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Developing Guidelines for Context Specific Crosswalk Design

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16. Abstract:

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The first stage of this study involved a literature review to establish known contexts of HVC effectiveness. Research found that HVCs have a positive impact on numerous measures of effectiveness (detection distance, pedestrian compliance, driver speed, acceleration, braking, and yielding). HVC studies are typically limited to lower speed midblock crossings and uncontrolled intersections and often include limited sites or timeframes. Surrogate safety measures capture near misses between road users and were identified as a measure of effectiveness that may be used to quickly gather larger datasets at signalized intersections. Based on the literature review, this study recommends no changes to the current guidance regarding HVCs in IIM-TE-384.1 because the available research supports HVC effectiveness under the contexts described.

In the second stage of this project, a survey was distributed to Virginia localities to understand how crosswalk marking application varies statewide, documenting the differences between VDOT and locality practices. The survey found that many localities were familiar with or reported following VDOT crosswalk standards. Many localities have markings currently in place that would be remarked as HVCs if they were painted today, reflecting a movement toward HVCs consistent with existing research and VDOT guidance. The types of crosswalks used across different environments also varied significantly statewide. Notably, bar pair HVCs, VDOT's recommended HVC marking type, were infrequently used. Based on the lack of bar pair crosswalks statewide, this study recommends further research on the lack of application.

The final stage of this study involved real-world data collection of pedestrian and vehicle near-miss data at urban signalized intersections with HVCs and transverse crosswalk markings through surrogate safety measures. Two statistical analyses were performed: the first assessed the rate of vehicle-pedestrian near misses, and the second analyzed the severity of vehicle-pedestrian near misses. HVCs were not found to affect the rate or severity of near misses at urban, high-speed, high-volume, signalized intersections. Results suggested nighttime hours increased the rate of near misses under these roadway conditions. Furthermore, right turning vehicles and higher pedestrian speeds were associated with lower post-encroachment time values, indicative of more severe near-miss interactions. This study recommends no changes to the current guidance to use engineering judgment regarding HVCs at signalized intersections in IIM-TOD-400. The literature review provides some evidence of improved pedestrian compliance at signalized intersections with HVCs. However, most studies do not include signalized intersections, and the current analysis of signalized intersections does not find evidence to support a change in the current guidance.

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FINAL REPORT

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ABSTRACT

Crosswalks can be marked as either transverse or high-visibility crosswalks (HVCs). The Virginia Department of Transportation (VDOT) mandates HVCs at marked crosswalks at all unsignalized crossings, roundabouts, and pedestrian hybrid beacons, except on stop-controlled approaches, as IIM-TE-384.1 describes. At signalized intersections, marking type is left to engineering judgment per IIM-TOD-400. VDOT is responsible for the routine maintenance of a large crosswalk inventory. As HVCs have higher costs than transverse crosswalks, appropriate deployment is important. This report summarizes existing research regarding the contexts in which HVCs are effective, a survey of crosswalk marking practices in Virginia localities, and a study of HVCs and transverse crosswalks on Virginia roads at signalized intersections.

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INTRODUCTION

Crosswalks are a component of pedestrian infrastructure often provided at intersections and midblock locations. In the United States, all crosswalks serve as designated locations where other road users are required to yield the right-of-way to pedestrians crossing the street. Marked crosswalks can be subdivided into two types: transverse crosswalks and high-visibility crosswalks (HVCs), as Figure 1 shows. The literature lacks consistency on the nomenclature for longitudinal and continental crosswalks, so this report will refer to them as longitudinal crosswalks hereafter. Similarly, transverse crosswalks are sometimes referred to as standard or parallel crosswalks in the literature but will be referred to as transverse crosswalks throughout this report.

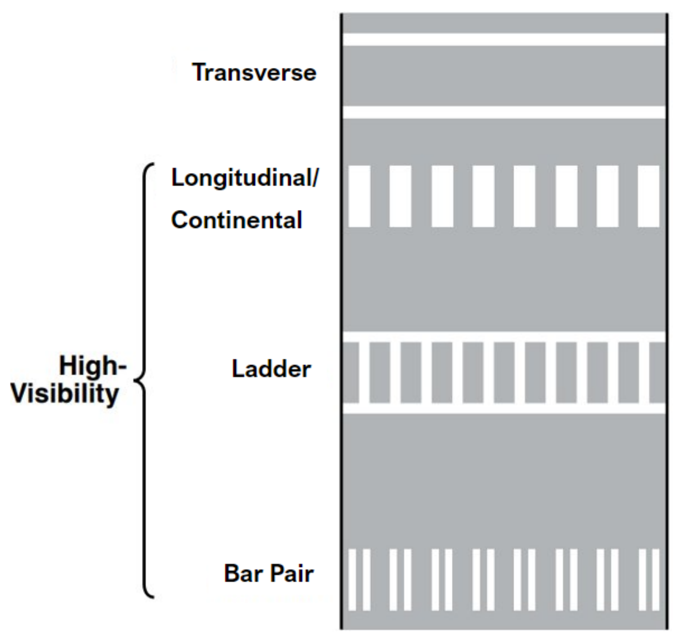

Figure 1. Figure of Transverse and High-Visibility Crosswalks, adapted from the *Manual on Uniform Traffic Control Devices for Streets and Highways* (Federal Highway Administration, 2023)

Crosswalks provide safety benefits for pedestrians by designating a crossing location and indicating to drivers the potential presence of pedestrians. Research shows that the type of crosswalk marking may affect safety metrics. However, the effectiveness of individual marking types is under researched and focuses on midblock crossings or uncontrolled intersections on low-speed roads (Fitzpatrick et al., 2010; Schroeder et al., 2023). Understanding how crosswalk marking type effectiveness varies in different roadway contexts is needed. This nuance is important to understand because HVCs are more expensive than transverse crosswalks, and the Virginia Department of Transportation (VDOT) has a large inventory of crosswalks that require routine maintenance. According to VDOT estimates, HVCs cost $8 per linear foot, approximately five times the cost of transverse crosswalks (VDOT, n.d.). Refreshing crosswalk markings is necessary because crosswalks with faded markings may not provide the same safety benefit as those that are in good condition. The additional cost of HVCs multiplies over time as they are maintained. This report will increase the understanding of the contexts in which HVCs are effective.

PURPOSE AND SCOPE

The purpose of this project was to assess the effectiveness of HVCs in different contexts through literature and real-world data collection. This objective allowed the researchers to determine whether data-driven support was available for VDOT crosswalk marking guidance and if any changes to existing guidance (IIM-TE-384.1 and IIM-TOD-400) were warranted (VDOT, 2022, 2024). The implication of the existing guidance is important because of the higher cost of HVCs, the large inventory of crosswalks managed by VDOT, and the routine maintenance required. This study does not address whether a crosswalk should or should not be marked, focusing instead on the effects of marking types in different contexts where crosswalks already exist. In addition, the scope included only crosswalks with markings in good condition.

METHODOLOGY

Overview

The researchers undertook several tasks to meet the project objectives. In the first task, the literature review established known contexts in which HVCs are effective and highlighted the contexts in which HVCs have not been evaluated. In the second task, a statewide survey assessed crosswalk marking practices in localities and compared them with typical VDOT practices. The final three tasks involved analyzing transverse crosswalks and HVCs to determine the contextual effects on crosswalk performance. The following sections describe the individual tasks in more detail:

1. Literature review.
2. Statewide survey of high-visibility crosswalk implementation practices.
3. Select characteristics of interest.
4. Crosswalk location identification.

5. Crosswalk data collection.
6. Crosswalk data analysis.

Literature Review

The literature related to crosswalk safety effectiveness in different locations (environmental context), effectiveness between marking types (transverse and high visibility), and life-cycle costs was reviewed. This endeavor informed the selection of crosswalk characteristics in Task 3, particularly the selection of location and type of traffic control. In addition, safety surrogate measures (SSMs) applicable to pedestrians were reviewed; SSMs help identify traffic conflicts other than crashes. Furthermore, the feasibility of SSM data collection via video cameras were reviewed. Finally, any literature on crosswalk material degradation and effectiveness was reviewed to help guide crosswalk selection. Search engines such as Google Scholar and Transport Research International Documentation were used to complete this task.

Statewide Survey of High-Visibility Crosswalk Implementation Practices

This step involved designing and disseminating a survey to Virginia localities operating their own roads to understand whether the current guidelines at the time of the survey—that is, VDOT HVC guidelines (IIM-TE-384.1 and IIM-TOD-400)—are known, followed, and if followed, how closely (VDOT, 2022, 2024). Questions were also asked regarding the types of crosswalk markings present at locations with different traffic control devices. Localities were also asked about the materials used for painting crosswalk markings and the factors affecting decisions on when to refresh markings. The full survey can be found in the Appendix.

Select Characteristics of Interest

Findings from the literature review were used to help identify characteristics that may affect pedestrian and vehicle interactions and could feasibly be collected from a large sample of sites (Table 1). The characteristics in Table 1 were noted as variables of interest for each site.

Crosswalk Location Identification

Data collection for this study focused on comparable transverse crosswalks and HVCs at signalized four-leg intersections. The objective was to identify signalized intersections with a four-lane major road and where transverse crosswalks and HVCs were in proximity to each other. Larger signalized intersections were selected as the focus of this study based on VDOT interest and the focus in the existing literature on crosswalk effectiveness on lower speed, lower volume roads. The characteristics in Table 1 were used to identify sites with similar geometric and land use characteristics. Google Maps and Google Earth Pro were initially used to identify 30 such locations. Pedestrian activity data and signal timing plans of the intersections were requested from the corresponding localities. Pedestrian activity data included pedestrian count data and pedestrian phase actuation data, depending on what was available at the site. The pedestrian activity data were cleaned and restructured to obtain estimates of the number of pedestrians per day at each intersection. Based on the approximate pedestrian counts per day, the 30 crosswalks were ranked from high to low pedestrian activity. Sites with relatively low pedestrian activity were excluded from consideration because they were not expected to yield sufficient pedestrian and vehicle interactions for near-miss analysis. Visits were then made to the remaining sites to verify whether the crosswalk markings were in acceptable condition and if the marking type was consistent with Google Maps and Google Earth images. Based on the site visits and the pedestrian activity data, six intersections were chosen for further analysis (Table 2).

Table 1. Site Characteristics Collected to Aid in Site Selection

Type of Roadway Characteristic	List of Characteristics
Intersection Specific	Traffic volume
	Number of traffic lanes (through and turning lanes)
	Presence of protected left turns
	Presence of no right turn on red
	Posted speed limit (mph)
	Presence of refuge island
	Presence of bike lanes
	Length of crosswalk (feet)
	Presence of near- and far-side and mid-block bus stops with respect to crosswalk location
	Intersection skew angle (degrees)
Land Use Type Present (within 250 feet of crosswalk)	Retail establishments
	Service establishments
	Residential establishments
	Recreational establishments
	Educational institutes
	Gas station/convenience stores
	Restaurants/bars
	On-street parking
	Parking lot

Table 2. Study Intersections and Crosswalk Marking Type

Intersection	Crosswalk Marking Type	Lane Configuration of Major Road
Braddock Road and Roanoke River Road	Longitudinal High-Visibility Crosswalk	TTT,LTTR and TT,LTTR
Braddock Road and Ox Road	Ladder High-Visibility Crosswalk	TT,LTTR and TT,LLTTR
Little River Turnpike and Backlick Road	Longitudinal High-Visibility Crosswalk	TT,LTT and TT,LTTR
Westpark Drive and Jones Branch Drive	Transverse	TT,LTT and TT,LTT
Westpark Drive and Park Run Drive	Transverse	TT,LTT and TT,LTT
Gallows Road and Boone Boulevard	Transverse	TT,LTT and TT,LTT

L = left turn lane; R = right turn lane; T = through lane.

Crosswalk Data Collection

A vendor specialized in using video data to compute safety analytics of road users, Street Simplified, carried out the data collection for this study. The vendor set up high-definition cameras at each intersection at suitable angles to allow all pedestrian-vehicle interactions to be captured. Video data were simultaneously collected at all six intersections from March 12, 2026, through March 18, 2026, capturing all hours of the day. The vendor then processed the video data using computer vision analysis to identify near-miss interactions between pedestrians and vehicles at the crosswalks of the intersection. The SSM used by the vendor was post-encroachment time (PET), which is a time-based SSM. PET quantifies the time between one road user departing a location and a second road user arriving at that location (Allen et al., 1978).

$$\mathbf{PET} = \mathbf{t_2} - \mathbf{t_1}.$$
$$\mathbf{t_1} = \textbf{time when the first road user reaches the potential conflict point}.$$
$$\mathbf{t_2} = \textbf{time when the second road user reaches the potential conflict point}.$$

Along with the PET values of each near-miss interaction, the vendor also provided other relevant data: timestamps of each near-miss event, the type of vehicle involved in the near miss (e.g., car, truck, bus, motorcycle), the type of vehicle movement (through and right or left turns), the instantaneous speeds of pedestrians and vehicles as they passed through the conflict area, and counts of the pedestrians and vehicles detected at the study sites in 15-minute intervals throughout the period of data collection.

Crosswalk Data Analysis

Several methods were used to analyze the near-miss data from the six study sites. For context, pedestrian crash data for the sites were collected and reviewed. Summary statistics were calculated for the crash data, intersection characteristics, and the pedestrian-vehicle near-miss events.

The near-miss event data were further analyzed in two phases. First, the rate of near-miss events was modeled for each hour at all 12 crosswalks across the six study intersections, identifying any characteristics that contribute to the rate of near-miss events. The distribution of near-miss frequency by hour during the 1-week data collection period contains hours in which no near misses occur, which may be managed by considering zero-inflated modeling techniques. The near-miss count at each crosswalk-hour was modeled using a zero-inflated negative binomial regression with a random intercept for each crosswalk. The random intercept accounts for the fact that crosswalks differ systematically in their baseline near-miss rates independent of the measured predictors, with an estimated between-crosswalk variance of 9.49 (standard deviation = 3.08). The model has two components. The first is a zero-inflated component that distinguishes hours during which a near miss was structurally impossible (e.g., no pedestrian activity) from hours during which conflicts could occur, using time of day, lighting, and crosswalk markings as predictors. The second is a count component that estimates the expected number of near misses in active intervals, controlling for pedestrian and vehicle exposure through log-transformed offsets and including time of day, vehicle turning movements, and crosswalk geometry as predictors. The negative binomial distribution was selected over Poisson to account for overdispersion (variance/mean ratio = 10.3), and the zero-inflated structure was confirmed by a Vuong test ($z = 8.72$, $p < 2.2e^{-16}$).

Furthermore, an analysis of the PET values for near misses at the 12 crosswalks at the six study intersections was performed to determine near-miss and site characteristics that contribute to the severity of a near-miss interaction. A gamma generalized linear model was selected to estimate the relationship between independent variables and PET values because the PET distribution is non-normal, negatively skewed, and strictly positive. Spearman, point-biserial, and chi-square tests were used to examine correlations between continuous variables, binary and continuous variables, and categorical variables, respectively. The variance inflation factor was computed, and variables with high multicollinearity were removed from consideration in the model.

RESULTS AND DISCUSSION

Literature Review

High-Visibility and Transverse Crosswalks

Research suggests that HVCs may be detected further upstream (Fitzpatrick et al., 2010), may improve driver behavior (increased distance from the crosswalk when yielding) and pedestrian behavior (looking before crossing) (Pulugurtha et al., 2012), reduce driver speed (Pantangi et al., 2021; Sarwar et al., 2017), reduce driver acceleration (Pantangi et al., 2021), increase the likelihood of driver braking (Sarwar et al., 2017), and increase driver yielding (O'Brien et al., 2022) under the contexts defined in each respective study. O'Brien et al. (2022) also found that increased saturation of HVCs does not appear to reduce effectiveness. The following paragraphs describe each study in detail.

A Federal Highway Administration (FHWA) report from 2010 studied how far upstream participants could discern transverse, longitudinal, and bar pair crosswalks (Fitzpatrick et al., 2010). Daytime and nighttime sessions were conducted, and participants followed a route where they encountered 17 crosswalks at midblock, unsignalized, and signalized locations, where all speed limits were between 30 and 45 mph. The detection distance of longitudinal crosswalks was about twice that of transverse crosswalks at midblock crossings, a statistically significant finding. Longitudinal crosswalks were detected about 350 feet further upstream than transverse crosswalks at midblock crossings. At 30 mph, this equates to identifying longitudinal crosswalks 8 seconds earlier than transverse crosswalks. At intersections, the difference between detection distances of longitudinal and transverse crosswalks was not statistically different. This finding was based on six intersections, a sample that included five stop-controlled intersections and one signalized intersection. All intersections had transverse crosswalks except one stop-controlled intersection that had longitudinal crosswalks. No signalized intersections with HVCs were studied.

A 2012 study in Las Vegas, Nevada, analyzed before-and-after data at locations that experienced various pedestrian improvements (Pulugurtha et al., 2012). At three locations, HVCs were deployed individually, without other infrastructure-based countermeasures. At these sites, a statistically significant increase was observed in pedestrians who looked for vehicles before crossing the road. In addition, a statistically significant increase in the distance between the crosswalk and drivers yielding to pedestrians was observed. These two measures of effectiveness constitute improved driver and pedestrian behavior upon HVC installation. Two of the sites were at intersections, and one was a midblock crossing. Speed limits on the roads were between 35 and 55 mph and had four to six lanes of traffic. Results did not separate findings between intersections and midblock crossings and did not describe traffic control at the intersections or crosswalk markings before HVC upgrades.

A study by Sarwar et al. (2017) used data from the Second Strategic Highway Research Program Naturalistic Driving Study (SHRP2 NDS). This study focused on three uncontrolled crossings in Erie, New York, with ladder-style HVCs. Two were at uncontrolled intersections, and one was midblock. A before-and-after analysis was performed at two of the locations, and speed, acceleration, brake application, and throttle pedal actuation were used as safety metrics. “Before” conditions were described as uncontrolled. Models found that HVCs decreased the throttle pedal actuation, increased the likelihood that speed reduction was statistically significant, and increased the likelihood that the brake was applied compared with the “before” condition.

Another study in 2021 made use of the SHRP2 NDS dataset to analyze HVC effectiveness (Pantangi et al., 2021). Midblock and end-of-block crosswalks in New York, Florida, Indiana, North Carolina, Pennsylvania, and Washington were selected for analysis. Speed limits at the sites varied between 25 and 40 mph. Data before and after the installation of HVC crosswalks were analyzed, and HVC types included ladder, bar pair, and longitudinal. Key findings included that HVC presence reduced speed, acceleration, and throttle pedal actuation between the HVC location and an upstream benchmark location. Traffic control at end-of-block crosswalks (presumably intersections) was not described in the study, nor were the “before” conditions of the crosswalk—that is, transverse or unmarked.

A 2022 study in North Carolina analyzed vehicle yielding rates and pedestrian compliance rates at sites in three localities (O’Brien et al., 2022). The “before” data included uncontrolled and signalized sites with unmarked, transverse, and longitudinal crosswalk markings. A portion of the unmarked and transverse sites were converted to HVC markings and additional data were collected. The analysis found a statistically significant increase in yielding rates and pedestrian compliance at sites where unmarked or transverse crosswalks were converted to HVCs. The increase in yielding rates was not significant at signalized intersections. The study notes that this result may have been due to most of the signalized sites being in a locality with higher overall yielding rates compared with the other localities studied. The increase in pedestrian compliance (whether the pedestrian crossed at the crosswalk rather than outside it) was statistically significant at signalized intersections. This study provides some support for HVC use at signalized intersections based on improved pedestrian compliance.

The FHWA report, *Crosswalk Marking Selection Guide* (Schroeder et al., 2023), comprehensively compared HVCs and transverse crosswalks on low-speed, low-volume roads on the uncontrolled leg of two-way, stop-controlled intersections on undivided two-lane roads. Using a staged pedestrian (a white, adult male), the results showed higher yielding at HVC sites (54% versus 40%), yielding inversely correlated with driver speed, and HVCs no more effective than transverse crosswalks at higher speeds. Above 30 mph, crosswalks alone become insufficient, and yielding rates fall precipitously. Based on these findings, the study recommends HVCs at all uncontrolled crossings. The FHWA study was comprehensive for low-volume, low-speed roads, but the conclusions may not be applicable to higher volume, higher speed roads; more diverse pedestrian populations; controlled crossings; or midblock crossings.

The FHWA report also discussed the costs of HVCs and transverse crosswalks (Schroeder et al., 2023). The installation cost of any type of crosswalk marking is contingent on multiple factors, such as the type of traffic control present at the site, because some agencies reported signalized locations and roundabouts being more expensive than unsignalized sites. Installation costs can vary depending on whether old markings need to be removed. Labor costs are also a major component of the total installation cost of any crosswalk marking type. Other factors that affect installation cost include the type of material being used (durable materials cost more than non-durable materials) and the height of the markings (e.g., profiling and recessing markings increase the cost of installation). In addition, the length and width of the crosswalk markings also affect installation costs, with longitudinal crosswalk markings costing more than transverse markings because of the increase in material needed. HVC marking patterns may also be more expensive than transverse markings because the design of HVC requires more labor to accurately place the markings. Two interviewed agencies reported that HVC markings may cost three to four times as much to install than a transverse marking. In terms of maintenance costs, not enough research was available to quantify whether longitudinal markings require less maintenance, but some interviewed agencies anecdotally mentioned that longitudinal bar and double-paired markings may need less maintenance than transverse markings.

As described previously, limited understanding exists regarding HVC effectiveness at signalized intersections. Those studies that do include signalized intersections often aggregate results with uncontrolled intersections and rely on yielding rates as a measure of effectiveness.

VDOT IIM-TE-384.1 and IIM-TOD-400

Current VDOT standards require HVC markings at all uncontrolled crossings, whether midblock or intersection crossings, except on stop-controlled approaches, where engineering judgment may determine the need for an HVC (VDOT, 2022). HVCs are also required at roundabout crossings and at pedestrian hybrid beacon (PHB) crossings (VDOT, 2022). At signalized intersections, VDOT guidance is to use engineering judgment to choose marking types (VDOT, 2024). VDOT standards are only applicable to VDOT-maintained roads and do not apply to locality-maintained facilities, although localities may choose to follow them. IIM-TOD-400 provides some factors that may indicate when an HVC may be appropriate (VDOT, 2024). These factors include high pedestrian crossing volume, proximity to generators of vulnerable pedestrians, many drivers who are unfamiliar with the area, and limited visibility of the crosswalk for drivers of turning vehicles.

VDOT policy recommends using only longitudinal or bar pair HVC patterns, unless zebra or ladder patterns are necessary to match adjacent crosswalks, as evidence for any additional benefits of zebra or ladder patterns is lacking (VDOT, 2022). It should be noted that "zebra" is not a recognized crosswalk marking type by the *Manual on Uniform Traffic Control Devices for Streets and Highways* (MUTCD; FHWA, 2023: Figure 1). In addition, VDOT recommends the bar pair over longitudinal because it is easier for bicyclists and pedestrians to avoid the marked areas, which may be slippery when wet (VDOT, 2022). Bar pair and longitudinal crosswalks have similar installation costs; bar pair markings use less material but are slightly more complicated to install. This recommendation is supported by research that has shown the detection distance to longitudinal and bar pair markings to be statistically similar (Fitzpatrick et al., 2010).

Pedestrian Safety Research Methods

In addition to understanding the context in which HVCs and transverse crosswalk markings have been studied, it is necessary to understand how pedestrian crossing safety may be evaluated. A variety of variables affect crosswalk performance, including location (at signalized and unsignalized intersections or at midblock locations), type of marking (transverse or high visibility), crosswalk art, additional safety technologies (i.e., rectangular rapid flashing beacons [RRFBs], audio cues for the visually impaired), vehicle traffic volumes, presence of on-street parking, roadway geometry, lighting conditions, speed limit, and land use, among others. As pedestrians prepare to cross a road, they must often make decisions regarding which gaps in traffic streams, that is, headways between consecutive vehicles, to accept (Brewer et al., 2006). To study the effectiveness of pedestrian crossing facilities, researchers have often studied different forms of gap acceptance (Li, 2013, 2014; Saleh and Lashin, 2020; Tezcan et al., 2019; Yannis et al., 2013). Driver yielding behavior has also been studied in the literature using observational studies (Chaudhari et al., 2021; Dougald, 2016; Knoblauch et al., 2001; Morris et al., 2023; O'Brien et al., 2022; Samuel et al., 2013; Stern and Li, 2023). Safety analysis with crash data, although valuable, also has drawbacks because pedestrian crashes are infrequent, underreported, and can only be studied reactively.

A growing number of studies have used SSMs to study traffic safety (Table 3). SSMs help identify traffic conflicts, or *near misses*—that is, interactions between road users approaching each other in space and time to an extent that a collision may result without evasive actions by one of the users (Amundsen and Hydén, 1977). SSMs have been found to be correlated with crashes (Qu and Wu, 2025; Tarko et al., 2009). PET and time to collision (TTC) are frequently used SSMs to evaluate pedestrian-vehicle traffic conflicts (Table 3). Both TTC and PET are time-based SSMs and have been found to be the most appropriate SSMs for organized traffic environments (Tageldin and Sayed, 2016). PET has been defined as the time between the first road user leaving a common spatial zone and the second user arriving in that zone (Allen et al., 1978). The time until two road users collide if they continue at their present speed and along the same paths has been defined as TTC (Chen et al., 2017; Hayward, 1972). Both measures capture severity; smaller TTC and PET values are generally more severe (Kathuria and Vedagiri, 2020).

Table 3. Surrogate Safety Measures in Existing Literature

Surrogate Safety Measure	Definition	Study
Time to Collision	The time remaining before collision if two road users continue their speeds and trajectories (Johnsson et al., 2021a)	Fancher and Bareket (1998); Gettman et al. (2008); Ghanim and Shaaban (2019); Hayward (1972); Hyden (1987); Ismail et al. (2010); Jiang et al. (2015); Johnsson et al. (2021a), (2021b); Kathuria and Vedagiri (2020); Ni et al. (2016); Nie et al. (2021); Radwan et al. (2016); Tageldin and Sayed (2016); Yang et al. (2016); Zhang et al. (2012); Zhang et al. (2020b)
Post-Encroachment Time	The time between one road user departing a location and a second road user arriving at that location (Allen et al., 1978)	Ahsan et al. (2024); Alhajyaseen (2014); Allen et al. (1978); Anwari et al. (2023); Babu and Vedagiri (2018); Chandrappa et al. (2015); Chaudhari et al. (2021); Chen et al. (2014); Fu et al. (2019); Gettman et al. (2008); Ghanim and Shaaban (2019); Goyani et al.

Surrogate Safety Measure	Definition	Study
		(2019); Ismail et al. (2010); Johnsson et al. (2021a), (2021b); Kathuria and Vedagiri (2020); Marisamynathan and Vedagiri (2020); Nasernejad et al. (2021); Ni et al. (2016); Olszewski et al. (2020); Radwan et al. (2016); Scholl et al. (2019); Shah and Vedagiri (2017); Tageldin and Sayed (2016); Zangenehpour et al. (2016); Zhang et al. (2020a); Zhang et al. (2020b); Zhu et al. (2021)
Spatial Gap/Temporal Gap	The time between one road user departing a location and a second road user arriving at that location if they continue their speeds and trajectories (Kathuria and Vedagiri, 2020)	Anwari et al. (2023); Archer (2004); Ismail et al. (2010); Kathuria and Vedagiri (2020); Knoblauch et al. (2001)
Deceleration to Safety Time	Deceleration needed so that a second road user reaches the conflict no sooner than the first user leaves it (Hupfer, 1997)	Bagdadi and Várhelyi (2011); Hupfer (1997); Ismail et al. (2010), (2011); Zaki et al. (2014)
Pedestrian Risk Indicator (PRI)	Collision risk is the time between time to zebra and the estimated time to stop. Severity is the potential impact speed squared. PRI is the collision risk multiplied by severity, summed during a potential collision course (Johnsson et al., 2018)	Cafiso et al. (2011); Johnsson et al. (2018); Scholl et al. (2019)
Relative Time to Collision	The absolute difference between the pedestrian and vehicle time to collision (Anwari et al., 2023)	Ahsan et al. (2024); Anwari et al. (2023); Chen et al. (2017); Zhang (2013)
Time to Vehicle	Distance between the conflict point and the point at which the pedestrian began to decelerate divided by the pedestrian's speed when deceleration began (Kumar et al., 2019)	Kumar et al. (2019)
Time to Accident (TTA)	Time remaining to collision if a road user maintains speed and trajectory when they detect a change in traffic conditions (Kumar et al., 2019)	Kumar et al. (2019)
Delta V	The change in velocity experienced by a road user (Laureshyn et al., 2017)	Augenstein et al (2003); Laureshyn et al. (2017); Ryb et al. (2007)

In sum, the existing literature analyzing pedestrian crossing safety has focused mostly on midblock locations (Ahsan et al., 2024; Anwari et al., 2023; Chaudhari et al., 2021; Fitzpatrick et al., 2010; Gómez et al., 2013; Knoblauch et al., 2001; Pantangi et al., 2021; Samuel et al., 2013; Sarwar et al., 2017; Yang et al., 2016; Zhang et al., 2019; Zhu et al., 2021). The locations are primarily roadways with two to four lanes and speed limits below 35 mph. Detailed studies are lacking on pedestrian-vehicle interactions using system-centric metrics such as SSMs at signalized intersections with four or more lanes in a variety of contexts (Abdel-Aty et al., 2023).

Statewide Survey of High-Visibility Crosswalk Implementation Practices

The survey on HVC implementation practices was disseminated to localities statewide. The full text of the survey is in the appendix. Thirty-four responses to the survey were received from 29 Virginia localities (Table 4), with 26 providing a complete response. In some cases, multiple people provided responses to the survey from the same locality; if one respondent provided a complete response and the other did not, only the complete response was retained in the dataset, resulting in 30 responses being analyzed. In just one case, two respondents provided a complete response for the same locality, with some conflicting responses.

Table 4. List of Localities that Responded to the Survey

Locality
City of Alexandria
City of Bristol
City of Buena Vista
City of Chesapeake
City of Covington
City of Danville
City of Hampton
City of Harrisonburg
City of Hopewell
City of Lynchburg
City of Manassas
City of Norfolk
City of Radford
City of Richmond
City of Suffolk
City of Waynesboro
Henrico County
Town of Abingdon
Town of Ashland
Town of Blacksburg
Town of Bluefield
Town of Broadway
Town of Culpeper
Town of Herndon
Town of Leesburg
Town of Luray
Town of Marion
Town of South Hill
Town of Vienna

Figure 2 shows the results of question 2 regarding what types of guidelines localities follow when selecting crosswalk marking types. Respondents could select multiple responses. Most localities follow MUTCD or VDOT marking guidelines, and some have developed their own set of guidelines. The two localities that stated "Other" described a blanket policy for all crosswalks. One described using HVCs with all new projects; the other noted that using HVCs (longitudinal) is the standard application. Several localities provided the researchers with the locality's own written guidelines in response to question 3.

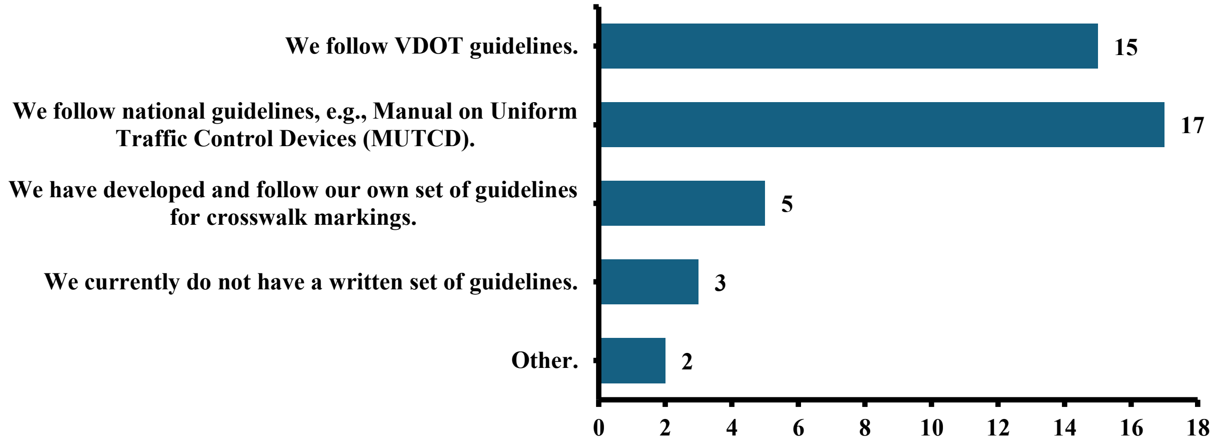

Figure 2. Responses to Question 2, "Which of the following applies to your locality regarding selecting crosswalk marking types?" (N = 29)

The City of Norfolk Standard Pavement Marking Detail dated May 2021 describes longitudinal HVC markings as the standard. In the City of Richmond, longitudinal and ladder HVC markings are used at all signalized intersections and at selected schools and parks. Transverse crosswalk markings are used at all unsignalized intersections and all other crossings. The City of Manassas Crosswalk Details dated February 2022 include descriptions for when transverse, HVC, and stamped asphalt crosswalk markings should be used. Transverse crosswalk markings are reserved for private roads with low pedestrian and traffic volumes. HVCs (longitudinal) are used on all public streets with marked crosswalks where stamped asphalt is not required. Stamped asphalt crosswalk markings are used in designated downtown areas. The Town of Herndon Standards for Traffic Calming and Crosswalks dated June 2024 describe when different crosswalk markings are used. HVCs are prioritized over transverse markings in locations with high pedestrian volumes or in locations frequented by vulnerable pedestrians, such as children, seniors, or people with disabilities. The town uses longitudinal HVCs and altered ladder-style HVCs at the Washington & Old Dominion Trail crossings.

Question 4 asked about respondents' familiarity with VDOT IIM-TE-384.1 Pedestrian Crossing Accommodations at Unsignalized Approaches. Figure 3 shows that representatives from most localities have not read VDOT IIM-TE-384.1, but most have heard of it (VDOT, 2022). As localities are under no obligation to follow these guidelines, the results show VDOT and localities maintaining communication regarding new guidelines.

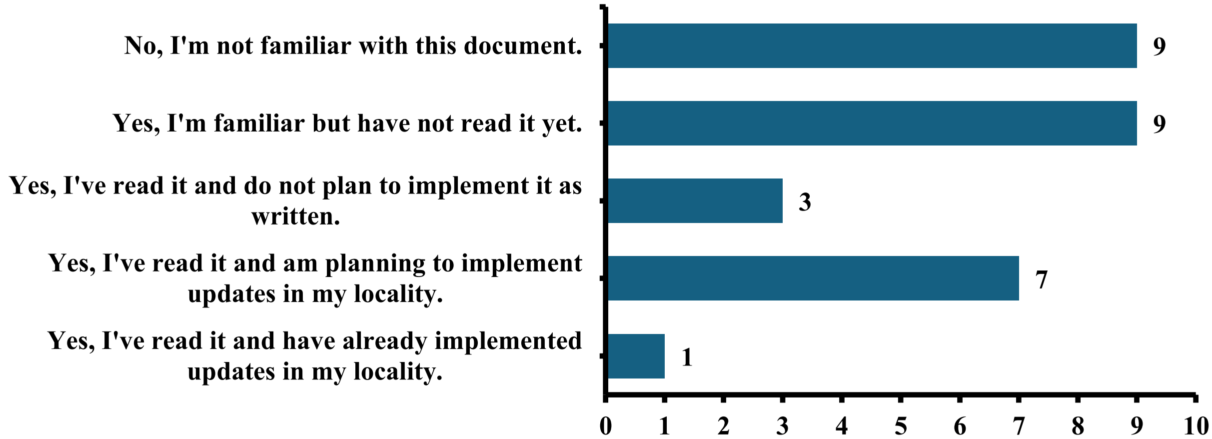

Figure 3. Responses to Question 4, "The VDOT Instructional and Informational Memorandum (IIM) 384.1 'Pedestrian Crossing Accommodations at Unsignalized Approaches' was last updated in August of 2022. Are you familiar with the updates that were made in this version?" (N = 29)

The purpose of question 5 was to understand what types of HVC markings are being used statewide because longitudinal, ladder, and bar pair markings are all considered HVCs. Nearly all localities (N = 26) that responded to the survey describe longitudinal HVC markings being present in their locality (Figure 4), often in combination with ladder and bar pair markings. One locality described the presence of bar pairs exclusively for HVCs, and two described ladder markings exclusively for HVCs. For HVC markings, VDOT policy recommends using longitudinal or bar pairs unless zebra or ladder markings are necessary to match nearby crosswalks (VDOT, 2022). VDOT also recommends bar pair over longitudinal markings when possible because it is easier for bicyclists, motorcyclists, and pedestrians to avoid marked areas, which could be slippery when wet. Despite this recommendation and that many localities report following VDOT guidelines, bar pair markings appear to be infrequently used, with only three localities reporting the presence of bar pair crosswalks.

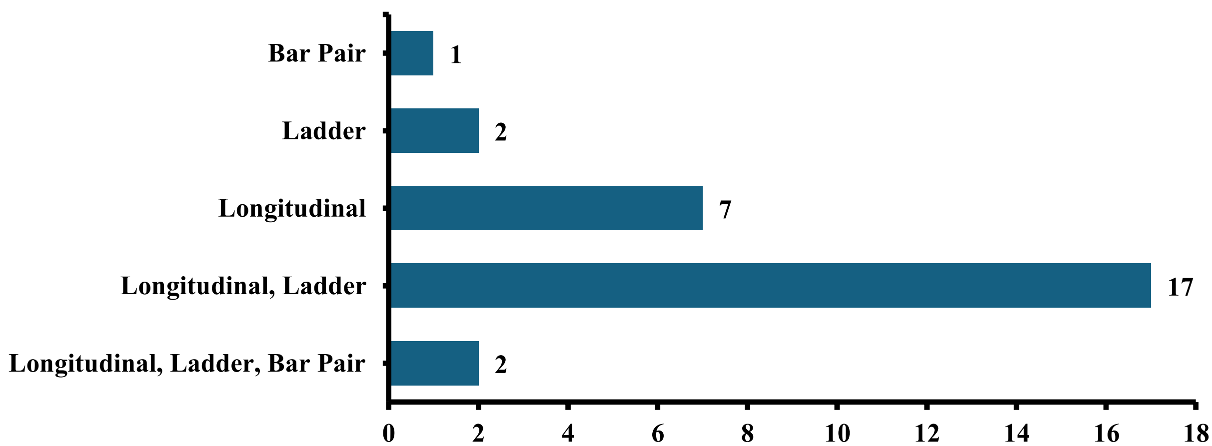

Figure 4. Responses to Question 5, "Which of the following HVC marking patterns currently exist in your locality? Select all that apply." HVC = high-visibility crosswalk.

Questions 6 and 8 asked about the types of markings used at unsignalized crossings and signalized intersections, respectively. Figure 5 shows that similar marking types are used for signalized and unsignalized intersections, and many localities selected multiple crosswalk marking types for signalized and unsignalized intersections. One takeaway is that HVCs are more commonly used than transverse or decorative crosswalks, regardless of whether the intersection is signalized or unsignalized. Of the 30 responses regarding marking types at unsignalized crossings and signalized intersections, only six respondents described using different markings at the two types of locations. Most respondents provided the same responses to both questions. Current VDOT standards, which do not automatically apply in localities that maintain their own roadways, require HVC markings at all unsignalized crossings, whether midblock or intersection crossings, except on stop-controlled approaches (VDOT, 2022). At signalized crossings, VDOT currently recommends using engineering judgment to choose marking types.

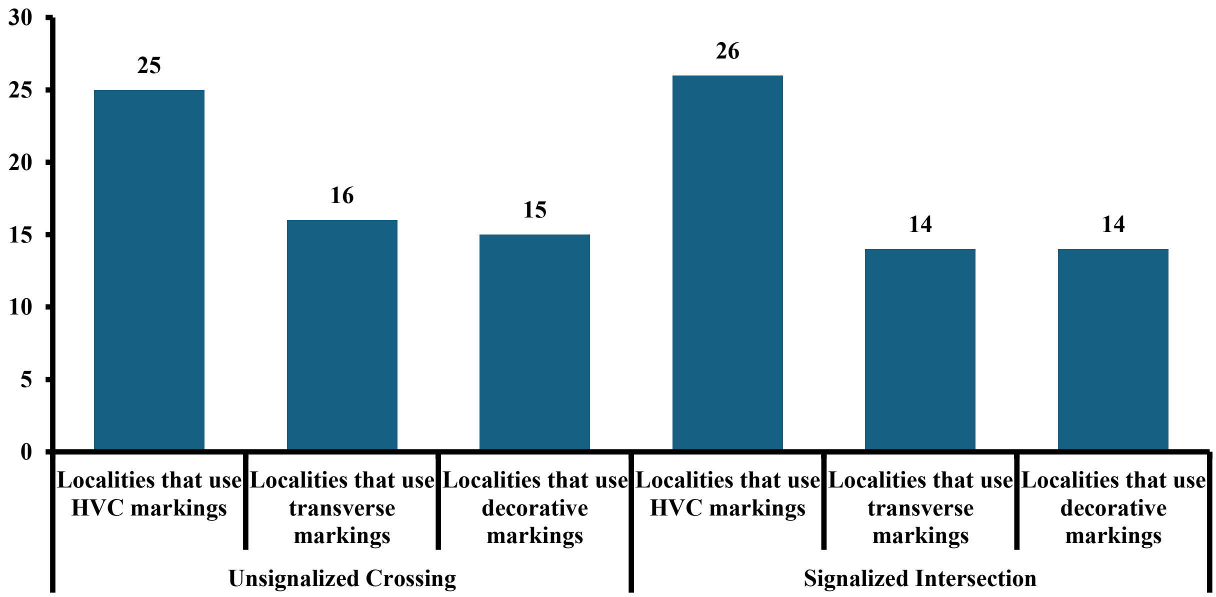

Figure 5. Responses to Question 6, “Which type(s) of crosswalk markings currently exist in your locality at UNSIGNALIZED crossings (either midblock or intersection)? Select all that apply.” and question 8, “Which type(s) of crosswalk markings currently exist in your locality at SIGNALIZED intersections? Select all that apply.” HVC = high-visibility crosswalk.

Questions 7 and 9 were open-ended responses that asked respondents to explain the factors affecting selecting the type of crosswalk markings at unsignalized and signalized intersections, respectively. A key takeaway was that several localities currently have HVC, transverse, and decorative markings but install only HVCs at all new crosswalks. This scenario was true of unsignalized and signalized intersections.

Questions 10 through 16 asked localities whether their locality has roundabouts, PHBs, or RRFBs. If a respondent stated that their locality has these types of infrastructure, they were then asked about what types of crosswalk markings are used at these locations. Figure 6 shows the responses to the latter question for roundabouts, PHBs, and RRFBs. This question was of interest because VDOT policy requires HVCs at roundabout crossings and at PHB crossings (VDOT, 2022).

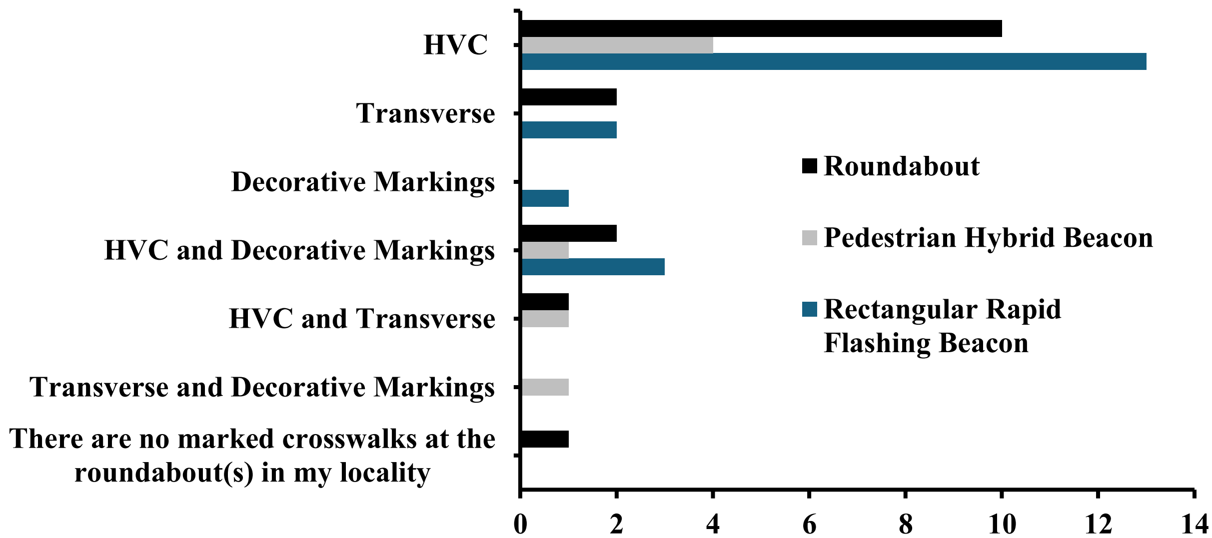

Figure 6. Responses to Questions 11, 13, and 15, "Which type(s) of crosswalk markings exist in your locality at roundabouts/pedestrian hybrid beacons/rectangular rapid flashing beacons? Select all that apply." HVC = high-visibility crosswalk.

Sixteen respondents reported having roundabouts in their locality. Ten of the 16 respondents (63%) stated that their localities have only HVCs at roundabouts, and another 3 (19%) use HVCs along with either transverse or decorative crosswalks at roundabouts. Two localities (13%) have only transverse crosswalks at their roundabouts, and 1 locality (6%) has roundabouts with no crosswalks. The localities with HVCs note safety, visibility, speed, volume, and policies (local, VDOT, and MUTCD) as reasons for using HVCs at roundabouts. Of those localities with decorative markings at roundabouts, some respondents note in question 12 that HVCs would be used if those roundabouts had been installed today, and 1 locality cites historic districts as a consideration for markings at roundabouts. Another cites the MUTCD as a reason for transverse crosswalks at roundabouts.

Of the seven respondents who stated they have PHBs in their localities, four (57%) stated that their localities use only HVCs at PHBs, and two localities (28%) use HVCs and either transverse or decorative crosswalks at PHBs. One locality (14%) reported both decorative markings and transverse markings at its PHBs. When asked about factors that influence the selection of crosswalk marking types at PHBs, most respondents stated that HVCs are the standard, either at PHBs or across their locality, regardless of crossing type.

Nineteen respondents reported that their localities have RRFBs, and 13 of those localities (68%) use only HVCs at RRFBs. Another 3 localities (16%) use both HVCs and decorative markings at RRFBs. Two localities (11%) have transverse markings at RRFBs, and 1 locality (5%) has only decorative markings at its RRFBs. When asked about factors that influence the selection of crosswalk marking types at RRFBs, most respondents stated that HVCs are the standard, either at RRFBs or across their localities. Respondents also cited pedestrian activity, safety, traffic volume, and the presence of historic or business districts as factors.

Questions 17 and 18 presented respondents with a grid in which they could check which types of materials are used for HVC and transverse crosswalk markings currently (Table 5) and what will be used in the future (Table 6). The types of materials to choose from included thermoplastic, preformed tape, methyl methacrylate, epoxy, and paint. The respondent could also check “Unsure” or “Other.” For both questions, the most common response was that thermoplastic is used for HVC and transverse crosswalks now and will be in the future. The second most common material is paint for both HVC and transverse crosswalks now and will be in the future. Some localities report that paint is currently used for HVC and transverse crosswalks but will not be used in the future. One respondent checked “Other” for questions 17 and 18 to indicate that transverse crosswalks are not used in their city.

Table 5. Responses to Question 17, “Within your locality, which of the following materials are used for HVC and Transverse crosswalk markings? Select all that apply.”

	Thermoplastic	Preformed Tape	Methyl Methacrylate	Epoxy	Paint	Unsure	Other (please describe below)
HVC	27	5	1	0	14	0	0
Transverse	19	4	1	0	13	1	1

HVC = high-visibility crosswalk.

Table 6. Responses to Question 18, “Which of the following materials will your locality be using for marking HVC and Transverse crosswalks moving forward? Select all that apply.”

	Thermoplastic	Preformed Tape	Methyl Methacrylate	Epoxy	Paint	Unsure	Other (please describe below)
HVC	27	4	0	0	11	0	0
Transverse	18	4	0	0	6	0	1

HVC = high-visibility crosswalk.

Question 19 asked about factors that affect how frequently crosswalk markings are replaced or refreshed. Four factors were provided, and the respondent was asked to select all that apply. These factors include staff observations, citizen requests, fixed schedule, and based on an asset management system or inspection program. Most respondents selected multiple factors (Table 7), with the most common being staff observations and citizen requests. The more structured factors, fixed schedule and an asset management system or inspection program, were selected less frequently.

Table 7. Responses to Question 19, “Which of the following factors affect decisions on frequency of refreshment/replacement of HVC and Transverse markings in your locality? Select all that apply.”

	Staff Observations	Citizen Requests	Fixed Schedule, e.g., annually	Based on an asset management system or inspection program
HVC	23	20	10	10
Transverse	16	13	4	8

HVC = high-visibility crosswalk.

Question 20 asked respondents to describe whether any other factors affect decisions on the frequency of refreshment or replacement of HVC and transverse markings. Most respondents provided the same answer for HVC and transverse markings and cited numerous other factors that influence when crosswalk markings are refreshed. These factors included street resurfacing, parking restriping, weather, traffic volume, pavement type, utility patching, snowplow damage, equipment and staff availability, contractor suggestion, funding, and condition.

In a final open-response question, respondents discussed how frequently crosswalk markings are refreshed or replaced in their localities. Responses described that frequency varies greatly and is dependent on traffic volume, marking material, pavement condition, funding availability, staff, and equipment. Some respondents provided target refreshment timelines of 3 to 5 years, 5 to 7 years, or 5 to 10 years and stated that timelines may vary depending on the roadway classification. Some described crosswalks being replaced only when pavement is replaced, or when the crosswalks reach their target lifetime. Flexibility in timing, based on many factors, is expected, particularly given that crosswalk installation costs tend to be lower when they are part of a resurfacing project (Schroeder et al., 2023). Most respondents state that this procedure is an as-needed process dependent on the factors described previously and that it is based on staff monitoring.

Some respondents interpreted the question as how often crosswalk replacement happens in their locality, rather than how often a specific crosswalk is replaced, which was the intent. In these cases, respondents stated that replacement is done annually or biannually.

Crosswalk Location Identification

The crosswalk location identification task was the start of the field data collection phase. As previously described, the preferred site characteristics (four-lane major road, sufficient pedestrian activity, higher speed environment, and both transverse and HVCs) resulted in six sites selected for analysis. The preferred characteristics skewed the available pool of sites to larger cities. Ultimately, all the chosen study sites were in Fairfax County in Northern Virginia to minimize variation in the driver population and thus driver behavior. The crosswalk markings on the two parallel, major approaches at each intersection were considered for analysis. Figure 7 shows the six sites selected for analysis.

(a) Braddock Road and Roanoke River Road
(Google Earth Pro, 2026)

(b) Braddock Road and Ox Road
(Google Earth Pro, 2026)

(c) Little River Turnpike and Backlick Road
(Google Earth Pro, 2021)

(d) Westpark Drive and Jones Branch Drive
(Google Earth Pro, 2018)

(e) Westpark Drive and Park Run Drive
(Google Earth Pro, 2018)

(f) Gallows Road and Boone Boulevard
(Google Earth Pro, 2019)

Figure 7. Intersections Selected for Analysis in Fairfax County, Virginia. Major roads run horizontally.

Table 8 provides the characteristics of the six study sites. Characteristics were collected using recent street images from Google Earth and verified through site visits. All six intersections were signalized, with four lanes of through traffic on the major approach. None of the intersections had restricted right turns on red, and all intersections allowed protected-permissive left turns except Braddock Road and Ox Road, which had protected-only left turns. The speed limit on the major road for all sites was 35, 40, or 45 mph. Two speed limits are given in two cases because the intersection served as a change point in the speed limit along the road. Two of the intersections have longitudinal HVCs, one has ladder HVCs, and three have transverse crosswalks. The crosswalk lengths vary between 70 and 150 feet, rounded to the nearest 5 feet to account for uncertainty in Google Maps measurements. Two crosswalk lengths are indicated for each intersection because both crosswalks along the major road of each intersection were used in the analysis. All the intersections except Braddock Road and Ox Road had one or two bus stops within 250 feet of the intersection. All the intersections had some level of lighting at night, as measured by the number of streetlights within 250 feet of the intersection. The number of streetlights within that radius varied from 1 to 16, indicating that the amount of lighting varies between intersections, but because the brightness level, timing, and condition of the streetlights is unknown, the streetlight count serves as an approximate surrogate for lighting level. Skew angles varied from 64 to 90 degrees. All intersections except Westpark and Jones Branch had no street parking in the intersection's immediate vicinity.

Table 8. Characteristics of the Six Intersections Selected for Study

Intersection Characteristics	Braddock and Ox	Braddock and Roanoke River	Little River and Backlick	Gallows and Boone	Westpark and Jones Branch	Westpark and Park Run
Crosswalk Marking Type	HVC	HVC	HVC	Transverse	Transverse	Transverse
Crosswalk Length (on the NB/EB major street approach)	150	105	85	80	80	70
Crosswalk Length (on the SB/WB major street approach)	110	90	65	100	80	70
Number of Bus Stops Within 250 Feet of the Intersection	0	2	2	2	1	1
Number of Streetlights Within 250 Feet of the Intersection	14	14	16	1	11	6
Speed Limit (on the NB/EB major street approach)	45	40	35	35	35	35
Speed Limit (on the SB/WB major street approach)	40	40	35	40	35	35
Skew Angle	64	90	72	82	83	86
On-Street Parking Within 250 Feet of Intersection	No	No	No	No	Yes	No
Left Turn Signal	Protected	Protected-Permissive	Protected-Permissive	Protected-Permissive	Protected-Permissive	Protected-Permissive

EB = eastbound; HVC = high-visibility crosswalk; NB = northbound; SB = southbound; WB = westbound.

Crash statistics for the six intersections were compiled using VDOT's crash database from 2017 through 2025. The total number of pedestrian crashes during the 9-year period at each site varied between zero and four crashes, indicating that fewer than one pedestrian crash occurred per year at each site (Table 9). Because pedestrian crashes at the sites are infrequent, and the crosswalk markings at the intersection of Braddock and Ox Roads were transverse before 2026, no conclusions may be drawn regarding injury distribution between HVC and transverse crosswalk sites. This inconclusion highlights the challenge of studying pedestrian safety using crash data exclusively, even when observed during a long timeframe.

Table 9. Pedestrian Crash Data from 2017 Through 2025 for Study Intersections by KABCO Rating

Intersection	Total Crashes	K	A	B	C	O
Braddock and Roanoke River Road	3	0	1	2	0	0
Braddock Road and Ox Road	3	0	1	2	0	0
Little River Turnpike and Backlick Road	1	0	0	1	0	0
Westpark Drive and Jones Branch Drive	0	0	0	0	0	0
Westpark Drive and Park Run Drive	4	0	0	3	1	0
Gallows Road and Boone Boulevard	0	0	0	0	0	0

KABCO = (K) - Fatal Injury, (A) - Suspected Serious Injury, (B) - Suspected Minor Injury, (C) - Possible Injury, (O) - No Apparent Injury.

Crosswalk Data Collection

Summary Statistics of Near-Miss Pedestrian and Vehicle Events

A vendor provided the researchers with near-miss event data between all road users at the study sites after video data collection, computer vision analysis, and manual data cleaning. The researchers completed further data cleaning. This section details the summary statistics of the near-miss event data and the results of models used to analyze the data. The intersections studied were chosen for the characteristics on the major road approaches (four-lane roads with speed limits of 35 through 45 mph), and the near misses were filtered for those occurring when pedestrians were crossing the major road on either side of the intersection. The filtered sample included interactions between pedestrians and passenger vehicles, pickup trucks, trucks, buses, and articulated trucks. The study was conducted from March 12, 2026, through March 18, 2026, for 7 full days of data collection.

Each near-miss event has a corresponding PET value indicating the time between the first road user leaving the location and the second road user arriving at that location. Figures 8 and 9 show the distribution of PET values at the HVC and transverse sites, respectively. All PET values below 5 seconds were captured, and a lower PET value indicates a closer interaction between the pedestrian and the vehicle. A PET value of 0 would indicate that a collision occurred.

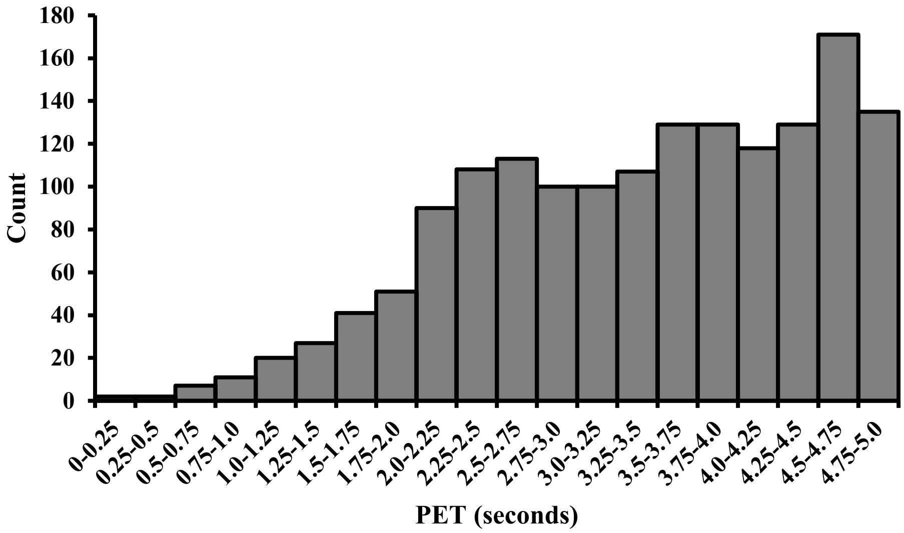

Figure 8. Histogram of PET Values at All High-Visibility Crosswalks. PET = post-encroachment time.

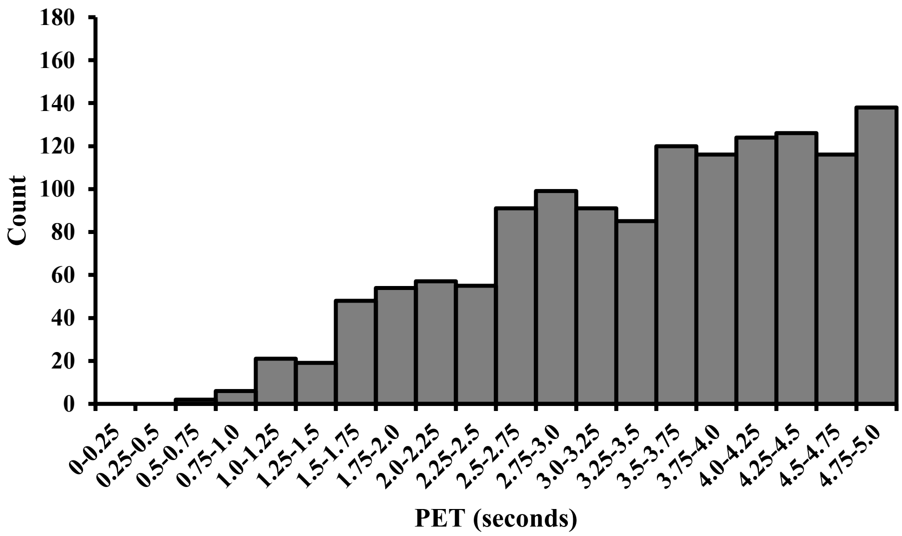

Figure 9. Histogram of PET Values at All Transverse Crosswalks. PET = post-encroachment time.

The absolute number of near misses observed differed at each study site, likely primarily related to the volume of vehicles and pedestrians at each site. The distributions of the near-miss PET values were similar across all sites, where the proportion of less severe interactions (> 2.5 seconds) ranged from 76% to 82%, and the proportion of more severe interactions (≤ 2.5 seconds) ranged from 18% to 24% (Table 10). The cutoff for the definition of a near miss varies in the literature (Johnsson et al., 2018), and lower PET cutoffs are used to isolate interactions that are more likely to have been dangerous.

Table 10. Near-Miss Count, Near-Miss Rate, and Pedestrian Volume Observed at the Six Intersections Along the Major Road Crossings at Different PET Thresholds. Totals for the entire study period.

Near-Miss and Volume Definition	HVC			Transverse Crosswalks			All HVCs	All Transverse Crosswalks
	Braddock and Ox	Braddock and Roanoke River	Little River and Backlick	Gallows and Boone	Westpark and Jones Branch	Westpark and Park Run		
> 2.5 and ≤ 5 Seconds PET	86 (77%)	813 (78%)	330 (76%)	185 (79%)	562 (81%)	359 (82%)	1,231 (77%)	1,106 (81%)
≤ 2.5 Seconds PET	26 (23%)	228 (22%)	105 (24%)	50 (21%)	135 (19%)	77 (18%)	359 (23%)	262 (19%)
≤ 5 Seconds PET	112 (100%)	1,041 (100%)	435 (100%)	235 (100%)	697 (100%)	436 (100%)	1,590 (100%)	1,368 (100%)
< 2.5 Second PET Rate Crossing Major Road	6.9%	8.8%	8.6%	7.2%	6.5%	5.6%	8.5%	6.3%
≤ 5 Second PET Rate Crossing Major Road	29.6%	40.0%	35.5%	34.1%	33.5%	31.9%	37.8%	33.1%
Total Pedestrian Volume Crossing Major Road	379	2,603	1,224	690	2,079	1,368	4,206	4,137

HVC = high-visibility crosswalk; PET = post-encroachment time.

Most of the near-miss events occurred during the daytime, when pedestrian and vehicle volumes are highest, allowing for interactions to occur (Figure 10). The proportion of near misses occurring during the daytime is relatively similar at HVC and transverse crosswalks, with slightly higher counts of dusk and night crashes at HVCs and slightly higher counts of dawn near misses at transverse crosswalks.

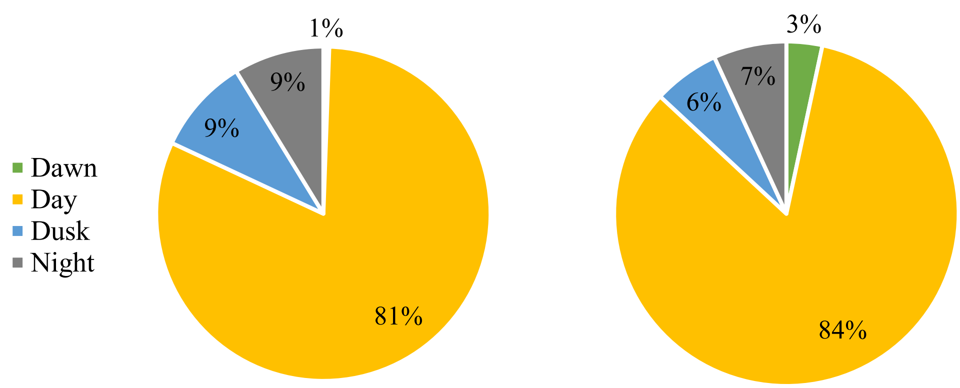

Figure 10. Percentage of Near Misses Occurring During Dawn, Daytime, Dusk, and Night for High-Visibility Crosswalks (left) and Transverse Crosswalks (right)

The time-of-day variables may be further explored by looking at cross-tabulations of time-of-day and PET values. Table 11 shows the percentage of near misses occurring during different temporal periods, broken down by PET values less than or equal to 2.5 seconds and

PET values greater than 2.5 seconds. Smaller PET values indicate a closer interaction between the vehicle and the pedestrian.

Table 11. Count and Percentage of Near-Miss Events with PET Values Below 2.5 Seconds and Between 2.5 and 5 Seconds at HVCs, Transverse Crosswalks, and All Sites

	Near-Miss Events at HVCs		Near-Miss Events at Transverse Crosswalks		Near-Miss Events at All Sites	
PET (seconds)	≤ 2.5	> 2.5 and ≤ 5	≤ 2.5	> 2.5 and ≤ 5	≤ 2.5	> 2.5 and ≤ 5
Dawn	2 (0.6%)	7 (0.6%)	9 (3.4%)	37 (3.3%)	11 (1.8%)	44 (1.9%)
Day	285 (79.4%)	1,009 (82.0%)	216 (82.4%)	927 (83.8%)	501 (80.7%)	1,936 (82.8%)
Dusk	33 (9.2%)	115 (9.3%)	19 (7.3%)	66 (6.0%)	52 (8.4%)	181 (7.7%)
Night	39 (10.9%)	100 (8.1%)	18 (6.9%)	76 (6.9%)	57 (9.2%)	176 (7.5%)
Total	359 (100%)	1,231 (100%)	262 (100%)	1,106 (100%)	621 (100%)	2,337 (100%)

HVCs = high-visibility crosswalks; PET = post-encroachment time.

Across all crosswalks studied, a slightly higher percentage of more severe near misses (PET values < 2.5 seconds) occurred at dusk and night (8.4% and 9.2%, respectively) compared with less severe near misses (PET values > 2.5 seconds), of which 7.7% and 7.5% occurred at dusk and night, respectively (Table 12). This outcome is driven by a slightly higher rate of severe nighttime near misses at HVCs and a slightly higher rate of severe dusk near misses at transverse crosswalks compared with the rates of less severe near misses. Figure 11 shows how the cameras and computer vision analysis performed by the vendor captured near misses under various lighting conditions.

Table 12. Near-Miss Counts by Vehicle Movement at Each Study Site

Vehicle Movement Type	High-Visibility Crosswalk			Transverse Crosswalk			All HVCs	All Transverse
	Braddock and Ox	Braddock and Roanoke River	Little River and Backlick	Gallows and Boone	Westpark and Jones Branch	Westpark and Park Run		
Left	0 (0%)	276 (26%)	114 (26%)	79 (34%)	83 (12%)	120 (28%)	390 (25%)	282 (21%)
Right	109 (97%)	703 (67%)	275 (63%)	61 (26%)	427 (61%)	243 (56%)	1,087 (68%)	731 (53%)
Through	3 (3%)	62 (6%)	46 (11%)	93 (40%)	181 (26%)	73 (17%)	111 (7%)	347 (25%)
U-Turn	0 (0%)	2 (0%)	0 (0%)	2 (1%)	6 (1%)	0 (0%)	2 (0%)	8 (1%)
Total Near Misses	112 (100%)	1,043 (100%)	435 (100%)	235 (100%)	697 (100%)	436 (100%)	1,590 (100%)	1,368 (100%)

HVCs = high-visibility crosswalks.

Figure 11. Near-Miss Examples Under Various Lighting Conditions

The sample of near-miss events may also be examined using cross-tabulations of each study site and vehicle turning movements. The dataset includes four vehicle movement types: left turns, right turns, through movements, and U-turns. At all intersections except Gallows Road and Boone Boulevard, most near misses occurred between right turning vehicles and pedestrians—between 56% and 97% of the total near misses at the intersection. At Gallows Road and Boone Boulevard, a greater proportion of near misses occurred between through vehicles and pedestrians (40%). Another notable difference between the near-miss events at each site is that at Braddock and Ox Roads, no left turning vehicles were involved in near misses with pedestrians. This result is likely related to the protected left turn movements at the intersection. At the remainder of the intersections, left turning movements were 12% to 34% of the near-miss sample. Table 13 also provides information about near misses by vehicle movement type, showing the mean PET value for each vehicle movement at each intersection. Across all sites, right turn movements have the lowest mean PET values.

Table 13. Near-Miss Mean PET Values by Turning Movement by Study Site

Vehicle Movement Type	High-Visibility Crosswalk			Transverse Crosswalk			All HVCs	All Transverse
	Braddock and Ox	Braddock and Roanoke River	Little River and Backlick	Gallows and Boone	Westpark and Jones Branch	Westpark and Park Run		
Left	N/A	3.53	3.55	3.56	3.48	3.70	3.53	3.60
Right	3.26	3.35	3.30	3.20	3.46	3.37	3.33	3.41
Through	2.58	3.40	3.68	3.33	3.45	3.62	3.49	3.46
U-Turn	N/A	4.63	N/A	2.41	3.69	N/A	4.63	3.37
All Movements	3.24	3.41	3.40	3.37	3.47	3.50	3.39	3.46

HVCs = high-visibility crosswalks; N/A = no near misses occurred with this vehicle movement; PET = post-encroachment time.

Crosswalk Data Analysis

Near-Miss Rate Model

A single model was used to study the near-miss rate at all six intersections along the major road. The model examines each of the 12 crosswalks at every hour during the 7-day study period and determines how temporal, intersection, and traffic characteristics affect the frequency of pedestrian-vehicle near misses during that hour. The traffic data were available in 15-minute intervals but were aggregated to hourly data to reduce time intervals with no near-miss data and to reduce the zero-inflated component. Tables 14 and 15 present the summary statistics for all the variables tested in the model for all sites. The dependent variable was the rate of near misses, analyzed at each of the 12 crosswalks for every hour during the 1-week study timeframe. Pedestrian volume (hourly pedestrian volume on the crosswalk being analyzed) was included as an offset to account for pedestrian exposure. Vehicle volume (hourly vehicle volume on all movements that conflict with the crosswalk of interest) was included as an offset to account for vehicle exposure. Other variables included left turn, right turn, through, and U-turn volumes, the time of day, crosswalk marking type, bus stops, parking, skew angle, presence of protected left turn, and speed limit.

Table 14. Summary Statistics of Discrete Variables Used in the Near-Miss Count Model Estimation

Variable	Description	Mean	Standard Deviation	Min.	Max.
Count of Near Misses	The number of near-miss events that occur each hour at the crosswalk being analyzed	1.28	3.63	0	60
Pedestrian Volume	The hourly pedestrian count at the crosswalk being analyzed	4.26	6.15	0	45
Vehicle Volume	The hourly vehicle count for all vehicle movements conflicting with the crosswalk being analyzed	621.98	607.45	3	2,967
Left Turn Volume	The hourly count of left turn movements conflicting with the crosswalk being analyzed	56.62	62.14	0	433
Right Turn Volume	The hourly count of right turn movements conflicting with the crosswalk being analyzed	58.85	114.76	0	890
Through Movement Volume	The hourly count of through movements conflicting with the crosswalk being analyzed	286.39	346.68	0	1,366
U-Turn Volume	The hourly count of U-turn movements conflicting with the crosswalk being analyzed	13.04	34.89	0	246

Table 15. Definitions of Categorical Intersection Variables Used in the Near-Miss Count Model Estimation

Variable	Description	Category
Time of Day	Temporal classifications.	Dawn
		Day
		Dusk
		Night
Crosswalk Marking Type	Indicates whether an HVC or a transverse crosswalk is present.	Transverse
		HVC
Bus Stops	Indicates whether a near-side bus stop is present where a stopped bus would obscure the crosswalk being analyzed from vehicles approaching behind the bus stop.	No Obscuration Due to Bus Stop
		Bus Stop Obscures Crosswalk
Skew Angle	Indicates whether the intersection is skewed. Intersection angle > 75° is not skewed.	Not Skewed
		Skewed
Parking	Indicates whether on-street parking could obscure the crosswalk being analyzed from vehicles approaching behind the parked vehicles.	No Obscuration Due to Parking
		Parking Obscures Crosswalk
Left Turn	Indicates whether the intersection has permissive-protected left turns or protected-only left turns.	Protected-Permissive
		Protected

HVC = high-visibility crosswalk.

Table 16 shows the results of the zero-inflated negative binomial regression. The model includes a random intercept for each crosswalk and has a count component and a zero-inflated component. The model estimates how many near misses occurred given the pedestrian and vehicle exposure.

Time of day was found to be a significant variable in the near-miss rate model. Nighttime hours were associated with a higher rate of near-miss events compared with daytime hours. Furthermore, dawn was associated with a lower rate of near-miss events compared with daytime. Lighting at the intersection was incorporated as an interaction variable with time of day to determine whether the number of streetlights at the intersection affected safety at night. The variable was not significant, and all the study sites had some level of intersection lighting.

The presence of skew at an intersection was associated with an increase in the rate of near-miss events compared with those intersections without skew. Among the six intersections studied, the Braddock and Ox and the Little River and Backlick intersections were classified as skewed. The Little River and Backlick intersection was slightly below the cutoff of 75 degrees that was used to designate a skewed intersection (FHWA, n.d.). Both intersections defined as skewed had HVCs.

The last variable that was significant in the near-miss rate model was crossing length. An increased crossing length was associated with a lower rate of near-miss events. However, although this variable retained significance in the model, it was correlated in early correlation tests with the presence of a protected left turn and with the intersection speed limit. The result may not exclusively reflect the effect of the crossing distance and should be interpreted with this understanding.

Table 16. Results of Zero-Inflated Negative Binomial with Random Effects Model for Near-Miss Rates at Study Intersections (N = 1,958)

Count Component								
Variable	**Category**	**Coefficient**	**Standard Error**	**p-Value**	**IRR**	**95% CI Low**	**95% CI High**	**% Change**
Period	Day (reference)	-	-	-	1.000	-	-	-
	Dawn	– 0.4005*	0.1837	0.029	0.670	0.467	0.960	– 33.0%
	Dusk	0.1512	0.1251	0.227	1.163	0.910	1.487	+ 16.3%
	Night	0.3105*	0.1305	0.017	1.364	1.056	1.762	+ 36.4%
Right Turns	per vehicle	0.0010	0.0009	0.259	1.001	0.999	1.003	+ 0.1%
Through	per vehicle	– 0.0003	0.0002	0.111	0.100	0.999	1.000	0.0%
U-Turns	per vehicle	0.0039	0.0021	0.059	1.004	1.000	1.008	+ 0.4%
HVC	0 = No (reference)	-	-	-	1.000	-	-	-
	1 = Yes	– 1.4480	1.4770	0.327	0.235	0.013	4.249	– 76.5%
Skew	0 = No (reference)	-	-	-	1.000	-	-	-
	1 = Yes	2.9607**	1.1105	0.008	19.311	2.190	170.25	+ 1,831%
Crosswalk Length	per unit	− 0.1311***	0.0375	< 0.001	0.877	0.815	0.944	– 12.3%
Zero-Inflated Component								
Variable	**Category**	**Coefficient**	**Standard Error**	**p-Value**	**Odds Ratio**	**95% CI Low**	**95% CI High**	-
Period	Day (reference)	-	-	-	1.000	-	-	-
	Dawn	– 2.8055	2.3699	0.237	0.061	0.001	6.293	-
	Dusk	0.1630	0.8120	0.841	1.177	0.240	5.781	-
	Night	– 1.1917	0.6782	0.079	0.304	0.080	1.148	-
Lights	numeric	3.0196	25.320	0.905	20.48	-	-	-
HVC	1 = Yes	– 33.243	670.6	– 0.050	0.0	-	-	-

Akaike Information Criterion = 3,661.9; CI = confidence interval; HVC = high-visibility crosswalk; IRR = incidence rate ratio; R^2 = 0.661; *** Significant at 99.9% CI; ** Significant at 99% CI; * Significant at 95% CI.

Near-Miss Severity Model

To complement the near-miss rate model, which examined intersection characteristics that could affect the rate of a near miss at individual crosswalks, another model was developed to examine the near-miss characteristics and predictor variables of the near-miss severity, or PET value. In this model, additional variables may be included that represent the characteristics of a known near-miss event. One model was used to study the near-miss interactions at all six intersections across 12 crosswalks (Tables 17 and 18). The summary statistics reflect the conditions when these near misses occurred.

Table 17. Summary Statistics of Continuous and Discrete Variables Included in the Near-Miss Severity Model Estimates

Variable	Description	Type	Mean	S.D.	Min.	Max.
Post-Encroachment Time	Post-encroachment time (seconds) for each near-miss event between a pedestrian and vehicle	Continuous	3.42	1.04	0.10	4.99
Crosswalk Length	The distance (feet) the pedestrian must travel in the crosswalk where the near miss occurred	Continuous	86.82	15.19	65	150
Pedestrian 15-Minute Count	The number of pedestrians at the crosswalks being analyzed during the 15-minute period in which the near miss occurred	Discrete	7.87	6.37	1	34
Vehicle 15-Minute Count	The number of vehicles whose movements conflict with the crosswalks being analyzed during the 15-minute period in which the near miss occurred	Discrete	512.96	288.58	34	1321
Pedestrian Speed	The instantaneous speed (mph) of the pedestrian at the conflict point	Continuous	1.86	0.96	0.05	12.00
Vehicle Speed	The instantaneous speed (mph) of the vehicle at the conflict point	Continuous	6.98	3.77	0.02	46.87
Lighting	The number of streetlights within 250 feet of the intersection where the near miss occurred	Discrete	11.37	4.32	1	16
Speed Limit	The speed limit (mph) on the major road approach where the near miss occurred	Discrete	35.66	5.09	35	45
Speed Limit 2	The speed limit (mph) on the major road approach opposite where the near miss occurred	Discrete	36.47	4.41	35	45

S.D. = standard deviation.

Table 18. Summary Statistics of Categorical Variables Included in the Near-Miss Severity Model Estimates

Variable	Description	Type	Categories	Count	Percentage
Time of Day	Temporal classification when the near miss occurred	Categorical	Dawn	55	1.9%
			Day	2,435	82.3%
			Dusk	233	7.9%
			Night	233	7.9%
Vehicle Type	Type of vehicle involved in the near miss	Categorical	Articulated Truck	3	0.1%
			Bus	34	1.1%
			Passenger Car/ Pickup Truck	2,913	98.5%
			Truck	5	0.2%
Vehicle Movement	Movement of the vehicle involved in the near miss	Categorical	Left	670	22.7%
			Right	1,818	61.5%
			Through	458	15.5%
			U-Turn	10	0.3%
Crosswalk Marking Type	Indicates whether an HVC or a transverse crosswalk was present where the near miss occurred	Categorical	Transverse	1,368	46.2%
			HVC	1,588	53.7%
Skewed	Indicates whether the intersection where the near miss occurred was skewed	Categorical	Not Skewed	2,409	81.4%
			Skewed	547	18.5%
Left Turn	Indicates whether the intersection where the near miss occurred had permissive-protected or protected-only left turns	Categorical	Protected-Permissive	2,844	96.1%
			Protected	112	3.8%

HVC = high-visibility crosswalk.

A gamma generalized linear model was used to model the independent variables described in Table 17 and their effect on PET values. Lower PET values indicate higher severity crashes. Variables included in the final model are pedestrian speed at the time of the near miss, vehicle type, and vehicle movement. The results of the model are in Table 19.

Table 19. Results of Gamma Generalized Linear Model for Near-Miss Severity at Study Intersections

Variable		Estimate	Standard Error	T-Value	P-Value	Percent Change in PET
Pedestrian Speed		0.036***	0.008	4.611	$4.18 \times e^{-6}$	– 3.63
Vehicle Type	Heavy Vehicle	– 0.15*	0.062	– 2.411	0.016	13.93
	Cars/Pickup Trucks (Reference)	-	-	-	-	-
Vehicle Movement	Left Turn	-0.043^{+}	0.024	– 1.766	0.078	4.23
	Right Turn	0.041^{+}	0.021	1.941	0.052	– 4.20
	U-Turn	– 0.096	0.129	– 0.742	0.458	9.14
	Through (Reference)	-	-	-	-	-
Intercept		0.861***	0.024	35.548	$< 2 \times e^{-16}$	– 136.64

Akaike Information Criterion= 8337.8; PET = post-encroachment time; *** Significant at 99.9% confidence interval; * Significant at 95% confidence interval; $^{+}$ Significant at 90% confidence interval.

The pedestrian speed variable represents the instantaneous speed of the pedestrian at the point where the vehicle trajectory and the pedestrian trajectory crossed. The speed of the pedestrian at the point of conflict was found to be statistically significant and inversely correlated with the PET value of the near miss, indicating that a faster pedestrian is correlated with a lower (more severe) PET value and near-miss interaction. Studies have found that pedestrian crash risk increases with increasing pedestrian speed (Ankunda et al., 2024) and that conflicts are more severe when the pedestrian speeds up or runs (Singleton et al., 2023). Possible explanations may be behavioral: a pedestrian running across the road outside the pedestrian signal; running late, such as for a bus; or running for exercise. Computer vision analysis of video footage can also contain erroneous data, such as a person on a scooter mistaken for a pedestrian.

Both left- and right-turn vehicle movements were found to affect the PET value in near-miss interactions compared with through movements. A left turn movement was associated with a higher PET value (less severe) in a near-miss interaction, and a right turn movement was associated with a lower PET value (more severe) in a near-miss interaction compared with through movements. All the intersections in the study had either protected-permissive or protected left turns, and none of the intersections had right-turn-on-red restrictions, which may have contributed to the results. In this analysis, the intersection with protected-only left turns experienced no near misses between left turning vehicles and pedestrians. At the remainder of the intersections (with protected-permitted left turns), left turning vehicles constituted 12% to 34% of the near-miss sample. Furthermore, right turning vehicle conflicts constituted 62% of all near misses observed at the six study sites. A separate analysis of PET near-miss data at two Virginia intersections found that 73% of all near misses occurred between pedestrians and right turning vehicles at a site where a right turn on red was permitted compared with 23% at a site with right-turn-on-red restrictions (Raida, 2026). These statistics highlight the potential pedestrian safety benefits of turning movement restrictions, especially for right turns that were associated with more severe PET values compared with through movements. Studies have also shown that right-turn-on-red restrictions can reduce all crashes, especially right-turn crashes (Singleton et al., 2023).

Heavy vehicles were associated with a higher PET (less severe) in a near-miss interaction compared with passenger cars and pickup trucks. Buses, trucks, and articulated trucks were aggregated into the variable heavy vehicles because the number of pedestrian interactions involving trucks and articulated trucks was very low.

The data used for the near-miss severity model included all near-miss interactions with PET scores less than 5 seconds. To determine whether lower PET values had different characteristics, the gamma generalized linear model was also used to process the near-miss dataset with PET values less than 2.5 seconds. Results had similarities to those from the full dataset. Vehicle type was no longer significant in the model, and only pedestrian speed and vehicle movement were preserved as significant predictors of PET severity (Table 20). Higher pedestrian speeds were again correlated with a lower (more severe) PET value, left turns were associated with a higher (less severe) PET value, and right turning vehicles were no longer significant in the model.

Table 20. Results of Gamma Generalized Linear Model for Near-Miss Severity at Study Intersections (PET < 2.5 seconds)

Variable		Estimate	Standard Error	T-Value	P-Value	Percent Change in PET
Pedestrian Speed		0.022*	0.010	2.100	0.036	– 2.20
Vehicle Movement	Left Turn	– 0.120**	0.039	– 3.076	0.002	11.28
	Right Turn	– 0.018	0.032	– 0.578	0.563	1.81
	U-Turn	– 0.042	0.204	– 0.210	0.834	4.19
	Through (Reference)	-	-	-	-	-
Intercept		0.463 ***	0.036	12.826	$< 2 \times e^{-16}$	– 58.84

Akaike Information Criterion= 716.25; PET = post-encroachment time; *** Significant at 99.9% confidence interval; ** Significant at 99% confidence interval; * Significant at 95% confidence interval; $^{+}$ Significant at 90% confidence interval.

Limitations

The near-miss rate model and the near-miss severity model both rely on a 7-day sample of data from six intersections. Although the number of near-miss events captured during this timeframe lends itself to model interpretation, some limitations exist. First, it should be emphasized that the six sites selected for analysis have high vehicle volumes, relatively high speeds, are on multilane roads, and are in Fairfax County, Virginia, an urban area. Although this similarity was the intention of the data collection and necessary to capture sites with high pedestrian volumes, the results may not be transferable to other settings. Furthermore, because the scope of the study is limited to crosswalk markings in good condition, the findings may not apply to sites with faded or deteriorated markings. The data for this study relied on machine vision analysis of recorded video footage at the sites; therefore, the data may contain some erroneous events, such as pedestrians on scooters classified as pedestrians or missing data when the footage did not capture all pedestrians.

CONCLUSIONS

- *VDOT IIM-TE-384.1 guidance regarding HVC usage at unsignalized and uncontrolled crossings is supported by the existing literature on HVC effectiveness*. VDOT IIM-TE-384.1 requires HVCs at all unsignalized and uncontrolled crossings except stop-controlled approaches. The literature generally found HVCs to have a statistically meaningful effect on driver behavior in these contexts. Many localities reported using transverse or decorative markings at unsignalized crossings, where research would support the use of HVCs to improve safety.

- *The available research does not support a change to VDOT IIM-TE-384.1 guidance regarding HVCs at roundabout crossings and at pedestrian hybrid beacon crossings*. VDOT-IIM-TE-384.1 requires HVCs at roundabouts and PHBs. No research has been conducted on HVC effectiveness in these contexts. However, the safety findings from midblock crossings may be relevant to PHB environments, and those from uncontrolled intersections may be relevant to roundabout environments.

- *The available research does not support a change to the VDOT IIM-TE-384.1 recommendation of bar pair over longitudinal HVCs*. The available research does not indicate that one is more effective than the other. VDOT identifies bar pair markings as easier for motorcyclists, bicyclists, and pedestrians to avoid, and the markings may become slippery when wet. However, during the site selection for this research study, it was observed that longitudinal markings appear to be more common than bar pair markings statewide. Furthermore, in the survey conducted in Task 2, localities rarely reported HVCs with bar pair markings.

- *The available research and the findings from this study do not support a change to VDOT IIM-TOD-400 recommendations regarding HVCs at signalized intersections. No differences in near-miss behavior were detected between HVCs and transverse markings at signalized intersections in this study*. VDOT IIM-TOD-400 recommends using engineering judgment to determine crossing marking type (HVC versus transverse) at signalized intersections. The existing literature lacks findings that would support a more precise recommendation. Some evidence suggests that HVCs at signalized intersections improve pedestrian compliance (i.e., whether pedestrians crossed at the crosswalk rather than outside it). In locations where pedestrian compliance is a concern, an HVC may be an appropriate safety intervention. HVC variables were not significant in either the near-miss count model or the near-miss severity model presented in this report. This finding indicates that in the intersection contexts examined in the study, crosswalk marking type was not a primary indicator of the likelihood of a near miss occurring or of its severity. This outcome supports the existing guidance that engineering judgment be used to determine crosswalk marking type at signalized intersections.

- *Analysis of pedestrian-vehicle near-miss rates suggests that skewed intersections increase the rates of near misses*. This finding, along with the preceding conclusion, provides support for the importance of conducting the ongoing Virginia Transportation Research Council (VTRC) project "Investigating Contributing Factors and Potential Countermeasures to Reduce Pedestrian Crashes at Intersections," which examines skew and turning radius impacts on pedestrian visibility and safety.

- *Analysis of pedestrian-vehicle near-miss rates suggests that nighttime hours increase the rates of near misses*. This result was significant despite the presence of streetlights at all study sites.

- *Analysis of pedestrian-vehicle near-miss severity suggests that right turning vehicles are associated with lower PET values (more severe near misses) compared with through vehicles*. Right turning vehicles are a known risk factor for pedestrian safety. None of the study sites had right-turn-on-red restrictions or leading pedestrian intervals which are possible pedestrian safety interventions for right turning vehicles.

- *Analysis of pedestrian-vehicle near-miss severity suggests that higher pedestrian speeds are associated with lower PET values*. Pedestrian behavior under these circumstances, such as running for a bus or crossing against the pedestrian signal, may explain the association; however, it cannot be determined from the available data.

- *Protected left turn phasing at one intersection eliminated conflicts between pedestrians and left turning vehicles during the study period*. Although this finding appears to be intuitive, it is not necessarily expected because it relies on pedestrian compliance with the pedestrian signal during a left turn movement and driver compliance with the left turn signal. During the study period, hundreds of near misses occurred at the study sites between through vehicles and pedestrians that likely represent a vehicle running a red light or a pedestrian crossing against the pedestrian signal, both related to compliance. The vendor provided data, including some information regarding compliance, but not for all interactions. The protected left turn was effective in preventing pedestrian-vehicle interactions at this intersection, but this resolution does not necessarily imply generalizability because the intersection also had a very long crossing distance that may have discouraged pedestrians from attempting to cross without a pedestrian signal.

RECOMMENDATIONS

1. *VDOT should continue to recommend the use of HVCs at unsignalized and uncontrolled crossings where a crosswalk is marked as described in VDOT IIM-TE-384.1 and continue to recommend engineering judgment for the use of HVCs at signalized intersections as described in VDOT IIM-TOD-400*. No changes to the existing VDOT Instructional and Informational Memorandums are recommended based on the results of this study.

2. *VTRC should conduct additional research on several topics relevant to this study*. First, use available data to assess the correlation between pedestrian phase activation and pedestrian counts. The data collected for the six sites analyzed in this study include pedestrian phase activation and pedestrian counts. A follow-up analysis could examine the relationship between these two datasets to understand use cases for readily available pedestrian phase activation data. Second, identify the rationale for infrequent use of bar pair crosswalk markings. VDOT identifies bar pairs as being the preferred HVC crosswalk marking because they are easier for pedestrians, bicyclists, and motorcyclists to avoid when slippery and use less marking material than longitudinal markings. However, they appear to be infrequently used, as researchers identified during the site selection process and based on locality survey responses. Considering VDOT's identification of a safety benefit to bar pair markings, VDOT may consider determining why they are infrequently used.

IMPLEMENTATION AND BENEFITS

The researcher and the technical review panel (listed in the Acknowledgments) for the project collaborate to craft a plan to implement the study recommendations and determine the benefits of doing so. This process is to ensure that the implementation plan is developed and approved with the participation and support of those involved with VDOT operations. The implementation plan and the accompanying benefits are provided here.

Implementation

Regarding Recommendation 1, the Traffic Operations Division will continue to recommend using HVCs at unsignalized and uncontrolled crossings where a crosswalk is marked, as described in VDOT IIM-TE-384.1, and continue to recommend engineering judgment for using HVCs at signalized intersections, as described in VDOT IIM-TOD-400.

Regarding Recommendation 2, the Traffic Operations Division and VTRC will develop two research needs statements for submission to the Traffic Operations and Safety Research Advisory Committee (TOSRAC) subcommittee on Safety and Traffic Control Devices in the fall of 2026. The first research needs statement will propose an analysis of pedestrian phase activation and pedestrian count data to determine the feasibility of pedestrian phase activation data as a surrogate for pedestrian exposure data at signalized intersections. The second research needs statement will revise the existing language in the 2025 TOSRAC research needs statement, "Variations of Marking Spacing on High Visibility Crosswalks," to highlight the two alternatives to traditional longitudinal markings (bar pairs and narrow longitudinal markings, which may share the same benefits of bar pairs). The forthcoming statewide crosswalk inventory may be used to determine potential cost savings based on existing crosswalk markings statewide.

Benefits

The benefits of implementing Recommendation 1 are as follows. Continuing to recommend HVCs at unsignalized and uncontrolled crossings as described in VDOT IIM-TE-384.1 ensures that HVCs are being used in contexts in which research has shown positive safety benefits. Continuing to recommend engineering judgment at signalized intersections allows for flexibility and cost savings at sites where VDOT engineers do not believe that HVCs are warranted because VDOT reports that HVCs are five times the cost of transverse crosswalks.

The benefits of implementing Recommendation 2 are as follows. This study identified that bar pair HVC crosswalk markings have a potentially underutilized safety benefit. VDOT recommends bar pairs when HVCs are marked, but practically, bar pairs are not broadly deployed. In addition, this study successfully used pedestrian signal actuation data to identify crosswalks with relatively high pedestrian activity suitable for near-miss analysis. Pedestrian signal actuation data represent a large dataset of surrogate pedestrian activity data that could be further explored, and establishing correlations between pedestrian actuations and count data could establish the degree to which actuation data are a reliable predictor of observed pedestrian volume.

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APPENDIX

Statewide Survey of High Visibility Crosswalk Implementation Practices

Researchers at the Virginia Transportation Research Council (VTRC, the research division of the Virginia Department of Transportation) are conducting VTRC Project 124330, "Developing Guidelines for Context Specific Crosswalk Design."

The purpose of this work is to assess the impact of crosswalk marking design on pedestrian safety metrics. To support this research a survey has been developed which asks about local guidance for High Visibility Crosswalk (HVC) markings. Your feedback will assist the researchers in understanding the state of practice for HVC marking types statewide. Traffic engineering staff and public works staff are best suited to answer the questions on this survey.

To assist this effort, please complete this survey by October 8, 2024. Please forward this email to anyone you think may be well-equipped to respond. If you have any questions about the survey, contact Erin Robartes at VTRC (erin.robartes@vdot.virginia.gov).

Question 1. Please provide the following information:

Name: ____
Locality: ____
Title: ____
Email address: ____

High Visibility Crosswalk Background

High Visibility Crosswalk (HVC) markings are distinctive from standard transverse (parallel) lines in that they consist of wide longitudinal lines, ladder markings or a bar-pair pattern (see Figure below).

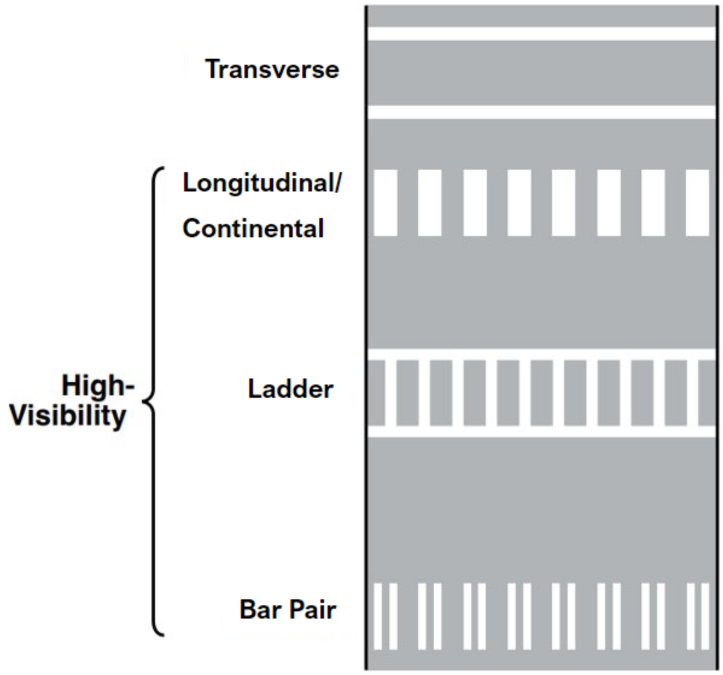

Figure adapted from the MUTCD.

Question 2. Which of the following applies to your locality regarding selecting crosswalk marking types?

- ☐ We have developed and follow our own set of guidelines for crosswalk markings.
- ☐ We follow VDOT guidelines (link to VDOT IIM-TE-384.1).
- ☐ We follow national guidelines, e.g. *Manual on Uniform Traffic Control Devices* (MUTCD).
- ☐ We currently do not have a written set of guidelines.
- ☐ Other (please specify below) ____

Question 3. Please share with the researchers any documentation of these guidelines by uploading below. Alternatively, you may email Erin.Robartes@VDOT.virginia.gov.

Question 4. The VDOT Instructional and Informational Memorandum (IIM) 384.1 "Pedestrian Crossing Accommodations at Unsignalized Approaches" was last updated in August of 2022. Are you familiar with the updates that were made in this version?

- ○ No, I'm not familiar with this document.
- ○ Yes, I'm familiar but have not read it yet.
- ○ Yes, I've read it and do not plan to implement it as written.
- ○ Yes, I've read it and am planning to implement updates in my locality.
- ○ Yes, I've read it and have already implemented updates in my locality.

Question 5. Which of the following HVC marking patterns currently exist in your locality? Select all that apply.

- ▢ Longitudinal/Continental
- ▢ Ladder
- ▢ Bar Pair
- ▢ HVC patterns are not used in my locality
- ▢ Unsure

Question 6. Which type(s) of crosswalk markings currently exist in your locality at UNSIGNALIZED crossings (either midblock or intersection)? Select all that apply.

- ▢ HVC (any pattern)
- ▢ Transverse
- ▢ Decorative markings (e.g. brick pavers, colored)
- ▢ Unsure

Question 7. Please explain what factors affect the selection of the type of crosswalk markings deployed at UNSIGNALIZED crossings in your locality.

Question 8. Which type(s) of crosswalk markings currently exist in your locality at SIGNALIZED intersections? Select all that apply.

- ▢ HVC (any pattern)
- ▢ Transverse
- ▢ Decorative markings (e.g. brick pavers, colored)
- ▢ Unsure

Question 9. Please explain what factors affect the selection of the type of crosswalk markings deployed at SIGNALIZED crossings in your locality.

Question 10. Which of the following does your locality currently have? Select all that apply. Please click this link for additional information on these options if unsure.

- ▢ Roundabout(s)
- ▢ Pedestrian hybrid beacon(s)
- ▢ Rectangular rapid flashing beacon(s)
- ▢ My locality does not have any of these.
- ▢ Unsure

Question 11. Which type(s) of crosswalk markings exist in your locality at roundabouts for pedestrian crossings? Select all that apply.

- ▢ HVC (any pattern)
- ▢ Transverse
- ▢ Decorative markings (e.g. brick pavers, colored)
- ▢ There are no marked crosswalks at the roundabout(s) in my locality
- ▢ Unsure

Question 12. Please explain what factors affect the selection of the type of crosswalk markings deployed at roundabouts in your locality.

____

Question 13. Which type(s) of crosswalk markings exist in your locality at pedestrian hybrid beacons? Select all that apply.

- ▢ HVC (any pattern)
- ▢ Transverse
- ▢ Decorative markings (e.g. brick pavers, colored)
- ▢ Unsure

Question 14. Please explain what factors affect the selection of the type of crosswalk markings deployed at pedestrian hybrid beacons in your locality.

____

Question 15. Which type(s) of crosswalk markings exist in your locality at rectangular rapid flashing beacons? Select all that apply.

- ▢ HVC (any pattern)
- ▢ Transverse
- ▢ Decorative markings (e.g. brick pavers, colored)
- ▢ Unsure

Question 16. Please explain what factors affect the selection of the type of crosswalk markings deployed at rectangular rapid flashing beacons in your locality.

____

Question 17. Within your locality, which of the following materials are used for HVC and Transverse crosswalk markings? Select all that apply.

	Thermoplastic	Preformed Tape	Methyl Methacrylate (MMA)	Epoxy	Paint	Unsure	Other (please describe below)
HVC	☐	☐	☐	☐	☐	☐	☐
Transverse	☐	☐	☐	☐	☐	☐	☐

Question 18. Which of the following materials will your locality be using for marking HVC and Transverse crosswalks moving forward? Select all that apply.

	Thermoplastic	Preformed Tape	Methyl Methacrylate (MMA)	Epoxy	Paint	Unsure	Other (please describe below)
HVC	☐	☐	☐	☐	☐	☐	☐
Transverse	☐	☐	☐	☐	☐	☐	☐

Question 19. Which of the following factors affect decisions on frequency of refreshment/replacement of HVC and Transverse markings in your locality? Select all that apply.

	Staff Observations	Citizen Requests	Fixed Schedule, e.g. annually	Based on an asset management system/inspection program
HVC	☐	☐	☐	☐
Transverse	☐	☐	☐	☐

Question 20. Please describe if there are any other factors that affect decisions on the frequency of refreshment/replacement of HVC and Transverse markings.

HVC ____

Transverse ____

Question 21. Please describe how frequently you refresh/replace crosswalk markings in your locality.

____