, but none were constructed to isolate and compare the crosswalk markings themselves. The findings revealed the following:

- Driver yielding rates can vary widely across similar sites: yielding at three sites with HVCs *and* high-visibility signs was shown to be as low as 10 percent on a 35-mph street or between 60 percent and 90 percent on a 25-mph street (36).
- Yielding was 30 percent to 40 percent higher in daylight conditions and 8 percent higher in nighttime conditions at two-lane sites with HVCs and illuminated overhead signs and advanced warning signs compared to locations with a basic design (20).

5.3 IMPLICATIONS OF EXISTING RESEARCH FOR PRACTICE

Research ultimately provides a mixed picture of the safety effects of crosswalk markings as well as basic versus HVC patterns:

- Marked crosswalks alone on multilane, higher-volume, and/or higher-speed facilities are not known to reduce crash risk and may in some cases be associated with higher crash risk.
- Marked crosswalks are associated with increased driver yielding compared to unmarked crosswalks. Yielding rates have high variance at different locations but are inversely correlated with speed.
- Yielding behavior is mediated by several factors, including roadway characteristics (i.e., width and speed limit), local driving culture, and sociodemographic characteristics of the driver and pedestrian.
- HVC designs are more visible to drivers than basic designs, and a limited body of research shows driver yielding improvement benefits associated with their use compared to unmarked crosswalks or a basic design.

The introduction to this guide posits that an effective roadway treatment accomplishes its core functions efficiently and cost effectively. The existing research findings cannot be reduced to a single crash reduction factor or yielding improvement factor that would allow for simple quantification of safety improvement from marking or selecting HVC over basic designs. Section 5.4 describes original research results that improve the understanding of benefits.

5.4 ORIGINAL RESEARCH FINDINGS

To build on the existing research and to inform recommendations for this guide, original field research was conducted that evaluated basic versus HVC markings at uncontrolled crossing locations. In addition, agency interviews were conducted to understand common marking practices; those results are incorporated in the discussion of materials, maintenance, and cost, in Section 7, Section 8, and Section 9, respectively.

5.4.1 Study Design

The field research evaluated whether basic versus HVC markings affect yielding rates at crosswalks by measuring and comparing driver yielding rates at sites with HVCs and sites with basic markings. Study sites were marked crosswalks on the uncontrolled legs of two-way stop-controlled intersections on undivided two-lane roadways with relatively low speeds (posted speeds 35 mph and below) and volumes (two-way volumes below 650 vehicles per hour during field tests). The 32 total sites were in four States—California, Florida, North Carolina, and Oregon—with eight sites in each State. Sites were selected as pairs, and each site pair included a basic and an HVC crossing at otherwise similar sites (sometimes along the same roadway a few blocks apart).

Sites were selected based on the following attributes, all of which are factors the 2009 MUTCD advises considering when marking a crosswalk:

- **Location and control:** uncontrolled crossings at intersections where the side street is stop-controlled.
- **Roadway configuration:** two-lane, undivided roadways.
- **Pedestrian volumes:** sites outside of commercial or urban contexts where pedestrians are most expected to be present.
- **Speeds:** sites with posted speeds of 35 miles per hour or below.

The site selection was intended to obtain findings that could be practically relevant. Wider (by number of lanes), higher-speed, and/or higher-volume crossings without traffic control or supplemental treatments would be more difficult to find and test. Likewise, future projects at such locations would probably include geometric or traffic control treatments (this topic is discussed in more detail in Section 6.2).

5.4.2 Results

- The results offered findings that relate driver yielding to marking style and site context:
- HVC sites exhibited a higher yield rate than basic sites. The yielding rates across all HVC and basic sites were 54 percent and 40 percent, respectively. Most paired sites—13 of the 16 pairs—showed higher yielding rates at the HVC sites compared to their paired basic sites.
- Yielding rates showed a negative relationship with driver speeds, as was shown in the existing research. As site speeds increase, yielding rates generally drop. Figure 8 shows this relationship (each point is a site). This relationship was found to be robust and is discussed in more detail below.

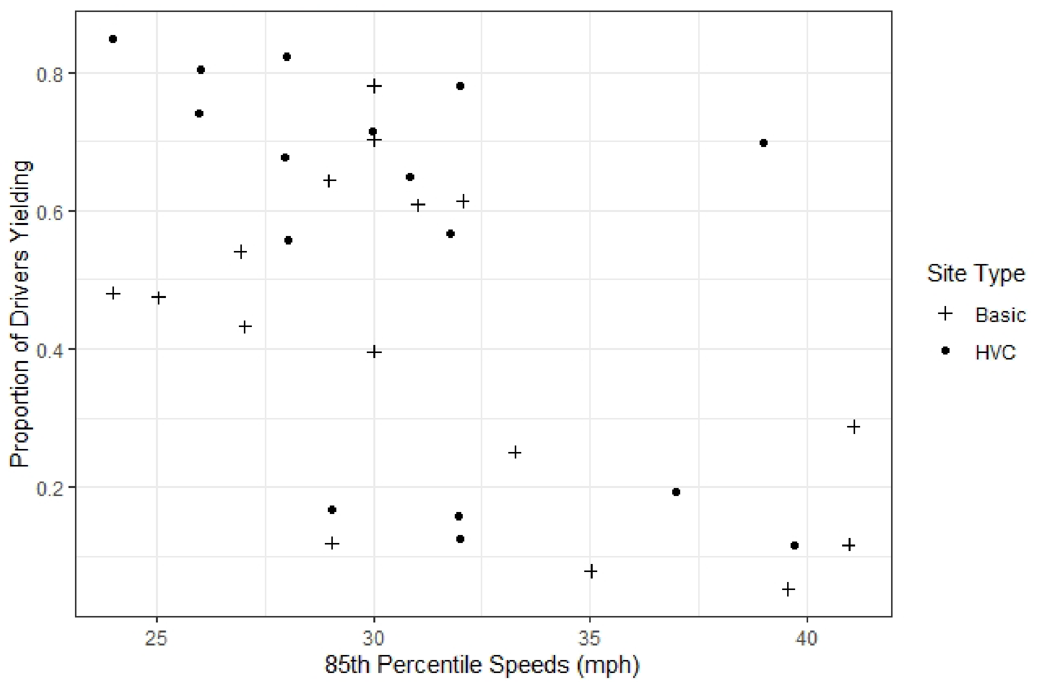


Figure 8: Yield rates versus speeds at field-tested locations.

Statistical Modeling Findings

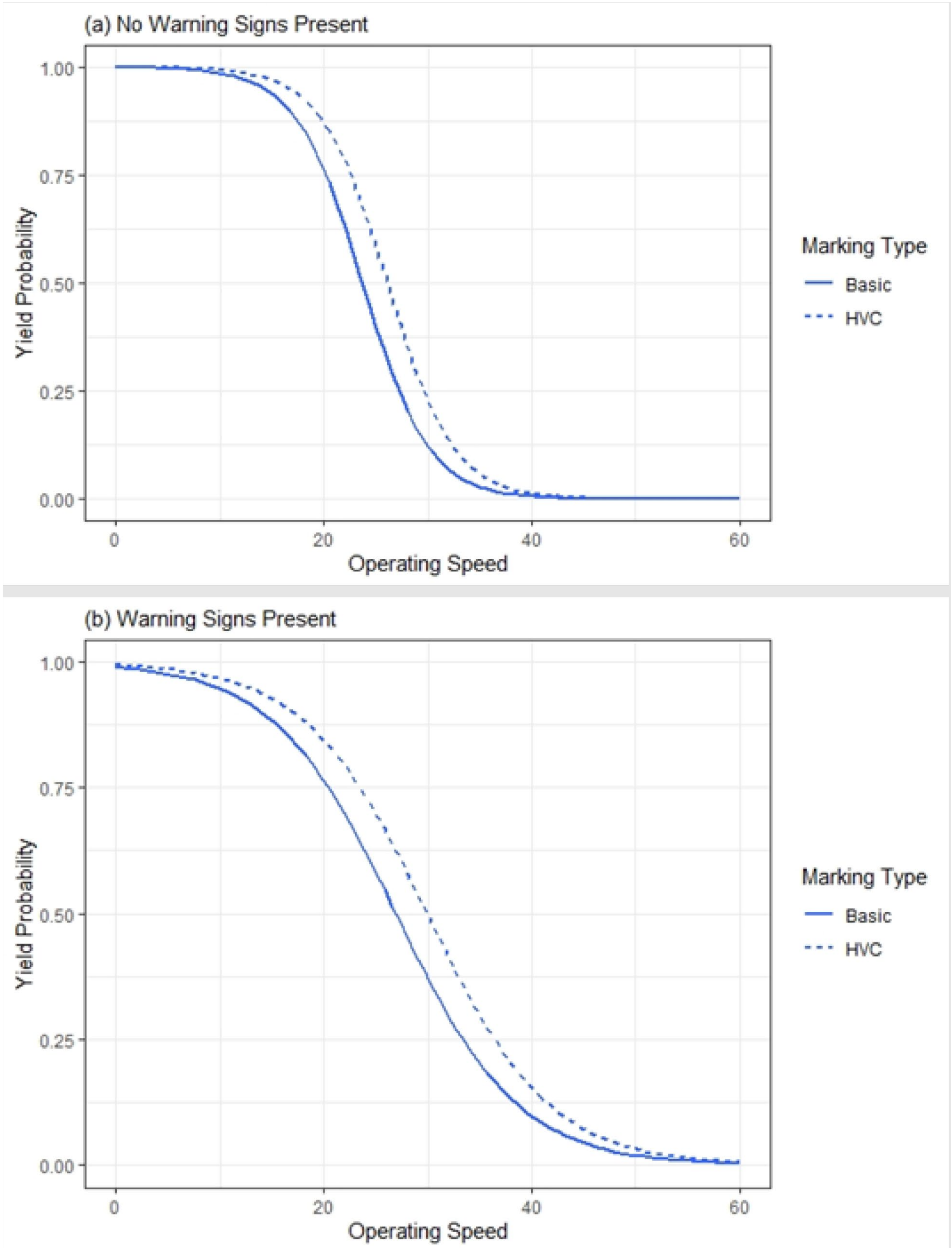
The study design also allowed for statistical modeling, testing the field data with a logistic regression. Logistic regression can be used to quantify the relationship between independent variables (predictors) and dependent variables (driver yielding). Appendix A provides detail about the modeling approach. Site variables tested, and the concluding findings of the HVC yielding effect, are in Table 1.

Table 1: Yielding Effect of HVC Markings in Relation to Site Characteristics

Site Characteristic	HVC Effect in Relation to Characteristic
85th percentile speed	At sites with higher operating speeds (85th percentile speed > 30 mph), HVCs alone were no more impactful on driver yielding than basic crosswalk markings.
Crossing distance	HVC markings were associated with increased driver yielding after controlling for crossing distance, indicating effectiveness across a range of crossing distances.
Site hourly traffic volume	HVC markings were associated with increased driver yielding after controlling for hourly traffic volume, indicating effectiveness across the range of traffic volumes tested. The range tested varied from under 100 vehicles per hour to approximately 600 vehicles per hour (two-way).
Presence of bike lanes and street parking	HVC markings were associated with increased driver yielding after controlling for bike lanes and street parking. This finding held at sites on roadways serving a mobility function (collector streets) not located within a dense grid street network but not on local streets within a dense grid context. (Refer to Appendix A for details on site classification.)
Presence of warning signs (MUTCD W11-1 and S1-1)	HVC markings have a stronger positive effect on driver yielding in the absence of warning signage but still provide benefit to induce yielding with warning signs treatments present.
Site Context	HVC markings were associated with increased driver yielding at sites on roadways serving a mobility function (collector streets) not located within a dense grid street network. The HVC effect is lost on local streets within a dense grid context. (Refer to Appendix A for details on site classification.)

Speed and Yielding

The modeling revealed another robust and important finding: speed is a strong determining factor in driver yielding. Across all models tested, a driver's speed always showed a strong negative effect on yielding likelihood. This finding was established in the existing research and is bolstered by the results of this study (18,30,31). Figure 9 shows the regression models fit to sites broken into those with and without warning signs present.



The charts represent the probability of yielding based on a driver's approach speed and the presence of HVC or basic crossings. For a given speed, drivers are likelier to yield at crosswalks with HVC markings. The effect is strongest between 20 and 35 miles per hour.

Figure 9: Logistic Regression Model demonstrating the relationship between vehicle speed and yielding probability.

The regression models illustrate the speed-yielding relationship. In both sets of sites, a sharp decline in yield probability is observed between approximately 20 and 40 miles per hours in both models. Given the observed taper in yielding rate, at 40 miles per hour or above (perhaps lower, based on site context), drivers can essentially be expected not to yield at uncontrolled crossings—irrespective of the crosswalk marking pattern.

5.4.3 Implications for Marking Decisions

The study design focused on a narrow set of crosswalk site contexts—low volume, low speed, two-lane uncontrolled intersect crossings. Locations with higher volumes, speeds, and crossing distances will be recommended for supplemental treatments, and local or residential roadways with no centerline may not justify a marked crosswalk. This study tested whether there is an "in-between" location type, where crosswalk markings alone or with warning signs may be provided, to determine if HVCs offer a benefit compared to basic designs. The results indicate that in such locations, HVCs are associated with higher yielding rates. **If an uncontrolled crosswalk is worth marking, it appears to be worth marking with an HVC design.**

The yielding benefit was quantifiable at the following locations:

- Lower-speed locations (85th percentile speeds below 30 mph)
- Collector streets outside a dense grid street network. HVC yielding effectiveness appears to be diminished on local streets with a dense grid network, slower speeds, and environmental cues (e.g., bike lanes) that may prime drivers to expect crossing pedestrians.

The experiment focused on two-lane locations with no additional supplemental crossing treatments or with warning signs at the crossing. It tested crossing locations without traffic control, with posted or *prima facie* speeds 35 mph or below, and with 85th percentile speeds 41 mph and below.

5.5 SUMMARY

Existing research presents mixed results on the safety effects of marking crosswalks and using an HVC design, with the takeaway that context matters. Safety outcomes appeared to improve with the application of marked crossing locations on narrower roads but appeared to degrade along wider or higher-speed roads. HVCs have been shown to be more visible from twice the distance of basic markings.

Research testing crossing treatment effects has shown a large variance in yielding rates across site and contexts. Yielding rates are inversely correlated with speed and are influenced by several factors including roadway characteristics, local driving culture, and roadway and site context. A growing amount of research also shows disparities in yield rates based on perceived race, gender, age, and socioeconomic status of both the driver and the pedestrian that can impact the effectiveness of crosswalk markings. Drivers have been shown to be less likely to yield for pedestrians who are Black (versus white), male (versus female), or demographically different from the driver (in age or perceived gender).

Original research conducted for this guide focused on crosswalks at low volume, low speed, two-lane roads. The results offer strong findings relating driver yielding to site context and treatments:

- HVCs are associated with greater increased driver yielding than basic markings.
- Yielding rates showed a robust negative relationship with driver speeds. HVC effectiveness is strongest with lower driver speeds (sites with 85th percentile speeds ≤ 30 mph).
- HVCs show a positive yielding effect with and without supplemental warning signs present, with a stronger effect in the absence of warning signs.

Section 6. When should HVCs be used?

The previous sections indicate the safety effects of marked crosswalks generally and of HVCs compared to basic crosswalks, including original research findings describing yielding effects of HVCs at uncontrolled crossings. This section builds on that research and on existing guidance to provide recommendations for practitioners on:

- Why HVCs are appropriate for all uncontrolled marked crosswalks
- Where marking HVCs may be most effective
- When supplemental treatments are recommended

6.1 HVC MARKING LOCATIONS

6.1.1 Existing Guidance for HVC Use

2009 MUTCD

The 2009 MUTCD provides options for using diagonal or longitudinal markings with or without transverse markings "for added visibility…where substantial numbers of pedestrians cross without any other traffic control device, at locations where physical conditions are such that added visibility of the crosswalk is desired, or at places where a pedestrian crosswalk might not be expected" (Section 3B.18(08-09), *4*).

National Committee on Uniform Traffic Control Devices (NCUTCD)

The NCUTCD is a volunteer group of transportation professionals that develops recommendations for changes to the MUTCD for FHWA's consideration but has no official association with the federal government. In 2011 and 2012, the NCUTCD recommended changes that included more specific guidance for using HVCs. The recommended changes differentiated between basic and HVC designs, allowing longitudinal or diagonal markings for HVC designs. The recommendations also proposed that HVCs should be used at all nonintersection marked crossings and should have a minimum width of 8 feet (32,33).

FHWA Guide for Improving Pedestrian Safety at Uncontrolled Crossing Locations

This 2018 guide provides a matrix for selecting safety countermeasures at uncontrolled crossing locations based on the following site conditions: AADT, posted speed, number of lanes, and raised median presence. The matrix recommends considering HVCs at *all* uncontrolled crossing locations and using

HVCs in combination with other countermeasures under the following conditions (34):

- Posted speed ≥ 40 mph.
- Posted speed = 35 mph and AADT > 15,000.
- Crossing more than 2 lanes and AADT ≥ 9,000.
- Posted speed = 35 mph, AADT < 9,000, and crossing 4 or more lanes without a raised median.

The guide also recommends strongly considering HVCs at all established midblock crossings because "a high visibility crosswalk is much easier for an approaching driver to see than the traditional parallel lines."

National Association of City Transportation Officials (NACTO)

NACTO's *Urban Street Design Guide* recommends that "high-visibility ladder, zebra, and continental markings are preferable to standard parallel or dashed pavement markings. These are more visible to approaching vehicles and have been shown to improve yielding behavior" (35). This recommendation is rooted in the need to increase crosswalk visibility and draw the drivers' attention to people using the crosswalks.

6.1.2 Marking Recommendation

This guide recommends HVCs over basic patterns anywhere uncontrolled crosswalks are marked.

Existing and original research have indicated potential crash reduction and yielding benefits from HVC markings in certain contexts. Those effects are difficult to isolate as part of experiment design. However, the visibility benefit over basic markings alone indicates HVC utility. Particularly, if an uncontrolled crosswalk is worth marking, it is worth marking as HVC for improved visibility.

Agencies may be reluctant to embrace HVC markings as their sole marking type for cost or installation reasons. Section 6 through Section 8 discuss those considerations and how maintenance and a life-cycle cost approach can be considered.

Which HVCs are best?

The discussion on types of HVCs in Sections 4.1 and 6.1.1 indicates the following:

- HVCs with longitudinal markings—the double-paired and longitudinal bar designs—are both suitable and are treated as such by the 2009 MUTCD and the NCUTCD recommendations.
- Transverse markings may be applied to either design (e.g., turning it into a perpendicular bar design). If maintained, the transverse markings may provide a wayfinding benefit.

In the scan of common agency marking practice, diagonal markings were found to be infrequently used. Diagonal markings cannot be designed to avoid tire tracks. (Further discussion provided in Section 8.3.) For these reasons, the designs in Figure 10 are recommended.

Agencies may prefer a particular design and have typical drawings for how the design is laid out. They may find benefits with, for example, a double paired design's ability to avoid tire tracks or efficiencies of scale with a certain standard stencil. These considerations are presented in Section 8 and Section 9.

The double-paired or longitudinal bar designs may be applied with or without transverse markings.

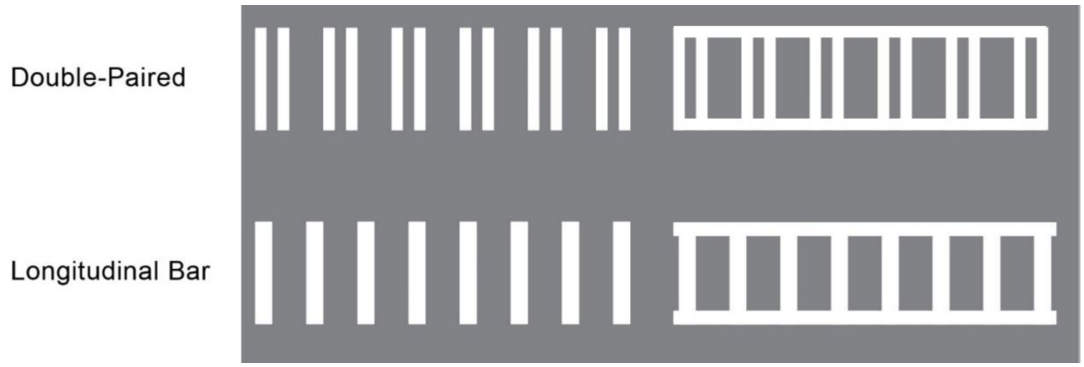


Figure 10: Recommended HVC Marking Styles for All Crosswalks.
Source: Adapted from Federal Highway Administration. Manual on Uniform Traffic Control Devices for Streets and Highways. Section 3B.18(04). Washington, D.C., 2009.

Are Basic Markings Still Suitable in Some Locations?

The key question of this guide can be reframed as, "Why not mark HVCs everywhere?" Indeed, this guide recommends using HVC markings everywhere an agency has determined to mark a crosswalk. However, agencies are often constrained in their application of traffic control devices—financially or in available labor. Section 6 through Section 8 discuss why HVCs may still be more cost effective on a life cycle basis, but for an agency that needs to decide which locations to prioritize for HVC markings, it is helpful to refer back to the core functions of crosswalk markings:

- **Alert drivers to pedestrians' potential presence and right of way.** There may be locations where the crosswalk marking is supplementary, but not essential, in providing this cue. For example, some agencies provide basic markings at signalized intersections on the rationale that drivers are controlled, and right of way is assigned, by the signal.
- **Establish pedestrian right of way at midblock locations:** As other guidance indicates, the crosswalk markings play an essential role in midblock locations, and HVCs are recommended.

- Establish pedestrian right of way at crossings lacking sidewalk connections on at least one side[2]: Here too crosswalk markings play an essential role, and HVCs are recommended.
- **Provide wayfinding cues to pedestrians with low vision:** The contrast provided by crosswalk markings is important. As indicated in Section 3.6, transverse lines may play an additional role (along with the HVC longitudinal markings). HVCs are recommended.

6.2 WHEN IS MARKING NOT ENOUGH?

Crosswalk markings are not the only treatments available to engineers attempting to make a pedestrian crossing location safer, and existing research and guidance clearly indicate that supplemental treatments are appropriate in many cases. For example, research has shown that driver yielding at sites with HVCs *and* high-visibility signs could be as low as 10 percent on a 35-mph street or between 60 percent and 90 percent on a 25-mph street (36). Using a combination of treatments for a single crossing improves pedestrian safety, especially at uncontrolled crossings on multilane, higher-speed roads (13,36). Supplemental treatments can make the crossing and pedestrians using the crossing more visible to drivers and can reduce pedestrian exposure when completing a crossing.

There are two sets of criteria that agencies may consider when determining whether to mark a crosswalk alone and whether to provide supplemental treatments:

- Roadway configuration, speed, and volume
- Pedestrian demand and delay

6.2.1 Roadway Configuration, Speed, and Volume

Three resources provide recommendations for the application of supplemental crossing treatments:

The 2009 MUTCD provides guidance for locations where marking alone is inappropriate, stating "…new marked crosswalks alone, without other measures designed to reduce traffic speeds, shorten crossing distances, enhance driver awareness of the crossing, and/or provide active warning of pedestrian presence, should not be installed"(Section 3B.18(08-09), *4*) at locations where:

- The roadway has 4 or more lanes of travel without a raised median or pedestrian refuge island and average daily traffic (ADT) of 12,000 vehicles per day or greater.

[2] Applicable to States that follow the UVC definition of an unmarked crosswalk.

- The roadway has 4 or more lanes of travel with a raised median or pedestrian refuge island and an ADT of 15,000 vehicles per day or greater.

In 2012, the NCUTCD's recommended changes proposed that crosswalk markings should not be installed on roads with speeds exceeding 35 mph unless they are supplemented with other safety treatments (32, 33).

The 2018 *Guide for Improving Pedestrian Safety at Uncontrolled Crossing Locations* (2018 FHWA Uncontrolled Crossing Guide) synthesizes practice and research, providing countermeasure recommendations based on a combination of roadway speed, motor vehicle volume, and roadway configuration. It advises:

- HVCs should be considered at all uncontrolled crossings.
- Agencies should strongly consider providing HVCs at all established midblock pedestrian crossings.
- Above certain volume, speed, and crossing distance thresholds, HVCs should be implemented and supplemented with other measures to improve crosswalk visibility—including pedestrian crossing warning signs, parking restrictions and/or curb extensions, and an appropriate level of lighting.

Figure 11 visually combines the locations at which these three sources recommend supplemental crossing treatments. The blank cells in the table are contexts in which HVC marking alone may be sufficient without supplemental treatments.

Roadway Configuration	Posted Speed Limit and AADT											
	AADT <9,000			AADT 9,000-12,000			AADT 12,000-15,000			>15,000		
	≤30	35	≥40	≤30	35	≥40	≤30	35	≥40	≤30	35	≥40
2 lanes			2,3			2,3			2,3		2	2,3
3 lanes with raised median			2,3		2	2,3		2	2,3	2	2	2,3
3 lanes without raised median			2,3	2	2	2,3	2	2	2,3	2	2	2,3
4+ lanes with raised median			2,3	2	2	2,3	2	2	2,3	1,2,3	1,2,3	1,2,3
4+ lanes without raised median		2	2,3	2	2	2,3	2	2	1,2,3	1,2,3	1,2,3	1,2,3

Figure 11: Combined guidance on marking crosswalks at uncontrolled locations.

Note:
1 = 2009 MUTCD recommended supplemental treatments.
2 = 2018 FHWA Uncontrolled Crossing Guide recommended supplemental treatments.
3 = 2012 NCUTCD recommended supplemental treatments.
Source: Adapted from 2009 MUTCD, Section 3B.18(08-09) (4), 2018 FHWA Uncontrolled Crossing Guide (34), and NCUTCD Crosswalk Markings Application Criteria, Attachment No. 12 (33)

Social Equity Prioritization

Agencies must consider social equity when prioritizing investment and selecting supplemental treatments in addition to Title VI requirements:[3]

- The quality and presence of existing transportation infrastructure in underserved communities, including those with a concentration of low-income residents or people of color. Research has shown disparities in the presence of infrastructure for walking and bicycling in these communities (37). Agencies should strive to make targeted infrastructure investments in communities that show these disparities.
- A recent study found disparities in marked crosswalk coverage (percent of total intersections featuring a crosswalk) in San Francisco. Of four

[3] The U.S. Department of Transportation (Department or DOT) Title VI of the Civil Rights Act of 1964 is the Federal law that is designed to ensure that no person in the United States, based on race, color, or national origin, is excluded, denied the benefits of, or otherwise subjected to discrimination under any program that receives Federal financial assistance.

neighborhoods analyzed more deeply, coverage was highest in a high-income, largely white neighborhood and lowest in a lower-income and more diverse neighborhood (38)

Documented sociodemographic safety effects. Research presented in this guide shows the growing research in known disparities in driver yielding due to perceived gender, race/ethnicity, economic status, and others. Although these effects have not been studied in relation to supplemental treatments, it follows that more interventions are appropriate in crossing locations serving underserved communities, particularly people of color, given findings on yielding to Black pedestrians and the disproportionate pedestrian risk for Black, American Indian, and Alaska Native people (38).

The original research conducted for this guide controlled for pedestrian-related factors known to impact driver yielding and used staged crossings with white males at all study sites. Further research may indicate variable effects of treatments in relation to sociodemographic characteristics.

6.2.2 Pedestrian Demand and Delay

NCHRP Report 562 recommends guidelines for pedestrian crossing treatments and proposes four categories of crossing treatment interventions (36):

- Marked crosswalk.
- Enhanced, high-visibility, or "active when present" traffic control device.
- Red signal or beacon device.
- Conventional traffic control signal.

The recommended thresholds for application include roadway crossing distance and vehicle volumes (like the guidance listed above) but add pedestrian crossing volume or demand as a parameter. The governing measure determining the level of treatment to provide is total pedestrian delay within the peak hour. Figure 12 provides an example of this measure. Each curve signifies a vehicle and pedestrian volume combination resulting in 1.3 total person-hours of pedestrian delay in the peak hour, assuming that no drivers yield the right of way. Below each curve, a marked crosswalk is recommended; above each curve, varying levels of supplemental treatments are recommended.

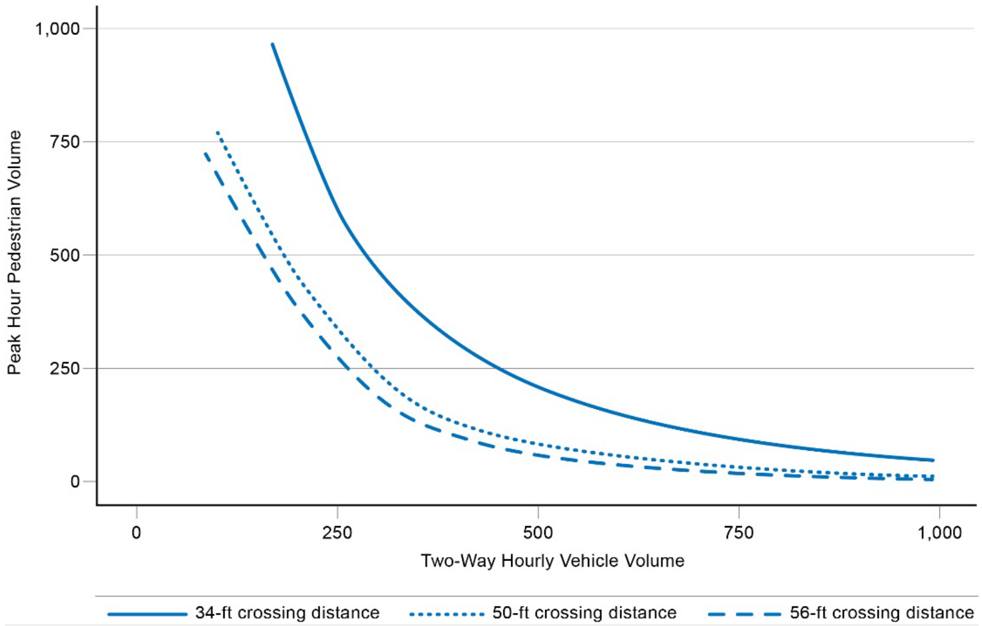


Figure 12: Example application of NCHRP Report 562 Crossing Treatment Guidelines
Source: Adapted from NCHRP Report 562, Appendix A (36)

Note: Figure illustrates the application of guidance assuming vehicle speeds at or below 35 miles per hour and walking speeds of 3.5 feet per second.

The lowest traffic volume category in Figure 12 was 9,000 vehicles per day or below. The incorporation of pedestrian volume and demand allows an agency to consider locations where traffic volumes may be low but pedestrian demand is reasonably high. Even at those lower-volume locations, pedestrian crossing volume or demand may increase the utility of supplemental crossing treatments.

However, there are limitations to pedestrian demand and delay. In areas such as more rural settings, collected pedestrian crossing volumes alone may be minimal or nonexistent and not warrant a treatment from this measure regardless of community need. It is important to evaluate community context, including land use and community generators in the area that people may walk to. For example, grocery stores, green space, or schools are all assets that contribute to pedestrian demand.

6.2.3 Marking Recommendations with Supplemental Treatments

Figure 11 combined similar recommendations and requirements for supplemental crossing safety treatments. Figure 12 provides a different approach to identifying locations based on pedestrian crossing volume and demand. The guidance indicates that as speeds, volumes, roadway crossing distance, and pedestrian demand increase, so too does the need for supplemental treatments.

Supplemental treatments provide crossing support above and beyond the core function of marked crosswalks, not only increasing visibility and highlighting crossing locations but also inducing driver yielding.

Several studies have found that a package of safety treatments including marked crosswalks can result in higher yielding rates and reduced crashes, including one study that compared yielding rates at sites with HVCs alone to infrastructure-based treatments that included HVCs. Studied treatments have included countermeasures that display a red signal indication to drivers, pedestrian refuge islands, and lane removals or narrowing, among others (36,40,41,42,43).

The original research described in Section 5.4 indicated that HVCs can still provide some yielding benefit in the presence of other safety treatments. HVCs are worth including and are recommended as part of any crossing safety improvement project. The conditions that make supplemental treatments desirable are the same conditions that logically make HVCs a useful choice relative to basic crossings.

Additionally, agencies may use the pedestrian delay framework presented in Figure 12 to determine where marked crosswalks are appropriate versus other treatments.

6.3 SUMMARY

- HVC markings are recommended for all uncontrolled marked crosswalk locations. The potential crash reduction and yielding benefits, and the documented visibility benefit over basic markings, make them worth installing wherever an agency chooses to mark a crossing.
- Agencies may prefer a particular HVC design and have typical drawings for how the design is laid out. Longitudinal, rather than diagonal, markings are more commonly used and are recommended.
- For an agency that needs to decide about which locations to prioritize for HVC markings, referring to the core functions of crosswalk markings can help determine potential locations for basic markings rather than HVCs.
- There are two sets of criteria that agencies may consider when determining whether to mark HVCs along with supplemental treatments:
    - Roadway configuration, speed, and volume
    - Pedestrian demand and delay
- HVCs are worth including and are recommended as part of any uncontrolled crossing safety improvement project. The conditions that make supplemental treatments desirable are the same conditions that logically make HVCs a useful choice relative to basic crossings.

Section 7. What materials are used for crosswalk markings?

Agency interviews conducted while developing this guide discussed marking materials as they relate to marking type decisions.

7.1 TYPES OF CROSSWALK MARKING MATERIALS

Crosswalk markings that include transverse marking elements are subjected to more traffic wear than longitudinal markings, such as lane lines. Consequently, durability is an important consideration when agencies select crosswalk marking materials. Pavement marking materials can be divided into three categories based on expected service life (43,44):

- Nondurable
    - *Waterborne* traffic paint: A single-component paint that is ready to apply without adding any additional ingredients.
    - Moderate durability
    - Epoxy: A 2-component system containing no solvents that is 100 percent solid material consisting of a resin and a hardener.
    - Polyurea: A 2-component, 100 percent solids polyurea film formulated to rapidly cure.
- Durable
    - *Thermoplastic*: A blend of solid ingredients (resins, pigments, and fillers) that becomes liquid when heated and then becomes solid again after cooling. It can be applied as a liquid, spraying the material over a stencil, or extruding the material. It can also be applied by melting hardened, preformed material in place using a torch. It can be installed level with the pavement surface, raised above the pavement surface (“profiled”), or below the pavement surface (“recessed”).
    - Methyl Methacrylate (MMA): A 2-component system that is 100 percent solid material and chemically reactive containing no volatile solvents. It can be applied profiled, level with the pavement surface, or recessed and can be sprayed or extruded.
    - Preformed Tape: One example is preformed thermoplastic that is applied to the pavement cold, employing a self-adhesive backing material or using a separate adhesive. Another example is a pliant polymer material consisting of a mixture of polymeric materials, pigments, and glass beads that can be applied with the aid of a

surface preparation adhesive. Tape can be applied recessed or on the pavement surface and can be patterned.

7.2 FACTORS CONSIDERED WHEN SELECTING MARKING MATERIALS

Agencies interviewed while preparing this guide indicated that different factors influenced their selection of marking material(s) for a particular site. These factors included:

- **Equipment availability.** Agencies that performed their marking in-house (as opposed to hiring contractors) indicated that a lack of equipment was a barrier to using certain marking materials. For example, liquid hot-laid thermoplastic requires equipment to melt the material on site. Multicomponent materials, such as epoxy, polyurea, and MMA, require special equipment to mix the components on site.
- **Desired material properties.** Desired properties included various combinations of durability, retroreflectivity under dry and wet conditions, repairability, ability to reapply without removing old material, drying, and curing time, and antiskid properties. In the context of HVCs, markings with antiskid properties are also important to be slip-resistant for pedestrians and skid-resistant for bicyclists and motorcyclists crossing the markings. Drying and curing time and the ability to reapply without removing old material affect the time it takes to install the marking and therefore how long traffic control crews are on site and the amount of delay road users experience.
- **Material cost.** Different materials have different unit costs, and some require one-time and ongoing maintenance costs for the special equipment used to melt or mix materials. Different marking patterns also require different quantities of materials for a given crosswalk area. Costs are discussed further as part of Section 8.
- **Job size.** Materials applied using machines can be applied more efficiently on large jobs, such as a pavement preservation project. Other types of materials are more efficient for small jobs, such as installing a new crosswalk.
- **Pavement type.** The type of pavement the material is applied to—asphalt or Portland cement concrete (PCC)—affects how well the material adheres to the pavement and how easily the markings can be seen under different conditions.
- **Lighting conditions.** Whether or not a crossing is lit affects the minimum level of retroreflectivity that the material must provide.
- **Climate.** Cold temperatures and the presence of moisture on or within the pavement can affect the ability of materials to adhere to the pavement (43). In addition, snowplowing operations can damage both profiled pavement

markings and those installed level with the pavement surface. One State DOT that experienced significant climatic variations across the State (mild coast, mountain passes, cold inland) considered the type of snowplowing blade when selecting marking materials, with less-durable materials used in ice chisel blade plowing areas, more durable materials used in steel blade plowing areas, and the most durable materials used in rubber blade plowing areas (44).

- **Traffic volume.** Less durable, but less expensive, materials are considered on roadways with lower traffic volumes, with more durable material used on busier roadways.
- **Time to the next planned pavement preservation project.** Less durable, but less expensive, materials are considered in locations where the markings would be replaced anyway within the next 1–2 years due to a pavement preservation project.
- **Environmental concerns.** Some agencies avoided using certain materials due to environmental concerns. For example, leftover epoxy is considered a hazardous material for disposal purposes, the Oregon DOT discontinued the use of MMA in part for environmental and health reasons, and the New York City DOT is increasingly using polyurea on higher-volume facilities and on PCC pavements because snowplows can pop off sections of thermoplastic, which end up washing into the harbor (43,44).
- **Experience.** Some agencies had stopped using certain materials due to unsatisfactory results in the past.

7.3 DURABILITY

The agencies interviewed while preparing this guide indicated that a crosswalk marking's durability depends on the climate, traffic volumes, whether the agency considered durability to be "time before refreshing" or "time before replacing," the crosswalk marking pattern used, and whether the markings were recessed. Examples of reported durability for common crosswalk marking materials are as follows:

- **Paint.** The interviewed agencies generally agreed that paint lasts no longer than one year (or one winter season in cold-weather climates). Minnesota DOT's guidance indicates that paint can last longer than one year for crosswalk locations in low-volume (<1,500 AADT) locations and when the markings are recessed. (45)
- **Thermoplastic.** The reported durability of thermoplastic before needing refreshing was as low as 2–3 years in high-volume locations, but most interviewed agencies using thermoplastic reported that markings usually lasted 5 or more years before needing refreshing. A few agencies reported

that thermoplastic could last 10–15 years before needing to be replaced, depending on traffic volume.

- **MMA.** The agencies that used MMA found that it generally lasted 3–5 years before needing refreshing.
- **Epoxy.** The one agency that reported durability for epoxy reported that it lasted 3–5 years before needing refreshing.
- **Preformed polymer tape.** Minnesota DOT's guidance indicates that preformed polymer tape's durability is similar to that of thermoplastic, lasting more than 5 years before needing refreshing and more than 7 years when the markings are recessed (45).

Minnesota DOT's guidance indicates that recessed markings can last two years longer than non-recessed markings, while markings at low-volume (<1,500 AADT) locations may last up to one to two years longer than markings at higher-volume sites.

7.4 SELECTING MATERIAL

A key finding of this guide's preparation interviews is that the application and maintenance tradeoffs of marking *materials* govern agency decision making rather than the marking designs, themselves, or even whether the materials are being used to mark a crosswalk or a lane line. Some agencies conduct their own material testing or rely on industry standards to guide their marking decisions to balance the desired outcomes with life-cycle costs.

Figure 13 shows an example of a selection matrix for transverse markings used by Minnesota DOT. This matrix incorporates Minnesota DOT's needs for winter weather durability; other agencies might use a different set of criteria that consider conditions within their jurisdiction.

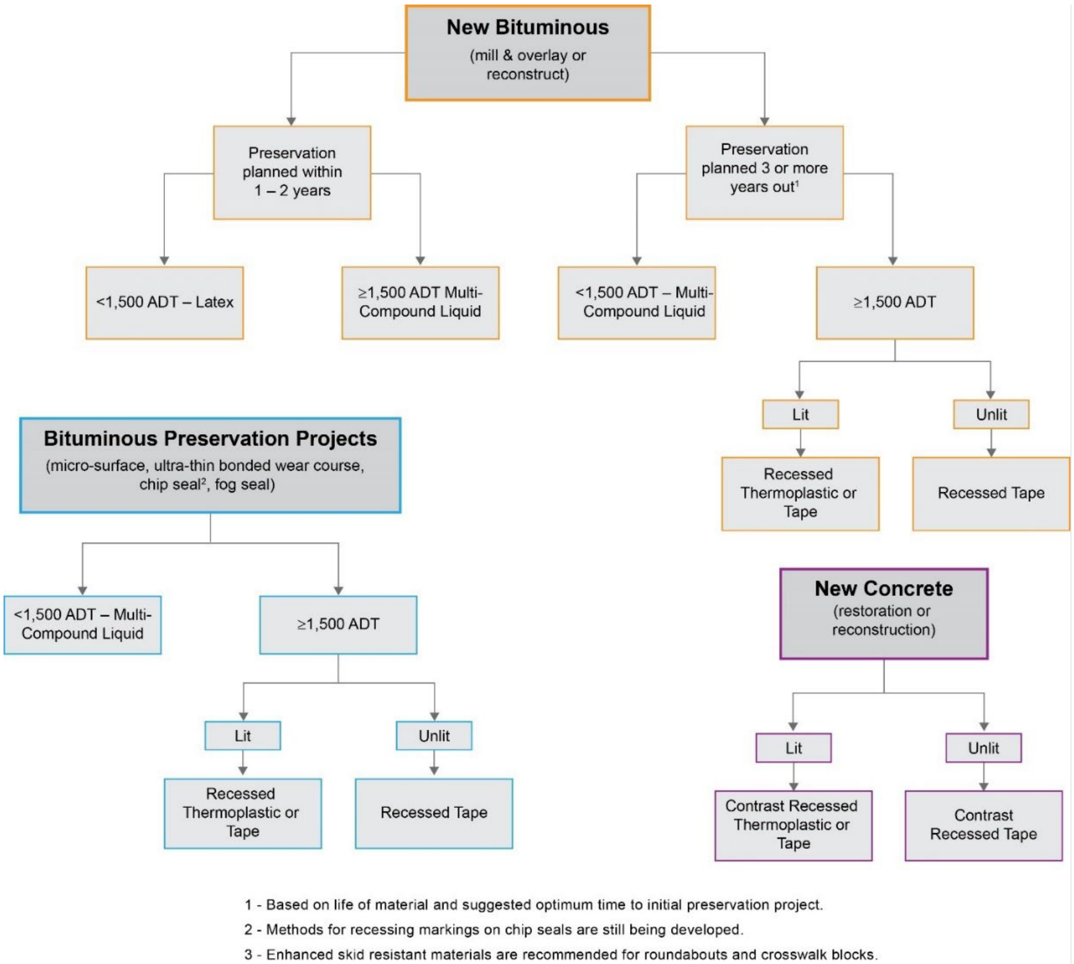


Figure 13. Graphic. Minnesota DOT Transverse Marking Selection Guidance.
Source: Adapted from Minnesota DOT. (46)

7.5 RECOMMENDATIONS

Agencies that perform their own pavement marking have developed a set of materials they work with that provides the desired properties for different marking applications and can be applied using the equipment the agency has available. Agencies that contract out pavement marking will typically specify the desired properties and leave it to the contractor to determine how best to meet the requirements. As a result, there is no one right answer to materials selection for marking crosswalks.

Table 2 presents recommendations for marking material types and application methods given certain site characteristics. An agency's decision on the specific marking material and application method to use for a given crosswalk will be based on the available material options, the characteristics of the crossing location, and life-cycle costs.

Table 2: Crosswalk Marking Material Recommendations for Different Site Characteristics

Site Characteristic	Material or Application Recommendation
High-visibility crosswalk	Incorporate antiskid properties into the marking material, given the larger area covered by markings compared to a basic crossing.
Unlighted crossing	In the absence of supplemental overhead lighting at the crossing, a material with high retroreflectivity is desirable (dry or wet retroreflectivity, depending on the climate).
Frequent winter snowplowing	Recessed markings are more resistant to snowplow damage; alternatively, nondurable markings can be used and refreshed annually.
High-volume location	Use durable markings; consider recessed markings.
Low-volume location	Moderately durable markings may provide sufficient durability at a lower cost.
Roadway will be resurfaced within the next 1–2 years	Nondurable markings will likely be more cost-effective than installing and replacing more durable markings.

7.6 SUMMARY

- A variety of marking materials and application methods can be used to mark crosswalks.
- An agency's decision on which material to use at a given crossing will depend on several factors, including but not limited to traffic volumes, snowplowing activity, lighting conditions, climate, and schedule for resurfacing the roadway.
- Incorporating antiskid properties into the material used to mark a high-visibility crossing is desirable due to the larger area covered by markings.

Section 8. What maintenance considerations apply to crosswalk markings?

8.1 INSPECTION

Agencies interviewed while preparing this guide identified three primary methods for identifying when crosswalk markings needed to be refreshed or replaced:

- **Staff observations and resident requests.** Agencies with no formal inspection program, typically due to insufficient resources, use this method. The need to refresh markings is identified by City staff during their other routine activities or when the public made requests or complaints. Markings might also be inspected by staff as part of the scoping effort for a larger scheduled pavement maintenance project. Agencies with formal inspection programs also use staff and public input to identify crosswalks requiring maintenance.
- **Fixed schedule.** This is the most common method among the interviewed agencies. All pavement markings are inspected on a fixed schedule—typically annually—but reported frequencies ranged up to 3 years. Agencies in areas that rarely experience snowfall report performing the inspections during the winter to help prepare their annual maintenance contract (if marking maintenance was contracted) or to develop their spring and summer maintenance schedule (if maintenance was performed in-house). One agency refreshes all its crosswalk markings annually rather than performing a separate inspection process to identify the need to refresh markings.
- **Asset management system.** A few agencies use asset management systems or are planning to implement one to determine when markings needed to be replaced based on typical marking durability. As a result, regular inspections are not performed. One agency that previously relied on citizen complaints to identify marking maintenance needs notes that "people in certain areas of the city were more likely to voice complaints, while very few complaints came in from other areas. Using the asset management system to monitor potential needs contributes to a more equitable process that can be more proactive in anticipating the need to refresh markings."

Crosswalk markings may need to be refreshed or replaced when (46):

- The markings begin to disappear due to wear. One interviewed agency noted that they used a lower threshold (20 percent wear) for determining when school crosswalks needed to be refreshed than the threshold used for other crosswalks (30 percent wear).
- The markings lose retroreflectivity, which is often the first property of marking materials to be lost.
- The markings (particularly thermoplastic and tape) become too slippery as they wear.

In addition to inspecting the quality of the crosswalk markings, crosswalk inspections also involve checking for pavement defects within the crosswalk that can pose hazards to people walking or using mobility devices (46).

8.2 REFRESHING MARKINGS

Once a crosswalk has been installed, the markings are slowly worn down by the vehicles passing over the markings. In cold-weather climates, snowplowing activities will also damage the markings. As a result, crosswalk markings may need to be touched up or "refreshed" (e.g. installing one or two faded bars rather than replacing and reinstalling the entire crosswalk) to maintain their visibility until the next scheduled pavement resurfacing project occurs. The frequency at which markings are refreshed vary among the interviewed agencies and depend in part on the method the agency uses to inspect markings. Typical schedules for refreshing markings include:

- Ad hoc as needs are identified.
- On the same schedule as the inspection program, but only if the crosswalk needs refreshing.
- On a fixed schedule, with all markings refreshed at regular intervals.

The latter is the most frequently used method among the interviewed agencies, with an average interval of 3 years and a range of 6 months to 5 years.

8.2.1 Materials

When refreshing markings, agencies do not necessarily use the same marking material as the original installation. Paint is commonly used to refresh markings when a relatively frequent refresh schedule (e.g., 1 year) is used, when the time to the next scheduled pavement resurfacing project is relatively short, or when the original marking material requires specialized melting or mixing equipment that would be inefficient to use for small projects. Some agencies use thermoplastic tape and torch-applied preformed thermoplastic to refresh thermoplastic markings, either in general or when temperatures are too low to use hot liquid thermoplastic.

8.2.2 Refresh or Replace?

Some agencies prefer to replace markings rather than refresh them as previously described. Reasons for doing so include:

- Unit costs are often the same to refresh as to replace.
- Mobilization is more efficient for larger projects.
- Traffic control is needed whether markings are being refreshed or replaced.

Several interviewed agencies using thermoplastic markings prefer to grind out the old markings rather than add new thermoplastic on top of the old. Reasons given are that the new thermoplastic is more easily damaged since it has a higher profile and that an agency has experienced problems with the new material not adhering properly to the old material. On the other hand, for cost reasons, one interviewed agency prefers to apply a new layer of thermoplastic on top of the old until the built-up material became a potential tripping hazard (typically after 3–4 applications) and needed to be replaced entirely.

8.3 MARKING DESIGN EFFECTS ON MAINTENANCE NEEDS

Agencies using crosswalk designs that place the markings outside the typical vehicle wheel path (e.g., longitudinal bar, double-paired) report that the markings lasted longer than with other designs. In addition, some interviewed agencies report that they could sometimes extend the life of a crosswalk by replacing only a single longitudinal bar that needs repair.

Across basic markings (top), tires consistently wear down the markings. Longitudinal bar markings (center) may be placed so the typical wheelbase does not impact markings. Perpendicular markings (bottom) may similarly be placed to avoid the most common tire tread path; even when vehicles do wear the transverse and longitudinal markings, more cumulative marking remains in place relative to other patterns.

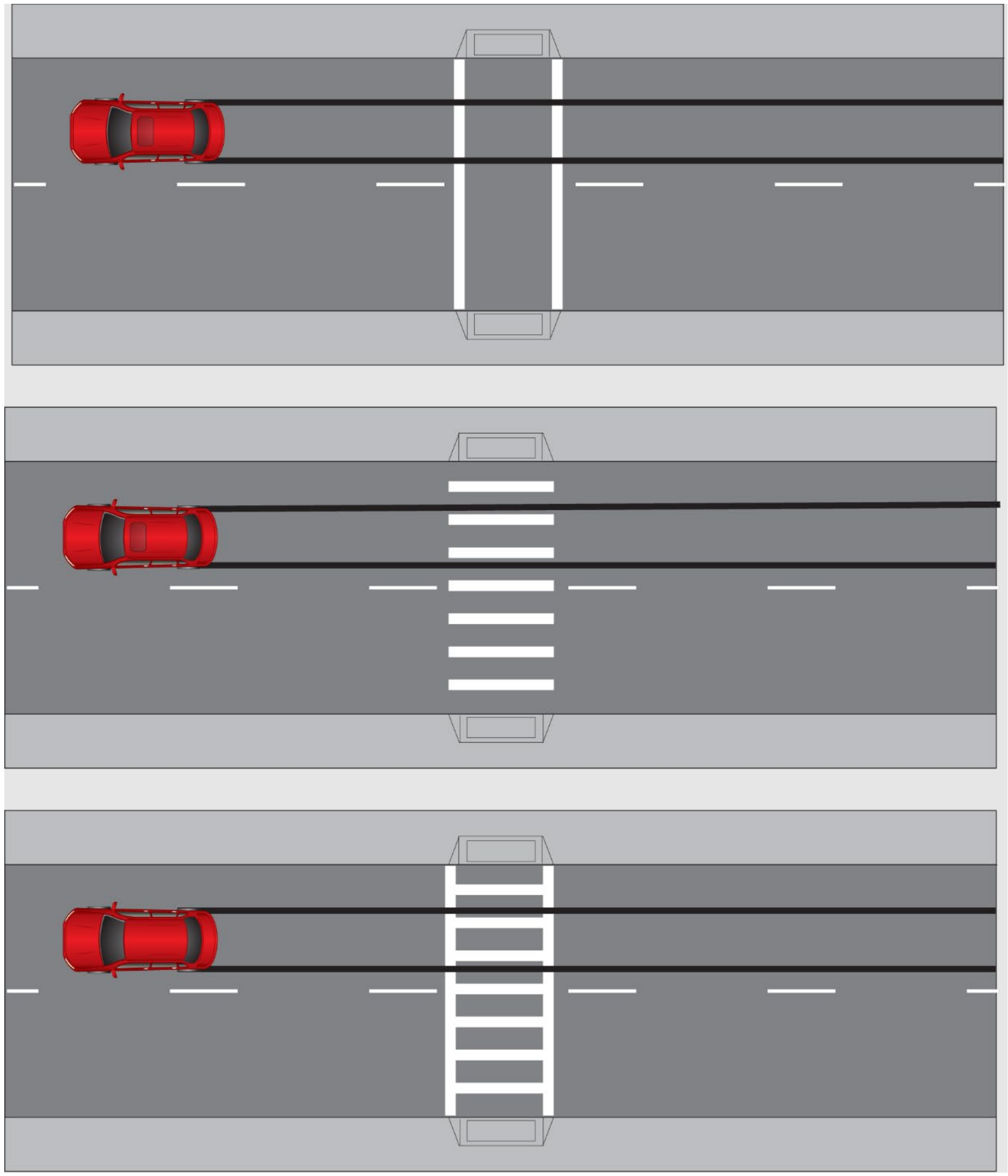


Figure 14: Tire tread in relation to crosswalk markings.

8.4 RECOMMENDATIONS

Inspecting crosswalks and crosswalk markings on a regular schedule (e.g., annually) helps ensure that the crosswalk markings remain sufficiently visible under both daytime and nighttime conditions, that the markings do not become too slippery as they wear, and that pavement defects do not create hazards for pedestrians using the crosswalk. Alternatively, if an agency has established an asset management program, crosswalk marking maintenance can be included in the program, taking advantage of agency staff experience with the durability of different marking materials in various conditions.

Staff observations and public input can supplement these methods, but it is not recommended to rely solely on responding to complaints—some neighborhoods and communities may be more vocal than others, which can lead to an inequitable distribution of maintenance work and can mean that some crosswalks requiring maintenance are not brought to the agency's attention.

It is often as cost-effective to replace markings as it is to refresh them. As discussed in Section 9 , labor costs for traffic control, grinding out old markings (if needed), and installing new markings are typically the biggest components of the overall project cost. In addition, unit costs of materials are lower when materials are purchased in greater quantities. By matching the initial marking material's durability to the site conditions, as discussed in Section 8, agencies can reduce the frequency at which the markings need to be refreshed or replaced. If a roadway is scheduled to be resurfaced within 1–2 years, using paint instead of more expensive marking materials to refresh a crossing is typically a more cost-effective option to maintain the markings until they are replaced as part of the resurfacing project.

Crosswalk markings are anecdotally reported to last longer when designs incorporating longitudinal elements are used because the markings can be placed outside the typical vehicle wheel path and, thus, experience less wear over a given period.

8.5 SUMMARY

- Regularly scheduling inspections or using an asset management system are two good options for maintaining crosswalk visibility.
- Staff observations and public input are supplemental means of identifying crosswalk markings that require maintenance sooner than expected. However, relying solely on complaints can lead to an inequitable distribution of maintenance work and reduced agency awareness of crosswalks requiring maintenance.
- Replacing markings can be as cost-effective as refreshing them.
- Designs incorporating longitudinal elements (e.g., longitudinal bar, double-paired) can place the markings outside typical vehicle paths to improve the markings' longevity.

Section 9. What are the cost tradeoffs?

9.1 INSTALLATION COSTS

Compared to longitudinal pavement markings (e.g., edge lines), which can be applied by a striping truck, crosswalk markings are more labor-intensive and expensive per unit length to install. The cost to install a crosswalk depends on several factors, including:

- **Traffic control.** Traffic needs to be directed around the worksite while the markings are being installed and must be adjusted during the work (one side of the crossing is marked first, and then the other side). Agencies interviewed while preparing this guide commented that traffic control was usually the most expensive component of a project. Traffic control for crosswalks at traffic signals and roundabouts was reported to be more complicated (thus more expensive) than traffic control at other sites.
- **Removing old markings.** As discussed in Section 8 , some agencies require that old thermoplastic be ground out and removed before installing new thermoplastic. One agency stated that this cost accounted for approximately one-quarter of the total project cost.
- **Labor to install the new markings.** Labor costs, overall, are a bigger component of the total crosswalk project cost than materials costs.
- **Material used for marking.** Depending on the jurisdiction, durable and higher-performance materials were reported to cost two to eight times more per unit length or area than non-durable material.
- **Crosswalk length and width.** The longer the crosswalk, the more material is required. The longitudinal markings used by HVC designs also require more material as the crosswalk width increases.
- **Marking pattern.** The marking pattern can affect the volume of material required (e.g., 2 parallel 8-inch lines versus multiple longitudinal 24-inch lines). In addition, HVC designs require more labor to position the markings correctly than do basic transverse markings.
- **Marking height.** Profiled and recessed markings cost more to apply than surface markings.

Installation costs also depend on the project scale. For example, unit costs of materials are usually lower when purchased in larger quantities. Other costs, such as traffic control, are lower when shared with the needs of a larger project, such as a repaving project.

Given all these variables, it is difficult to provide exact cost estimates for installing crosswalk markings. However, Table 3 provides comparative installation costs of basic and HVC markings.

Table 3. Comparative Crosswalk Installation Costs

Crosswalk Type	Median Cost	Average Cost	Minimum Cost	Maximum Cost	Cost Unit	Number of Sources
High Visibility	$3,692	$3,054	$721	$6,866	Each	4
Basic	$409	$926	$132	$2,513	Each	8

Source: UNC Highway Safety Research Center. Costs have been adjusted to 2020 U.S. dollars using the National Highway Construction Cost Index. (48)

Consistent with Table 3, the two interviewed agencies that were able to provide comparative costs of basic and high-visibility crosswalks using the same marking material indicated that an HVC cost three to four times as much to install as a basic crossing. The HVC used about 50 percent more marking material, with the remaining cost difference attributable to the extra labor time required to lay out the HVC markings and for traffic control during that time.

The costs in Table 3 present relatively wide ranges. However, simply considering the average cost difference of $1,770 per crosswalk marking ($7,080 per four-leg intersection), the cost difference has the potential to become significant when summed across a jurisdiction’s marked crossing locations. From this perspective, a life-cycle cost analysis may make the difference in determining whether HVCs are more cost-effective.

9.2 MAINTENANCE COSTS

Agencies interviewed while preparing this guide generally agreed that it cost as much to refresh a crosswalk as it costs to replace or install it, primarily because of the mobilization, traffic control, and other labor costs involved. From a life-cycle viewpoint, therefore, using durable materials will reduce the number of times a crosswalk will need to be refreshed, or, depending on how frequently resurfacing occurs, may eliminate the need to refresh the crosswalk before the next time it needs to be replaced.

No research is available to quantify the effect of longitudinal crosswalk markings on reducing the need for maintenance, but agencies interviewed while developing this guide report anecdotally that longitudinal bar and double-paired designs require less maintenance than basic markings.

9.3 LIFE-CYCLE COSTS

The life-cycle cost of marking a crosswalk is driven in large part by the cost to install the crosswalk initially and the number of times the crosswalk will need to be refreshed before the next time it is replaced. The latter is a function of the pavement marking's durability and how frequently pavement resurfacing occurs. Other costs to potentially consider include:

- **Initial equipment costs.** Marking materials that need to be melted or mixed from multiple components entail costs to purchase and maintain the special equipment used.
- **Traffic delay.** The less frequently that the markings need to be refreshed or replaced, the lower the delay incurred by traffic. The amount of delay will depend both on the roadway AADT and the time of day when marking activity occurs (i.e., lower volumes at night than during the day) (45).

9.4 SUMMARY

- Many factors influence crosswalk marking costs, with labor time being the largest cost component.
- Installation costs are typically lower when crosswalk marking is part of a larger roadway resurfacing project.
- Durable marking materials cost considerably more than non-durable materials but do not need to be applied as frequently.
- A life-cycle analysis may be needed to determine whether HVCs are more cost-effective than basic crosswalks at a given location.

Section 10. **References**

1. National Committee on Uniform Traffic Laws and Ordinances. *Uniform Vehicle Code.* 2000.

2. Matthiesen, Wickert & Lehrer, S. C. *Pedestrian and Crosswalk Laws in All 50 States.* https://www.mwl-law.com/wp-content/uploads/2018/10/PEDESTRIAN-AND-CROSSWALKS-50-STATE-CHART.pdf. Updated January 5, 2021.
3. Thornton, Christina M., et al. "Disparities in pedestrian streetscape environments by income and race/ethnicity." *SSM-population health* 2 (2016): 206-216.
4. Federal Highway Administration. *Manual on Uniform Traffic Control Devices for Streets and Highways.* Section 1A.02(02). Washington, D.C., 2009.
5. IPUMS NHIS database: Blewett, L. A., Rivera Drew, J. A., King, M. L., and Williams, K. C. (2019). IPUMS health surveys: National Health Interview Survey (Version 6.4) [dataset]. https://doi.org/10.18128/D070.V6.4
6. Conversation with international accessibility experts Janet Barlow and Dr. Beezy Bentzen with Accessible Design for the Blind. June 2021
7. U.S. Department of Justice, 2010.
8. California Department of Transportation. *2014 California Manual on Uniform Traffic Control Devices,* Revision 6. Section 3B.18(25–26). Sacramento, revised 2021.
9. National Committee on Uniform Traffic Control Devices. (2011). Attachment No.3 Section 3B.18
10. Federal Highway Administration. National Standards for Traffic Control Devices; the Manual on Uniform Traffic Control Devices for Streets and Highways; Revision. Proposed rule; notice of proposed amendments (NPA). *Federal Register,* December 14, 2020, pp. 80898–80979.
11. FHWA. Manual on Uniform Traffic Control Devices. 2009 edition. “Interpretation Letter 3(09)-24(I) – Application of Colored Pavement” Available: https://mutcd.fhwa.dot.gov/resources/interpretations/3_09_24.htm, last accessed November 2019.
12. FHWA. Manual on Uniform Traffic Control Devices. 2009 Edition. “Frequently Asked Questions.” Available: https://mutcd.fhwa.dot.gov/knowledge/faqs/faq_part3.htm#cpq4, last accessed November 2019.

13. Zegeer, C.V., J.R. Stewart, H.H. Huang, P.A. Lagerwey, J. Feaganes, and B.J. Campbell. *Safety Effects of Marked versus Unmarked Crosswalks at Uncontrolled Locations: Final Report and Recommended Guidelines*. Federal Highway Administration, Washington, D.C., August 2005.
14. Sørensen, M. W. J., and T. Loftsgarden. Tiltak for fotgjengere og kollektivtrafikk i bykryss — Internasjonale erfariner og effektstudier (Measures for pedestrians and public transport in city intersections — International experiences and evaluation studies). Institute of Transport Economics, Oslo, Norway, 2010.
15. United Nations. *Convention on Road Traffic, Vienna, 8 November 1968*. https://treaties.un.org/doc/Treaties/1977/05/19770524%2000-13%20AM/Ch_XI_B_19.pdf. Accessed June 4, 2021.
16. Project literature review.
17. Transportation Research Board. *Highway Capacity Manual,* 6th Edition, version 6.1. Exhibit 20-28, Effect of Pedestrian Crossing Treatments on Motorist Yield Rates. Washington, D.C., in publication 2021.
18. Bertulis, T., and Dulaski, D. M. "Driver approach speed and its impact on driver yielding to pedestrian behavior at unsignalized crosswalks." *Transportation Research Record*, *2464*(1), 46-51.2014.
19. 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 the 87th Annual Meeting of the Transportation Research Board, Washington, DC. 2008.
20. Nitzburg, M., and R. Knoblauch. An Evaluation of High-Visibility Crosswalk Treatments—Clearwater, Florida. Publication FHWA-RD-00-105, Federal Highway Administration. 2001. http://www.fhwa.dot.gov/publications/research/safety/pedbike/0105.pdf.
21. Goddard, T., K.B. Kahn, and A. Adkins. "Racial Bias in Driver Yielding Behavior at Crosswalks." *Transportation Research Part F: Traffic Psychology and Behaviour*, Vol. 33, pp. 1–6, 2015.
22. Kahn, K., J. McMahon, T. Goddard, and A. Adkins. Racial Bias in Drivers' Yielding Behavior at Crosswalks: Understanding the Effect. Report NITC-RR-869. Transportation Research and Education Center (TREC), Portland, OR, 2017.
23. Coughenour, C., S. Clark, A. Singh, E. Claw, J. Abelar, and J. Huebner. "Examining racial bias as a potential factor in pedestrian crashes." Accident Analysis & Prevention, Vol. 98, pp. 96–100, 2017.
24. Piffa, P.K., D.M. Stancatoa, S. Côtéb, R. Mendoza-Dentona, and D. Keltnera. "Higher social class predicts increased unethical behavior." Proceedings of the National Academy of Sciences, Vol. 109, No. 11, pp. 4086–4091, 2012.

25. Rosenbloom, T., D. Nemrodov, and A.B. Eliyahu. "Yielding Behavior of Israeli Drivers: Interaction of Age and Sex." Perceptual and Motor Skills, Vol. 103, Issue 2, pp. 387–390, 2006.
26. Fitzpatrick, K., S.T. Chrysler, V. Iragavarapu, and E.S. Park. Crosswalk Marking Field Visibility Study. Publication FHWA-HRT-10-068. Federal Highway Administration. November 2010.
27. Chen, L., Chen, C., Ewing, R., McKnight, C. E., Srinivasan, R., & Roe, M. "Safety countermeasures and crash reduction in New York City—Experience and lessons learned." Accident Analysis & Prevention, 50, 312-322. 2013.
28. Feldman, M., Manzi, J. G., & Mitman, M. F. "Empirical Bayesian evaluation of safety effects of high-visibility school (yellow) crosswalks in San Francisco, California." Transportation Research Record, 2198(1), 8-14. 2010.
29. Fitzpatrick, K., S. Turner, M. Brewer, P.C. Carlson, B. Ullman, N. Trout, E.S. Park, J. Whitacre, N. Lalani, and D. Lord. TCRP Report 112/NCHRP Report 562: Improving Pedestrian Safety at Unsignalized Crossings. Transportation Research Board, Washington, D.C., 2006.
30. Schroeder, Bastian, et al. Empirically-based performance assessment & simulation of pedestrian behavior at unsignalized crossings. No. 2012-016S. Southeastern Transportation Research, Innovation, Development and Education Center (STRIDE), 2014.
31. Schroeder, Bastian J., and Nagui M. Rouphail. "Event-based modeling of driver yielding behavior at unsignalized crosswalks." Journal of transportation engineering 137.7 (2011): 455-465.
32. NCUTCD. Crosswalk Markings. National Committee on Uniform Traffic Control Devices. Attachment No. 3, June 23, 2011. https://ncutcd.org/wp-content/uploads/meetings/2011B/Attach-No.-3-Markings-Sec.-3B.18-Apprvd-6-23-11.pdf
33. NCUTCD. Crosswalk Markings Application Criteria. National Committee on Uniform Traffic Control Devices. Attachment No. 12, January 19, 2012. https://ncutcd.org/wp-content/uploads/meetings/2012A/Attach-No.-12-Markings-No.2-Section-3B.18.pdf
34. Blackburn, L., C.V. Zegeer, and K. Brookshire. Guide for Improving Pedestrian Safety at Uncontrolled Crossing Locations. Federal Highway Administration, Washington, D.C., July 2017.
35. NACTO. Urban Street Design Guide. "Conventional Crosswalks." National Association of City Transportation Officials, New York. 2013.
36. Fitzpatrick, K., S. Turner, M. Brewer, P.C. Carlson, B. Ullman, N. Trout, E.S. Park, J. Whitacre, N. Lalani, D. Lord. NCHRP 562: Improving

Pedestrian Safety at Unsignalized Crossings. Transportation Research Board. 2006.

37. Braun, Lindsay M., Daniel A. Rodriguez, and Penny Gordon-Larsen. "Social (in) equity in access to cycling infrastructure: Cross-sectional associations between bike lanes and area-level sociodemographic characteristics in 22 large US cities." Journal of transport geography 80 (2019).
38. Moran, M. E. (2022). Where the Crosswalk Ends: Mapping Crosswalk Coverage via Satellite Imagery in San Francisco. UC Berkeley: Institute of Transportation Studies at UC Berkeley. Retrieved from https://escholarship.org/uc/item/67447864
39. Bellis, Rayla, et al. Dangerous by Design 2021. Smart Growth America, National Complete Streets Coalition. 2021.
40. Zegeer, C., Lyon, C., Srinivasan, R., Persaud, B., Lan, B., Smith, S., Carter, D. et al. (2017). NCHRP Report 841: Development of Crash Modification Factors for Uncontrolled Pedestrian Crossing Treatments. Transportation Research Board.
41. Pulugurtha, S.S., V. Vasudevan, S.S. Nambisan, and M.R. Dangeti. "Evaluating the Effectiveness of Infrastructure-Based Countermeasures for Pedestrian Safety." Transportation Research Record: Journal of the Transportation Research Board, No. 2299, pp.100-109. Transportation Research Board. 2012.
42. Fayyaz, K., Galvez de Leon, P., Schultz, G. G. (2019). Driver Compliance at Enhanced Pedestrian Crossings in Utah (Report No. UT-19.03). Salt Lake City, UT: Utah Department of Transportation Research & Innovation Division.
43. Morris, N.L., Craig, C. M., Van Houten, R. (2019) Evaluation of Sustained Enforcement, Education, and Engineering Measures on Pedestrian Crossings (Report No. MN/RC 2019-29). University of Minnesota, Twin Cities, Minnesota: Minnesota Department of Transportation. Available: http://www.dot.state.mn.us/research/reports/2019/201929.pdf, last accessed November 2019.
44. Oregon Department of Transportation. Pavement Marking Design Guidelines. Delivery & Operations Division, Salem, March 2021.
45. Migletz, J., and J. Graham. NCHRP Synthesis 306: Long-Term Pavement Marking Practices. Transportation Research Board, Washington, D.C., 2002.
46. Minnesota Department of Transportation. MnDOT Provisions for Pavement Marking Operations. Technical Memorandum No. 19-05-T-022019. St. Paul, December 2019.

47. Huber, T., K. Luecke, M. Hintze, V. Coffman, J. Toole, and M. VanOosten. A Guide for Maintaining Pedestrian Facilities for Enhanced Safety. Report FHWA-SA-13-037. Federal Highway Administration, Washington, D.C., October 2013.
48. Bushell, M.A., B.W. Poole, C.V. Zegeer, and D.A: Rodriguez, Daniel A. Costs for Pedestrian and Bicyclist Infrastructure Improvements: A Resource for Researchers, Engineers, Planners, and the General Public. UNC Highway Safety Research Center, Chapel Hill, NC, 2013.

Appendix A Data Collection and Analysis Details