RESEARCH & DEVELOPMENT

Yielding Compliance at High Visibility Crosswalks

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16. Abstract

Marked crosswalks are a type of traffic control device that indicate to drivers where to expect people crossing the street, indicate to pedestrians where to cross, and - in the case of a midblock location – create a legal crosswalk. Marked crosswalks can be either basic (e.g., transverse lines) or high-visibility (e.g., continental, bar pair, or ladder). The NCDOT's current state of practice is to only use high-visibility crosswalks (HVCs) at midblock locations, where there are vulnerable populations like children or the elderly crossing, or where drivers are less likely to expect pedestrians. Local agencies are starting to use HVCs more broadly, even as their standard marking. As the number of HVCs within an area increases, could it dilute their effectiveness at special emphasis areas? This report describes research conducted to determine what impact the crosswalk marking style has on driver yielding and pedestrian compliance, and, secondly, to determine what happens to the effectiveness at existing HVCs as a community's overall number of HVCs increases. The study sampled 65 out of 189 crossings across three study areas (Cary, Clayton, and Raleigh) where observational driver yielding events were collected using a staged pedestrian crossing protocol. Video footage collected at each site was also reduced to extract motor vehicle through and turning counts, pedestrian crossing volume, and pedestrian compliance. Sampled sites varied in marking style (HVC, transverse, or unmarked), signal control type (uncontrolled, signalized), posted speed limits (25-35 mph), and number of lanes (1-3). Data were collected at all 65 sites before and after 18 of the crossings were converted to HVCs. A comparative analysis of the before-after dataset found that on average driver yielding increased by 22% at sites that were converted to HVCs, which was statistically significant difference from the change in yield rate observed at the sites that where the crosswalk remained the same. The increase in yielding was most prominent at unmarked crossings that were converted to an HVC; however, sites where transverse lines were modified to HVCs also saw an increase in yielding rates. The increase in driver yielding at the signalized treated group it was not statistically significant from that of the signalized control group. Pedestrian compliance increased at a statistically greater rate at the treated sites. Increases in saturation rates of HVCs across the three study areas varied from 11.3% to 29% with a maximum of 35.7% saturation achieved in Raleigh in the after period. Further research is needed to determine whether yield rates begin to decline at HVCs as an area's saturation level increases to a percentage higher than 40%, but a cautious conclusion that can be drawn from this study is that the increase of the saturation of HVCs was not found to negatively impact the effectiveness of such a marking at existing sites. Based on these research findings, using an HVC style more prevalently does not appear to dilute their effectiveness and, indeed, their use is likely to result in drivers yielding more to pedestrians at crosswalks, thereby improving safety for people traveling on foot.

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Executive Summary

Marked crosswalks are a type of traffic control device that indicate to drivers where to expect people crossing the street, indicate to pedestrians where to cross, and – in the case of a midblock location – create a legal crosswalk. Marked crosswalks can be either basic (e.g., transverse lines) or high-visibility (e.g., continental, bar pair, or ladder). The NCDOT's current state of practice is to only use high-visibility crosswalks (HVCs) at midblock locations, where there are vulnerable populations like children or the elderly crossing, or where drivers are less likely to expect pedestrians. Local agencies are transitioning to using HVCs more broadly, or even as their standard marking. This raises a concern of whether increasing the number of HVCs within an area may dilute their effectiveness at special emphasis areas.

This report describes research conducted to determine what impact a high-visibility crosswalk marking style has on driver yielding and pedestrian compliance, which were used as performance measures, and, secondly, to determine what happens to the effectiveness at existing HVCs as a community's overall number of HVCs increases. The study sampled 65 sites out of 189 crossings across three study areas (Cary, Clayton, and Raleigh) where observational driver yielding events were collected using a staged pedestrian crossing protocol. Video footage also collected at each site was reduced to extract motor vehicle through and turning counts, pedestrian crossing volume, and pedestrian compliance (e.g., whether the pedestrian crossed at the crosswalk or outside of the crosswalk). Sampled sites varied in marking style (HVC, transverse, or unmarked), signal control type (uncontrolled, signalized), posted speed limits (25, 30, or 35 mph), and number of lanes (1, 2 or 3). Data were collected at all 65 sites before and after 18 of the crossings were converted to HVCs.

A comparative analysis of the before-after dataset found that on average driver yielding increased by 22% at sites that were converted to HVCs (treatment group), which was statistically significant difference from the change in yield rate observed at the sites that where the crosswalk remained the same (control group). The increase in yielding was most prominent at unmarked crossings that were converted to an HVC; however, sites where transverse lines were modified to HVCs also saw a marked increase in yielding rates. Further, splitting the treatment and control groups into those at signalized sites compared to those at uncontrolled sites, revealed that though there was an increase in driver yielding at the signalized treated group it was not statistically significant from that of the signalized control group. In other words, converting crosswalks to HVCs at signalized locations may not have a significant impact on driver yielding. At uncontrolled sites, though, converting a crosswalk to an HVC significantly increased the yield rates compared to the uncontrolled control group. Pedestrian compliance also increased at a statistically greater rate at the treated sites, regardless of whether it was a signalized or uncontrolled location.

While driver yielding and pedestrian compliance were the primary measures of effectiveness to determine how HVCs influence pedestrian safety, this study also developed a regression model for estimating driver yield rates in order to understand what other variables may also influence driver behavior. This exercise revealed the effect of marking type along with traffic control type, area type (e.g., residential, CBD, etc.), and other factors on driver yielding.

Answering the question of how an increase in the prevalence of HVCs may impact the effectiveness at existing HVCs proved difficult, in large part because HVCs are currently used very sparingly in North Carolina. This, combined with reliance on local agency support to convert a significant number of crossings to HVCs within the study period meant that the overall increases in saturation rates of HVCs across the three study areas varied from 11.3% to 29% from the before to after period, with a maximum of a 35.7% saturation level achieved in Raleigh in the after period. Further research is needed to determine whether yield rates begin to decline at HVCs as an area's saturation level increases to a percentage higher than 40%, but a cautious conclusion that can be drawn from this study is that the increase of the saturation of HVCs was not found to negatively impact the effectiveness of such a marking at existing sites in any of the study areas. Based on these research findings, using an HVC style more prevalently does not appear to dilute their effectiveness and, indeed, their use is likely to result in drivers yielding more to pedestrians at crosswalks, thereby improving safety for people traveling on foot.

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1 Introduction

Pedestrians are most vulnerable when crossing the street – almost 60% of pedestrian crashes in North Carolina occur when pedestrians are crossing, compared to less than 30% occurring in parking lots or other non-roadway areas (like private driveways) or about 10% involving a pedestrian walking along a road.[1] Marked crosswalks are one type of traffic control device that indicate to drivers where to expect people crossing the street, indicate to pedestrians where to cross, and – in the case of a midblock location – create a legal crosswalk. The 2009 Manual on Uniform Traffic Control Devices (MUTCD) allows for several different patterns or styles to mark a crosswalk, including basic transverse parallel lines or several different high visibility marking patterns that use diagonal or longitudinal lines (Figure 1-1).

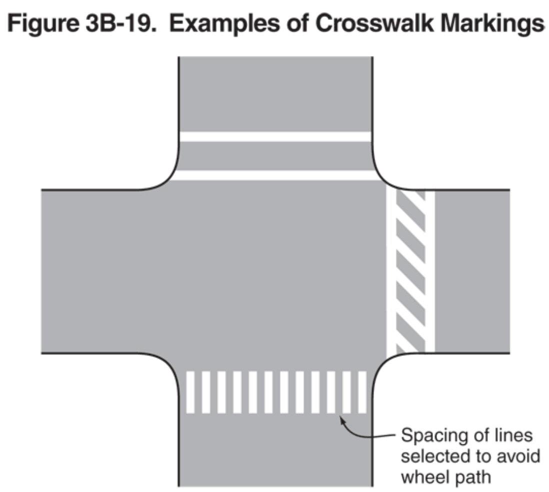

Figure 1-1. Copy of Figure 3B-19 from the 2009 MUTCD showing the basic crosswalk marking on the north leg and two variations of HVC style markings on the east and south legs.

Current MUTCD guidance suggests using the high visibility styles "at locations where substantial numbers of pedestrians cross without any other traffic control device, at locations where physical conditions are such that added visibility of the crosswalk is desired, or at places where a pedestrian crosswalk might not be expected."[2] This guidance leaves leeway for agencies to use engineering judgement and develop policies to determine where and how frequently high visibility crosswalks (HVCs) should be used. Discrepancies in the implementation of different marking styles within and across jurisdictions may lead to confusion for both pedestrians and drivers, creating the possibility of vehicle-pedestrian conflicts as both parties may have different expectations of the situation.

Currently, NCDOT's state of practice is to only use HVCs at midblock locations[3] or where there is a vulnerable pedestrian population like children or the elderly, or where drivers are less likely to expect pedestrians.[4] This limited use conflicts particularly with local agencies, such as Charlotte and Raleigh, that have transitioned to using an HVC style as its standard or default marking, regardless of whether the crosswalk is at an uncontrolled or controlled location. These agencies want to continue to use their HVC standard on state-owned roads within their jurisdiction; however, this raises a concern of whether increasing the number of HVCs within a community may dilute the effectiveness of a high visibility marking style in general. In other words, do drivers become so accustomed to seeing HVCs that they no longer stand out as a unique traffic control device to increase driver alertness to monitor for pedestrians? This concern implies that HVCs, in general, are more effective at inducing driver yielding compliance than the standard transverse markings.

In order to better inform NCDOT's policies regarding the broader use of HVCs, this report describes research conducted to first determine a) whether yield rates increase when HVCs are installed; and if so, then b) what happens to the yielding rate at any given HVC as an area becomes saturated with HVCs.

This report is organized into eight sections. Following this introduction, Section 2 provides an overview of relevant literature from peer-reviewed studies as well as context around existing national, state, and local policies, standards, and practices regarding the use of HVC markings. Section 3 explains the methods used in this study from site selection to data collection. Section 4 lays out the results and findings based on analyses conducted and offers a model of driver yielding behavior to demonstrate how other site factors may influence this measure of effectiveness. Conclusions based on these findings are summarized and recommendations for consideration of next steps are suggested in Section 5. Finally, the body of the report wraps up with Section 6, where the authors propose plans for future implementation and technology transfer to move from the research into practice. Sections 7 and 8 round out the report by supplying references cited throughout it as well as appendices for further background and documentation of the study sites, protocol details, and supplements to the model development work.

2 Review of the Literature

Other research and guidance can be consulted that focuses on where to mark a crosswalk. This report begins with the assumption that the decision has already been made to mark one, and the question is which marking style should be applied. Few studies have explicitly compared measures of effectiveness between basic (transverse parallel lines) and high visibility crosswalk styles. This section will highlight those studies, lay out national and state policies, current state and local practices, and briefly discuss research approaches used to measure safety impacts at crossing locations.

2.1 Marking Style Studies

While research suggests that motorists are more aware of pedestrians, lower their speeds, and are more likely to yield at marked crosswalks than unmarked crosswalks,[5,6] it is less clear for when that marking should be high visibility. Fitzpatrick et al. established that HVCs are indeed more visible to both drivers and pedestrians[7], but the research is mixed when teasing out what effect HVCs have on pedestrian safety when measured via pedestrian crash rates or vehicular yield rates.

For example, Zegeer et al. found no significant effect of marking style on pedestrian crashes when comparing sites with basic lines to those with HVCs, but their study only analyzed pedestrian crashes and did not consider the effectiveness of these treatments on yielding rates.[8] Another study conducted in New York evaluated the effects of five different treatments, one of which was HVCs, by counting the number of vehicle-pedestrian and vehicle-vehicle collisions before and after the treatments were installed and comparing results with those from untreated sites. Chen et al. found that vehicle-pedestrian collision rates decreased more at sites where HVCs were installed while vehicle-vehicle collisions decreased more at untreated sites, suggesting that HVCs "could potentially reduce pedestrian crashes but increase multiple-vehicle crashes."[9]

Rather than crash data, NCHRP 562 research focused specifically on the effect of various crossing treatments on driver yield rates and found that compliance varied from 10% to 61% (mean = 31%) across the three sites with HVCs and was largely influenced by vehicle speeds. Unfortunately, HVCs were combined with high visibility signage into one treatment type, and the study did not use a case control design to directly compare HVC sites to those with no marked crosswalks or basic marking styles.[10]

2.2 Other Studies on Yielding

It is difficult to isolate the effect of HVCs as a specific treatment as they are often installed in conjunction with other crossing treatments such as signage, beacons, curb extensions, or pedestrian refuge islands. In fact, a 2013 white paper by the Pedestrian and Bicycle Information Center recommends that HVCs be installed at uncontrolled crossing locations where a decision has been made to mark the crosswalk and further recommends additional treatments be used as a package along with the HVC.[11] These treatments make it safer and more comfortable for pedestrians to use the crossing as they aid in reducing or breaking up crossing distances, reducing motorist speeds, and make the crossing location itself and waiting pedestrians more visible to drivers. Therefore, other studies on yielding at HVCs are highlighted here for additional context.

A study in Florida evaluated the effect that the combination of an illuminated overhead sign and ladder style markings had on driver yielding and pedestrian behavior. The study found a significant increase in daytime yielding rate as well as an increase in nighttime yielding, although it was not statistically significant.[12] Another study used a before/after design to assess eight locations where HVCs were installed as part of a package of treatments (e.g., median refuges, Danish offsets, and pedestrian channelization) and found that yielding rates increased after the full installation of the package; however, the conclusions regarding the influence that HVCs had on this outcome are unclear because driver yielding rates appeared to decrease when five of the HVCs were first installed as individual treatments.[13]

2.3 Pedestrian Compliance

One reason to mark a crosswalk is to alert people walking to a specific crossing location, ideally helping to control where people choose to cross by attracting them to a safer, preferred location. Studies have shown mixed results on how effective HVCs are in attracting and increasing pedestrian use of the crosswalk location rather than crossing the street outside of the crosswalk. Nitzburg and Knoblauch found "that pedestrians are more likely to use high-visibility crosswalks than crosswalks marked with standard markings or unmarked crosswalks."[14] Pulugurtha et al. found that HVCs do not lead to a significant increase of pedestrians using a mid-block crossing. However, the study showed that other crossing treatments can improve pedestrian compliance, as there was a significant increase of pedestrians who went out of their way to cross when a Danish offset (2-stage crossing design using median refuge island) was available.[15] A study in Portland further showed the effects that multiple treatments can have on pedestrian compliance. The study found that a combination of treatments, including an HVC, had a higher percentage of pedestrian compliance than compliance found for marked crosswalks in another study. The effect that HVCs in particular had on this outcome was not determined, since they were a part of a package of treatments (e.g., installed along with rectangular rapid flashing beacons or Danish offset).[16]

2.4 National Policies

The National Committee on Uniform Traffic Control Devices (NCUTCD) released recommended changes to the MUTCD in 2011 and 2012 to add more specific guidance for the use of HVCs. These changes make a distinction between basic and high visibility marking styles (Figure 2-1.). They also proposed that HVCs should be used at all non-intersection crossings, be installed with other pedestrian crossing treatments where speeds exceed 35 mph, and have a minimum width of 8 feet.[17, 18]

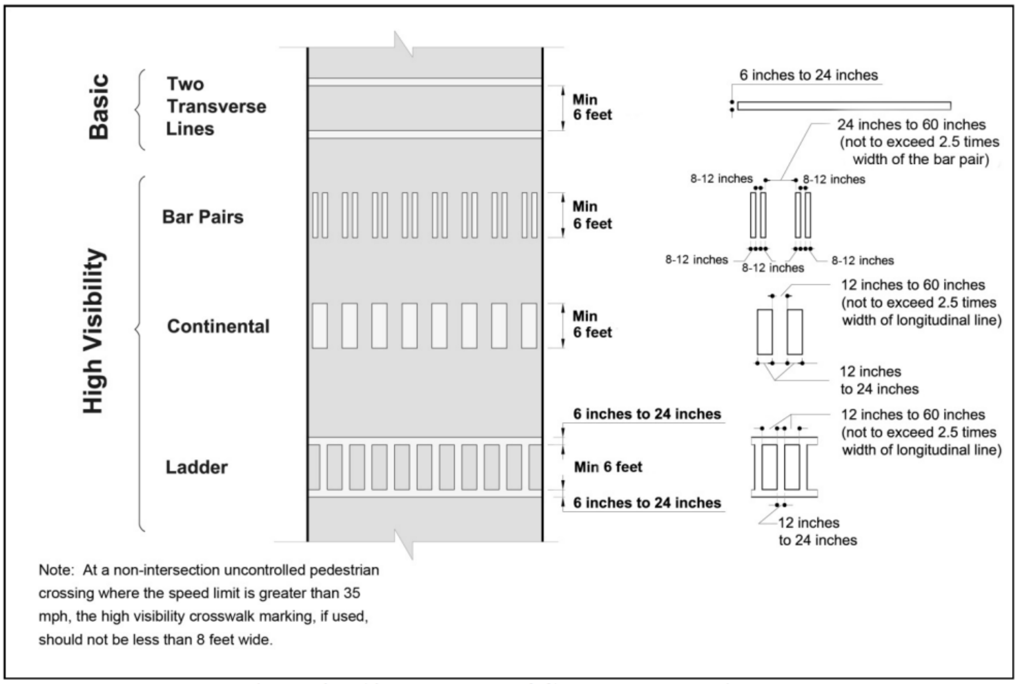

Figure 3B-19. Examples of Crosswalk Markings

Figure 2-1. NCUTCD recommended change for the MUTCD Figure 3B-19, approved by Council in January 2012, showing three different patterns of a HVC marking compared with the Basic marking style

The Federal Highway Administration (FHWA) states that HVCs should be strongly considered at all established midblock crossings. The reasoning is “A high visibility crosswalk is much easier for an approaching motorist to see than the traditional parallel lines.”[19] The FHWA also states that an HVC should be considered at all uncontrolled crossings and encourages parking restrictions and increased lighting in combination with an HVC to further increase pedestrian visibility.

AASHTO’s *Guide for the Planning, Design, and Operation of Pedestrian Facilities* (2021) states HVCs are recommended over basic markings where “(a) substantial numbers of pedestrians cross without any other traffic control device, (b) physical conditions are such that added visibility of the crosswalk is desired, or (c) a pedestrian crosswalk might not be expected.”[20]

The National Association of City Transportation Officials (NACTO) provides additional recommendations in their *Urban Street Design Guide*. The guide recommends to “stripe all signalized crossings to reinforce yielding of vehicles turning during a green signal phase.”[21] The guide also states that “high-visibility ladder, zebra, and continental markings are preferable to standard parallel or dashed pavements markings. These are more visible to approaching vehicles and have been shown to improve yielding behavior.”[20] Both of these recommendations are to increase the visibility of the crosswalks and to draw the drivers’ attention to pedestrians using the facilities.

2.5 North Carolina Policies and Standards

The *NC Pedestrian Crossing Guidance* is a useful resource to NCDOT and local agencies to help them determine when to consider marking a crosswalk[22]; however, the guide falls short in recommending which marking style to use beyond the reference to NCDOT’s midblock crossing policy.[23] Some municipalities within North Carolina offer other situations for when HVC styles should be used in lieu of the basic markings. For example, Wilmington's *Technical Standards and Specifications Manual* states that a "special emphasis crosswalk" or an HVC should be used "at busy signalized intersections where bicycle and pedestrian traffic require increased visibility."[24] Charlotte uses the bar-pair pattern at signalized intersections, school zones, and midblock locations.[25] Raleigh recommends using the continental pattern at all signalized and uncontrolled intersections.[26]

2.6 Other State or Local Agencies that use HVCs

Nationally, agencies are using HVCs more frequently. Below are examples of agencies outside of North Carolina that use HVCs as their standard as well as the criteria under which they may be used.

Brookline, MA switched to using basic and ladder marking styles in 2006. In the city's *Crosswalk Policy and Design Guidelines*, the ladder marking style is listed as the default style for all unsignalized intersections, uncontrolled intersections, and mid-block crossings; basic lines are only used at signalized intersections.[27] Chicago started using continental crosswalks as the default marking style in 2012.[28] The San Francisco Municipal Transportation Agency released a memo in 2014 setting continental markings as the standard, as well as setting a long-term goal of converting all of the crosswalks currently marked with the basic pattern to either continental or ladder style.[29] A few other municipalities who use HVCs as their standard include San Diego and New Orleans (continental),[30, 31] and Seattle (bar pair).[32]

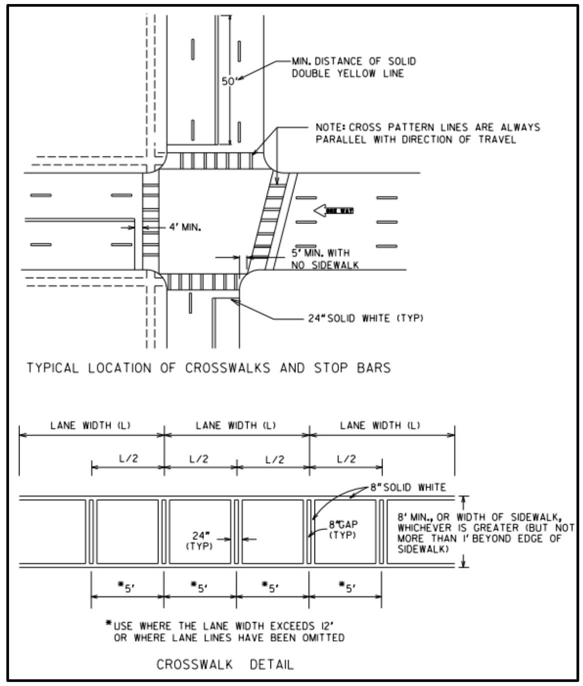

Figure 2-2. Example of bar pair marking detail with transverse lines, from Georgia DOT Detail T-11A.

At least three state DOTs also use HVCs as the standard marking style. Minnesota and Washington State Departments of Transportation use the continental pattern,[33, 34] while Georgia DOT's standard is a bar pair with transverse lines[35] (see Figure 2-2) regardless of the crossing location to be marked. Both Washington and Georgia allow all the marking styles listed in the MUTCD, but Washington only uses their standard "on state highways where the pavement markings are maintained by" WSDOT,[36] while GDOT "strongly prefer[s] for crosswalk patterns to be striped per" their detail.[37]

3 Methodology

3.1 Measuring Driver Yielding

An essential part of any study of the safety effects of crosswalk markings is finding a way to measure driver and pedestrian compliance with the crosswalks. Two commonly used measurements are vehicle-pedestrian interactions (e.g., crashes or conflicts) and drivers' yielding rates at a crosswalk. Often, crash data are too scarce or require a very large number of crosswalk sites to be meaningful. The yielding rates of drivers at a crosswalk are influenced by a multitude of factors but are often more straightforward to observe than conflicts. Previous studies on crosswalk safety and driver yielding rates have used techniques like incorporating comparison control sites and staging pedestrian crossings to control for these factors.

Studies have shown a bias in driver yielding rates depending on the physical characteristics of the pedestrian who is crossing. One study used a staged pedestrian holding a black cane similar to guide canes used by blind people for half of the crossings and holding a black umbrella in the other half. The study found that a driver was more likely to respond to a pedestrian who seemed blind.[38] Another study found that drivers are more likely to safely yield to pedestrians they perceive as similar to them (for example similar age and same sex).[39] Racial bias has also been shown to affect a driver's decision to yield. A study using three white and three black males, of similar age and build, wearing identical outfits, found that drivers were less likely to yield to black pedestrians and that black pedestrians experienced longer wait times.[40]

Some studies use staged pedestrian crossings to help provide a consistent situation for the drivers. In one such study, Fitzpatrick et al. had each pedestrian completing the crossing wear similar, neutral-color clothing. A second researcher recorded the driver yielding of each way of travel and any unusual events that might have occurred.[41] This technique of data collection helps control for consistency in how pedestrians approach the crossings across numerous trials and locations. Drivers might be less likely to yield if a pedestrian is standing too far away from the roadway, approaches timidly, or otherwise exhibits confusing behavior for the driver to interpret. Using the staged pedestrian method also allows for the researcher to generate a sufficient number of crossing trials to meet sampling demands and is thus a more efficient method than waiting to observe natural pedestrian behavior at a crossing, particularly ones that may have low pedestrian volume. Therefore, our team elected to use a staged pedestrian crossing protocol to conduct our study.

3.2 Site Selection

The research team conducted semi-structured interviews with NCDOT staff in Divisions 4, 5, 6, and 7 to identify prospective study areas in which to select candidate crossing sites. The team focused on this central region of the state in order to reduce travel costs and minimize the need for overnight trips. Questions aided to identify study areas where a Division may have contact information and a lead on a municipality that was interested in increasing the number HVCs and were willing and had the capacity to do so within the study timeframe. Study area criteria were as follows:

- Likely to be defined along a corridor, but could also be a small area of networked streets
- Must have at least 20 crossings within its inventory
    - Ideal if at least 5 of the crossing locations may be converted to an HVC style
    - Ideal if at least 10 of the crossings are already HVC style
- Where HVCs are to be installed, prefer they are NOT done as part of a resurfacing project

While it may be advantageous to use a corridor undergoing resurfacing as a study area, with the assumption that resurfacing could allow for virtually all the crossings impacted by the project to be converted to an HVC, the downside is that many other features of the corridor may also change, such as other marking features, pavement condition quality, and other factors that could inadvertently also impact driving behavior. Our goal was to identify sites where the only feature changing was the crosswalk marking, and all other road characteristics, geometries, and traffic patterns remained the same. The research team compiled a list of prospective municipalities to contact and narrowed it down to the three most promising study areas based on suitability of sites within each and the municipality's willingness to participate (i.e., restripe some crosswalks in a high-visibility pattern) during our study schedule. Additional phone interviews were attempted with staff from Apex, Cary, Clayton, Durham, Fuquay-Varina, Raleigh, and Wake Forest; and subsequent discussions were held with Division 4 staff regarding the inclusion of Clayton or Goldsboro, given that NCDOT Division forces were needed to carry out any installations of new markings in those locations.

The team ultimately selected study areas in Raleigh, Clayton, and Cary. These jurisdictions coordinated with the research team to identify areas within each municipality where a sample of at least 20 crossings met the following site selection criteria:

- 35 mph or less posted speed limit
- If 4 or more lane cross-section, Average Daily Traffic (ADT) is less than 12,000 vehicles per day (vpd)
- If 4 or more lane cross-section with a raised median, ADT is less than 15,000 vpd

and where at least 5 sites would be converted to an HVC. Each study area is further described in Table 3-1 along with a summary of the population of crossings and the sample where field observations were taken. We also preferred that sites be unsignalized, uncontrolled locations, but this proved difficult to meet, given the combination of factors for each given site and the need for all sites within a study area to be relatively proximate to one another.

Table 3-1 Quantity and Marking Type of Crossings in Each Study Area

a) Study Area Crossing Population	**Cary**	**Clayton**	**Raleigh**
Total number of crossings	62	57	70
Number with HVC (saturation as a percent of the population)	5 (8%)	1 (2%)	5 (7%)
Number with transverse line	23	17	57
Number unmarked	34	40	8
Number of crossings to be converted to HVC	7	8	20
Total Number of PBIN Point Features*	*129*	*85*	*341*
b) Sample of Crossing Sites Where Yields Were Observed	**Cary**	**Clayton**	**Raleigh**
Sample of crossings (intersections)	20 (12)	19 (8)	26 (12)
Sample with HVC	1	1	3
Sample with transverse line	14	12	21
Sample unmarked	5	6	2
Sample to be converted to HVC	7	6	6

**NCDOT's Pedestrian and Bicycle Infrastructure Network, a geodatabase of pedestrian and bicycle facilities*

Cary's study area is primarily along a neighborhood street corridor, Park St; however, it also includes more urban sites around Chatham St. just north of Park St for a total of 62 crossings. Of those, 20 were selected to gather observational field data around driver yielding and pedestrian compliance (Figure 3-1). There are five HVCs in Cary's study area, and seven new ones were added during the project, each of which were studied.

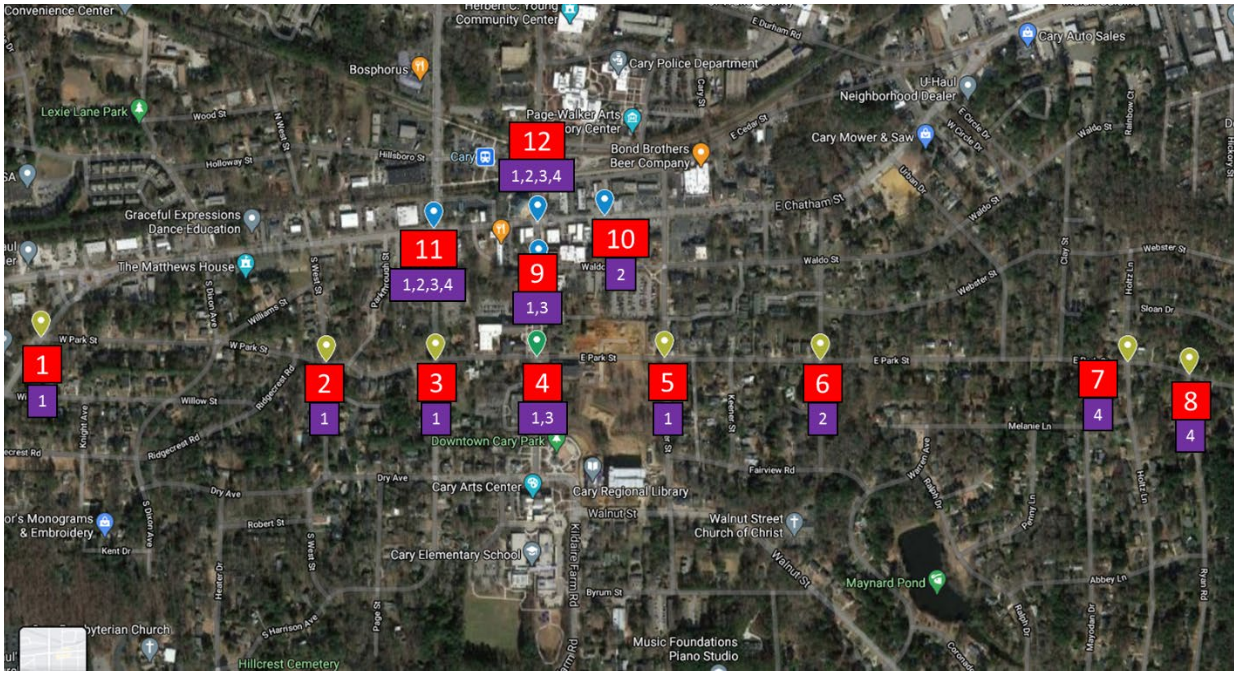

Figure 3-1. Cary Study Area Map. Red numbers identify each intersection where observational data were collected; purple numbers identify the crossing site sampled at a given intersection.

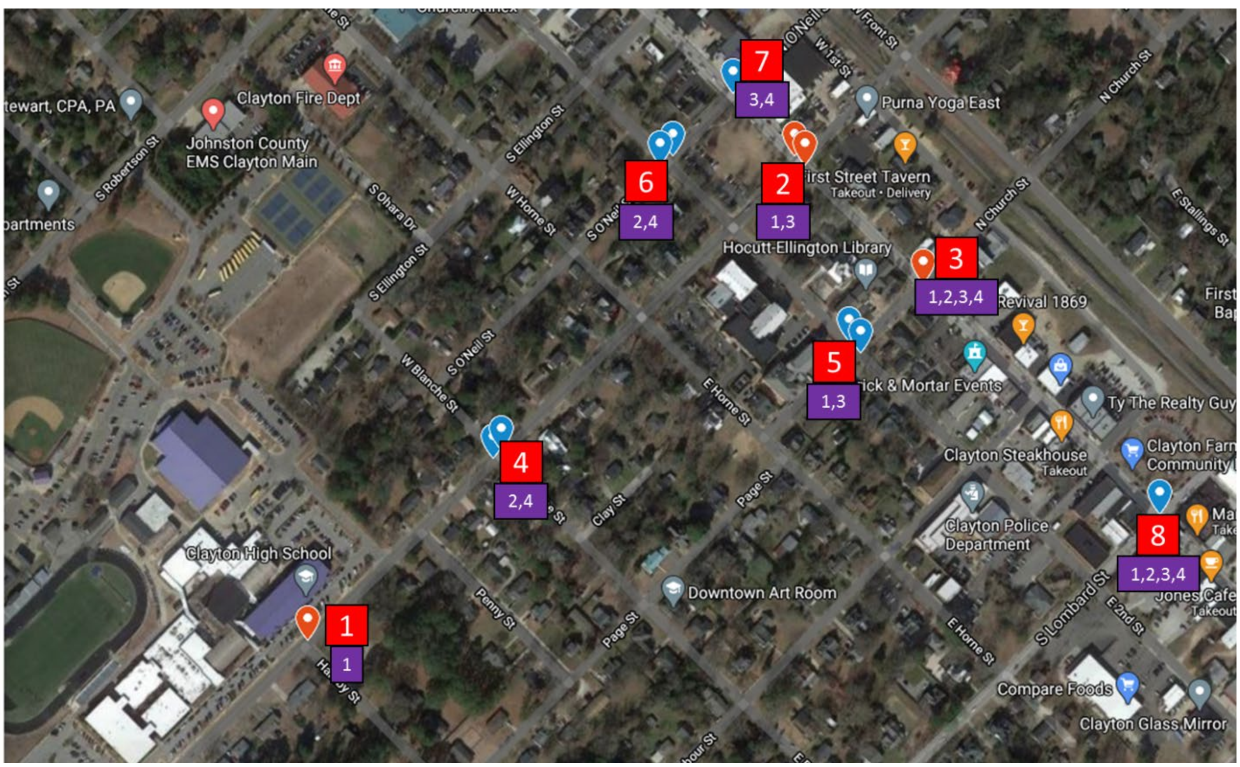

Figure 3-2. Clayton Study Area Map. Red numbers identify each intersection where observational data were collected; purple numbers identify the crossing site sampled at a given intersection.

Clayton’s study area consists of 57 crossings, with a sample of 19 locations where driver yield events were observed. (Figure 3-2) The majority of its sites are within its downtown core along three roads: Main Street, 2nd Street, and Fayetteville Street. Only one of its crossings was an HVC, and six crossings were converted to an HVC during the course of the study.

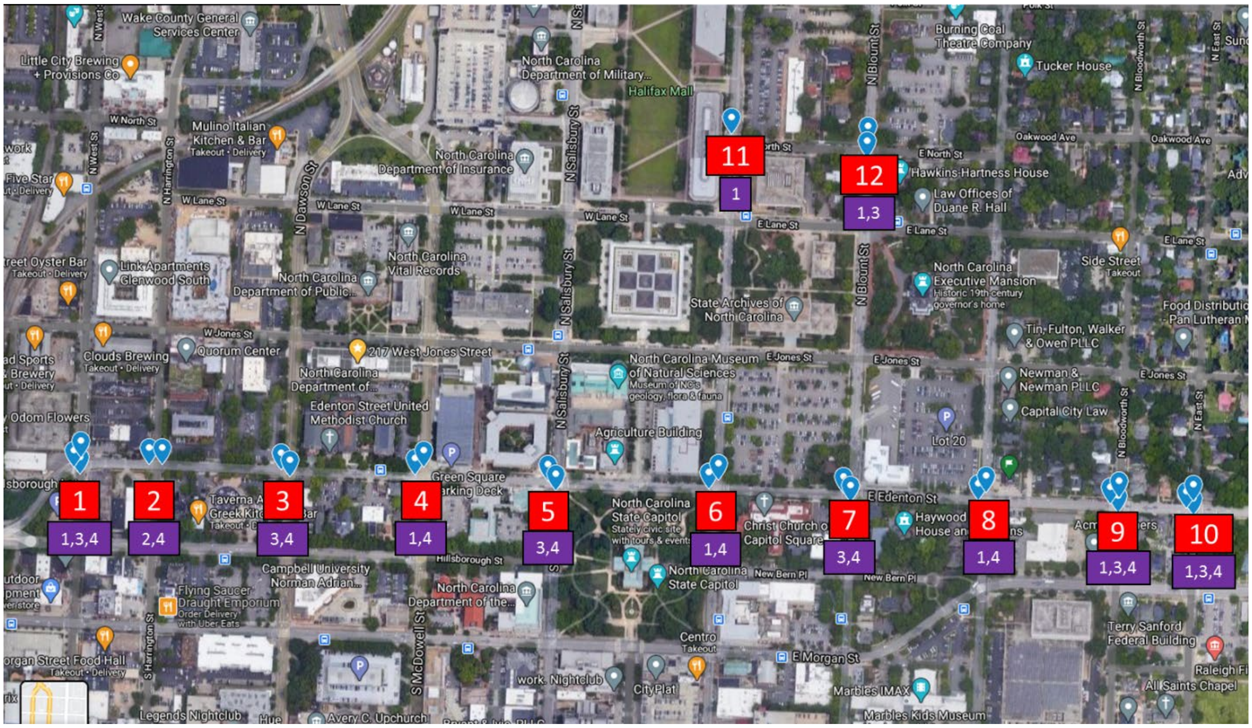

Figure 3-3. Raleigh Study Area Map. Red numbers identify each intersection where observational data were collected; purple numbers identify the crossing site sampled at a given intersection.

Raleigh’s study area focused primarily along the Edenton St. corridor in downtown. (Figure 3-3) This area was selected due to the high number of crossings to be converted by the City of Raleigh to HVCs. Unfortunately, the majority of this corridor’s intersections are signalized, so two additional non-signalized locations within two blocks of Edenton St. were added. Therefore, Raleigh’s study area consists of 70 total crossings, 26 of which were included for field data collection. Five of its 70 crossings were already marked in a high visibility style; 20 more HVCs were to be added during the project, and six of those were sampled for observational study.

3.3 Data Collection

Data collection consisted of two primary components: desktop review of each crossing location within the study area (e.g., the population of crossings) to create the study area inventory, and field observations at a sampling of those crossings to create additional data needed to understand driver yielding and pedestrian compliance.

3.3.1 Study Area Inventory

Researchers compiled an inventory of the population of crossings within each study area. Initial data was pulled from the existing facilities point data within the Pedestrian and Bicycle Infrastructure Network (PBIN). These PBIN data included:

- Existing Facility Type (pedestrian signal, curb ramp, curb extension, crosswalk)

- Existing Signage (Push Button (R10-3E), Pedestrian Traffic (W11-2), Yield Here to Pedestrians (R1-5))
- ADA Condition (0 = noncompliant, 1 = compliant)

Other facility types found in the PBIN beyond the standard attributes listed in the PBIN Data Catalog, which indicates it is not an exhaustive list, included advance stop markings, pedestrian button, or pedestrian pole.[42]

The PBIN data at each site were verified through a desktop review, where additional facility and site data were also added. The desktop review consisted of screening each crossing location in Google using both aerial and street view images to extract these site data. The additional data included:

- Posted speed limit
- Number of travel lanes
- Crossing distance (measured from curb to curb in Google)
- Existence of median/refuge island (0=no, 1=yes)
- Crosswalk marking style (none, transverse pair, ladder, continental)
- Marking condition (good, fair, poor, bad, not applicable)
- Other crossing treatments (yield markings, school crosswalk signage (S1-1))
- Area type (urban center, urban residential, suburban residential, suburban corridor, central business district)
- Sight distance considerations (nearby parking or driveway, grade, obstacle (tree, pole))

Area type categories used the definitions based on NCDOT's Complete Streets Guide. If known either from information provided by the municipality or through NCDOT maps, the AADT for each cross street was also added to the study area inventory for each site. From this inventory, crossing sites that met the selection criteria were labeled as "valid for study". Sites where marking condition was poor or worse, where there were site distance issues, where the speed limit was greater than 35, or where motor vehicle volumes were above our selection criteria cap were not considered for sampling. While we controlled for speed, motor vehicle volumes in relation to the number of lanes, and the traffic control type (to the extent possible), we allowed for variability in other factors such as area type crossing distance, and marking style. For those factors that varied, we attempted to select a balanced mix from those valid for study within and, to some extent, across each study area.

3.3.2 Field Data Collection

Field data were collected at the sample sites to round out the data variables of interest, including through and turning vehicle volumes, pedestrian crossing volume, pedestrian compliance, and yield events. Ultimately, field data were collected at 65 crossings within the three study areas. At each crossing site, two researchers collected driver yield data for up to two hours per intersection on dry-weather weekdays with an attempt to conduct the field data primarily in spring or fall seasons. One researcher served as the staged pedestrian while the other assisted with set-up and data recording tasks. The staged pedestrian was the same individual at each crossing site within a study area to ensure consistency in presenting the intent to cross, gender, positioning, stance, height, and race. The staged pedestrian also wore the same clothes at each crossing site. In addition to conducting staged pedestrian crossings, cameras were used to collect the volume data and pedestrian compliance events.

Set-up

Researchers measured out and discreetly marked the dilemma zone (which took into account motorist stopping distance based on the posted speed limit for that street, a default driver reaction time of three seconds and safe deceleration rate), upstream from the crosswalk using a small traffic cone near the curb or edge of the road. The cone was visible to the staged pedestrian from the crosswalk as well as to the camera setup.

The dilemma zone was marked for each vehicle approach to the crosswalk (i.e., for motorists approaching from either direction). At intersections (signalized or unsignalized), yielding of turning vehicles was also observed, and an assumed speed of 20 MPH was used to mark the dilemma zone for their approaches. The following pre-calculated distances were used based on posted speed limit:

- 35 MPH Posted speed: 183 ft
- 30 MPH Posted speed: 141 ft
- 25 MPH Posted speed: 104 ft
- 20 MPH Posted speed: 72 ft

Discreet mini-cameras were installed at least 8 ft high and in such a manner to ensure that:

- The crossing site and the marked dilemma zone(s) was seen,
- Approximately 150 ft of the street on either side of the crossing site was seen,
- The angle avoided capturing license plates, and
- The resolution was such that pedestrians, cyclists, and motorists could be classified as such, but not identified individually.

Video was collected over a 2-day weekday period from dawn to dusk (approximately 13 hours per day), to include the yielding study period. The additional video footage beyond the yielding study period was used to determine vehicle volumes, pedestrian volumes, and pedestrian compliance at each site.

Figure 3-4. Image of camera installation. Street view image depicting camera temporarily installed on a utility pole angled toward the intersection.

Staged Crossing Protocol

Individual motorists not part of a platoon of vehicles were identified for testing. The object was to target free-flowing vehicles as they approached from outside the dilemma zone, whose drivers could safely stop for a pedestrian detected in the crosswalk. At unsignalized locations, the staged pedestrian crossed back and forth from one side of the street to the other, repeating the process described below until the researchers obtained the at least 50 events or until a 1-hour data collection period expired at the crossing site. For intersections with more than one crossing study site, attempts were made to collect field data for the multiple crossings at the same time period. This particularly aided in reducing wait times for the staged crossings at signalized intersections due to the long delay between walk phases. Therefore, to take advantage of signal phasing at signalized locations where two adjoining, perpendicular crossings were studied, the staged pedestrian crossed the primary street and then the secondary street before turning back to retrace his steps. This was repeated until the researchers collected at least 50 events per crossing site or until a 2-hour data collection period expired at the signalized intersection.

- At Uncontrolled Crosswalks:

The staged pedestrian stood away from the crossing (so as not to display intent to cross) until the conditions were right (i.e., to target either the first vehicle in platoon or an individual motorist approaching who is still outside the dilemma zone). Once a subject motorist was identified, the field assistant time stamped a new record, and the following steps were followed by the staged pedestrian:

1) Upon identifying a suitable approaching motorist, the pedestrian placed one foot into the crosswalk (defined as a distance of 12 inches or more from the curb face.) They did not cross into the travel lane until the driver significantly slowed or stopped the vehicle.
2) If a motorist made no attempt to stop, the pedestrian did not proceed to cross. The field assistant coded this as a “no-yield”.
3) If the motorist clearly began to yield, the pedestrian completed the crossing, and the assistant coded this as a “yield”.

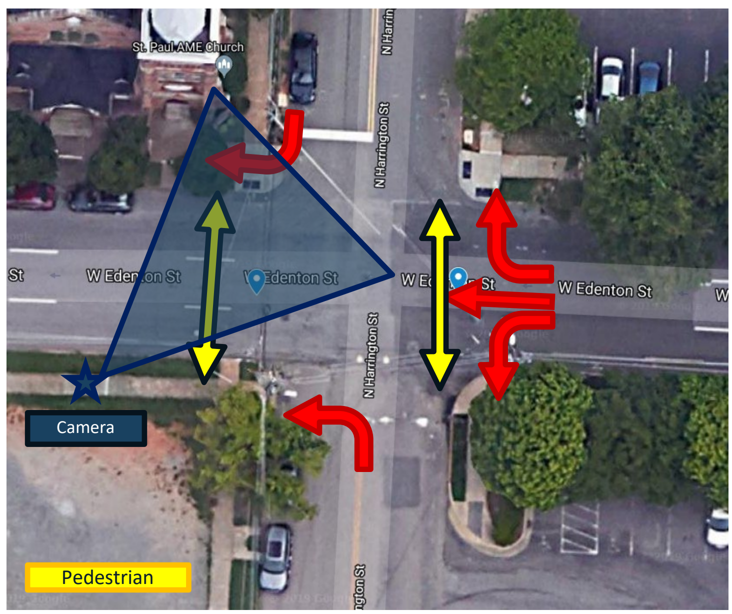

Figure 3-5. Example of set-up at two-way stop-controlled intersection.

Figure 3-5 shows an aerial satellite image of an intersection with two crossing sites, indicated by yellow arrows, across Edenton St (shown here running east-west), which is one-way and uncontrolled. Harrington St is stop-controlled. Driver yield events were observed for any free-flowing vehicle not in a platoon traveling along any of the paths indicated by red arrows.

- At Signalized Locations

The staged pedestrian actuated the pedestrian push button and waited for the WALK sign. When the WALK phase began, the staged pedestrian looked to each conflicting turning movement to indicate their intent to cross. If no conflicting vehicle was queued prior to the phase change, the pedestrian stepped back until the clearance interval to wait for another approaching conflicting vehicle. If no vehicles arrived by the clearance interval, the pedestrian completed the crossing and pushed the pedestrian button to call for the next crossing.

1) Upon identifying a suitable approaching turning motorist, the pedestrian placed one foot into the crosswalk (defined as a distance of 12 inches or more from the curb face.) They did not cross into the travel lane until the driver significantly slowed or stopped his/her vehicle.
2) If a motorist made no attempt to stop, the pedestrian did not proceed to cross. The field assistant coded this as a “no-yield”.
3) If the motorist clearly yielded, the pedestrian crossed. The field assistant coded this as a “yield”.

The field assistant watched for permissive turning movements that conflicted with the WALK phase (right or left turn) and observed and recorded if the first vehicle for each conflicting movement yielded for the staged pedestrian. Subsequent queued or platooned vehicles were not considered.

3.3.3 Video Reduction

A data technician reduced the video footage collected to extract data for aggregation. The full details for video reduction protocol are provided in Appendix B. Two days of video were processed for each site to collect and aggregate approximately 16 hours of the following data by 15-minute increments:

- Motor vehicle counts by direction (through, right turn, left turn)
- Natural pedestrian crossing counts
  - Pedestrian was counted if they crossed within the camera’s field of view, up to 150 feet of the crosswalk site. (Note, due to the field of view, sites in the camera’s foreground were more constrained in the distance of street that could be seen on legs approaching the intersection.)
- Natural pedestrian compliance (within the crosswalk vs. outside the crosswalk)
  - Where a crosswalk was unmarked, the data technician identified an imaginary centerline for where a crosswalk would go and counted the pedestrian as within the crosswalk if they were within approximately 10-feet of either side of the imaginary centerline (e.g., the ‘crosswalk zone’).
  - Pedestrians who crossed within a marked crosswalk or within 5 feet of the outside edge of the marking were recorded as “compliant”.
  - Pedestrians who crossed outside of the 5-ft buffer of a marked crosswalk or crosswalk zone were recorded as “non-compliant”.

If any questionable yield events were noted in the field under the staged pedestrian crossings, the data technician found the corresponding event based on the record’s timestamp and reviewed it. A select number of additional staged pedestrian crossings were cross-checked for quality control in accurately documenting yield/no-yield outcomes

4 Results and Findings

This chapter presents the results of the analyses conducted on the yielding behavior of drivers, compliance of pedestrians, and the effect of crosswalk marking type on these traits. Driver yielding is the primary measure of effectiveness the researchers used to understand the impact that HVCs may have on safety; however, some consideration was also given descriptively to the impact that HVCs may also have on pedestrian compliance.

The overall yielding behavior of drivers observed at a crosswalk is expressed as the yield rate. The yield rate at each crossing site *i* is estimated as:

$$\text{Yield rate, } Y_i = \frac{\text{Number of times a vehicle yielded to a pedestrian at that crosswalk}}{\text{Total number of interaction events between a vehicle and a pedestrian observed}} \qquad \text{Eq. 1}$$

Similarly, pedestrian compliance behavior is expressed as the percentage of pedestrians who crossed within the marked or unmarked crosswalk at each crossing site. The pedestrian compliance rate is estimated as:

$$\text{Pedestrian compliance rate, } P_i = \frac{\text{Number of times a pedestrian crossed at that crosswalk}}{\text{Total number of pedestrian crossing events observed within 150 ft of that crosswalk}} \qquad \text{Eq. 2}$$

General traits of the observed data such as the sample size, pattern of driver yield rates and pedestrian compliance rate across different locations in the before and the after periods are discussed below.

4.1 Before Conditions

Table 4-1 through Table 4-3 offer summary results and basic roadway characteristics or infrastructure for each site where observational field data were collected. Some sites had on-street parking, bike lanes, or other features that may impact effective crossing distance. For simplicity, this study uses number of lanes as a proxy for crossing distance.

Raleigh study area data were collected across 9 days of field work in May and June of 2019. Cary data were collected across 11 days of field work in January, March, and June 2020. The dates in January were unseasonably warm. Clayton data were collected across 10 days of field work in early March and August 2020. The pause in data collection from March 2020 to June 2020 was due to disruptions in travel patterns from the COVID-19 pandemic. No data were collected when North Carolina or individual communities had stay-at-home orders in place, and the research team monitored traffic volumes to determine they had sufficiently rebounded before continuing data collection. Sites where yield observations and video were collected before the pandemic in Cary and Clayton are denoted in Table 4-2 and Table 4-3 with an asterisk. All Raleigh locations were observed before COVID-19 (Table 4-1.)

Note that the number of interaction events and number of yields across different sites were observed for varying time durations, based on the goal of achieving at least 50 events within one hour of observation per site (e.g., more time was spent to attempt to collect events at lower volume sites.) However, since the yield rate normalizes this inconsistency, the observation duration is not reported here. Also, the raw vehicle and pedestrian volumes collected over approximately 24 hours of video footage was converted to a per day unit of measure, as shown in the tables below.

Table 4-1. Before Conditions - Raleigh Study Area Results

Site ID	Control Type	Posted Speed (mph)	Ped Signage	Num. Lanes	Xwalk Style	Num. Thru Veh (per day)	Num Turn Veh (per day)	Num. Peds (per day)	Num. Events	Num Yields	Yield Rate (%)	Ped Compliance (%)
1-1	signal w/PH	25	N	2	T	2453	1807	197	17	15	88%	88.4%
1-3†	signal w/PH	25	N	2	T	2403	504	41	6	6	100%	88.9%
1-4	signal w/PH	25	N	3	C	9213	713	209	11	8	73%	84.7%
2-2	uncontrolled	35	N	3	U	9888	912	409	57	16	28%	73.3%
2-4	uncontrolled	35	N	3	U	9888	725	270	62	15	24%	93.3%
3-3	signal w/PH	35	N	4	T	39065	3020	166	60	46	77%	92.2%
3-4	signal w/PH	35	N	3	T	7893	2680	182	25	23	92%	92.9%
4-1	signal w/PH	35	N	4	T	32474	4990	485	50	43	86%	98.6%
4-4	signal w/PH	35	N	2	T	8829	2150	209	19	16	84%	98.3%
5-3	signal w/PH	35	N	2	C	4503	3215	501	44	37	84%	90.9%
5-4	signal w/PH	35	N	2	T	12243	1928	734	28	25	89%	95.1%
6-1	signal w/PH	35	N	2	T	8119	2442	1045	45	42	93%	96.4%
6-4	signal w/PH	35	N	3	T	11801	4174	994	51	44	86%	95.7%
7-3	signal w/PH	35	N	3	T	12925	3037	402	39	38	97%	95.1%
7-4	signal w/PH	35	N	3	T	11929	2149	817	37	33	89%	83.5%
8-1	signal w/PH	35	N	3	T	12186	3323	360	43	35	81%	92.0%
8-4	signal w/PH	35	N	3	T	12230	2376	226	42	40	95%	94.3%
9-1†	signal w/PH	35	N	2	T	1683	754	204	4	3	75%	89.4%
9-3†	signal w/PH	35	N	2	T	1683	1367	138	9	4	44%	95.5%
9-4	signal w/PH	35	N	3	T	14171	1544	150	33	32	97%	91.8%
10-1†	signal w/PH	30	N	2	T	1283	489	129	1	1	100%	90.2%
10-3	signal w/PH	30	N	2	T	1283	1604	79	20	17	85%	78.0%
10-4	signal w/PH	30	N	3	T	13514	1281	113	43	35	81%	95.8%
11-1	uncontrolled	35	Y	1	C	7912	310	625	67	41	61%	61.2%
12-1	uncontrolled	35	Y	2	T	12616	760	245	13	11	85%	83.9%
12-3	uncontrolled	35	Y	2	T	12616	404	152	16	11	69%	83.0%

C = continental, T = transverse, U = unmarked. Observations at all Raleigh crossing locations were collected pre-COVID 19 pandemic. Six sites highlighted grey were identified for conversion to an HVC. Sites marked with a dagger (†) indicate less than ten events were observed and were removed from subsequent analyses.

Sites 4-1, 4-3, 9-1, 9-3, and 10-2 in Cary also had curb extensions, which effectively reduce the crossing distance. Note also that site 10-2 in Cary is a midblock crossing rather than at an intersection; however, given the presence of a driveway, the research team observed yielding behaviors for turning vehicles there, too. (See Table 4-2.)

Table 4-2. Before Conditions - Cary Study Area Results

Site ID	Control Type	Posted Speed (mph)	Ped Signage	Num. Lanes	Xwalk Style	Num. Thru Veh (per day)	Num Turn Veh (per day)	Num. Peds (per day)	Num. Events	Num Yields	Yield Rate (%)	Ped Compliance (%)
1-1*‡	uncontrolled	35	Y	3	U	8287	66	5	50	1	2%	66.7%
2-1*	uncontrolled	25	N	2	U	699	182	85	11	0	0%	90.6%
3-1*	uncontrolled	25	Y	2	U	11796	666	61	50	8	16%	77.5%
4-1*	uncontrolled	25	N	2	T	12042	1038	132	50	33	66%	85.2%
4-3*	uncontrolled	25	N	2	T	12042	548	177	20	13	65%	62.7%
5-1*	uncontrolled	25	Y	2	U	1442	402	65	30	2	7%	66.7%
6-2*	uncontrolled	25	N	2	T	519	146	78	30	7	23%	67.3%
7-4*	uncontrolled	25	N	2	U	912	315	80	21	4	19%	78.3%
8-4*	uncontrolled	25	N	2	U	351	684	35	33	2	6%	17.4%
9-1*	uncontrolled	25	N	2	T	11741	473	110	57	20	35%	89.0%
9-3	uncontrolled	25	N	2	T	11766	866	221	101	51	50%	85.7%
10-2*	uncont. - MB	25	Y	2	C	11338	86	540	89	44	49%	65.1%
11-1*	signal w/PH	35	N	3	T	7812	9813	318	50	9	18%	98.4%
11-2*	signal w/PH	35	N	3	T	11280	3404	81	28	7	25%	94.4%
11-3*	signal w/PH	35	N	3	T	7859	2052	386	14	4	29%	100.0%
11-4*	signal w/PH	35	N	3	T	11123	8523	182	50	7	14%	83.5%
12-1	signal w/PH	25	N	3	T	1176	1094	189	14	3	21%	88.2%
12-2	signal w/PH	25	N	3	T	8163	2166	236	22	12	55%	81.6%
12-3	signal w/PH	25	N	3	T	1167	6108	342	35	15	43%	98.7%
12-4	signal w/PH	25	N	3	T	8121	5186	128	41	29	71%	87.3%

C = continental, T = transverse, U = unmarked. Observations denoted with an asterisk were collected pre-COVID 19 pandemic. Seven sites highlighted grey were identified for conversion to an HVC. Sites marked with a double dagger (‡) indicate less than ten pedestrians were observed and were removed from subsequent pedestrian compliance analyses.

While all of the signalized study locations in Raleigh and Cary included pedestrian signal heads, six of Clayton's signalized sites did not (See Table 4-3.) On average, yielding rates observed in Clayton were lower than both Raleigh and Cary sites.

Table 4-3. Before Conditions - Clayton Study Area Results

Site ID	Control Type	Posted Speed (mph)	Ped Signage	Num. Lanes	Xwalk Style	Num. Thru Veh (per day)	Num Turn Veh (per day)	Num. Peds (per day)	Num. Events	Num Yields	Yield Rate (%)	Ped Compliance (%)
1-2	uncontrolled	25	Y	2	C	3286	842	131	72	12	17%	62.7%
2-1	uncontrolled	25	N	2	T	12285	1285	87	83	7	8%	87.7%
2-3	uncontrolled	25	N	2	T	12341	1381	73	77	2	3%	64.6%
3-1	signal	25	Y	2	T	12848	1160	44	13	7	54%	86.2%
3-2	signal	25	Y	2	T	522	1815	239	34	10	29%	75.5%
3-3	signal	25	Y	2	T	12879	1469	99	29	14	48%	33.3%
3-4	signal	25	Y	2	T	534	815	105	10	4	40%	100.0%
4-2	uncontrolled	25	N	2	U	3375	200	42	66	1	2%	7.1%
4-4	uncontrolled	25	N	2	U	3377	387	14	73	2	3%	77.8%
5-1*	uncontrolled	25	Y	2	U	2094	534	123	28	2	7%	56.9%
5-3	uncontrolled	25	Y	2	U	2087	569	77	89	10	11%	87.8%
6-2	uncontrolled	25	N	2	U	755	1812	57	50	6	12%	7.9%
6-4	uncontrolled	25	N	2	U	8541	5763	47	24	1	4%	N/A
7-3*	signal	25	N	2	T	2067	488	29	50	16	32%	87.1%
7-4†	signal	25	N	2	T	7934	5136	144	6	1	17%	100.0%
8-1*	signal w/PH	25	N	2	T	273	596	482	48	19	40%	62.7%
8-2†	signal w/PH	25	N	2	T	7947	1854	102	0	0	0%	86.0%
8-3†	signal w/PH	25	N	2	T	270	6258	216	0	0	0%	91.2%
8-4	signal w/PH	25	N	2	T	3286	842	131	16	5	33%	97.9%

C = continental, T = transverse, U = unmarked. Observations denoted with an asterisk were collected pre-COVID 19 pandemic. Six sites highlighted grey were identified for conversion to an HVC. Sites marked with a dagger (†) indicate less than ten events were observed and were removed from subsequent analyses.

Looking across driver and pedestrian volumes at the Cary and Clayton study area sites where data were collected before the COVID-19 pandemic compared to sites where data were collected during the pandemic after traffic began to resume, most sites show similar volumes of turning and through movements as well as pedestrian activity. For example, Clayton sites 8-1 and 8-3 are opposing legs of the same intersection, where one would expect the through volumes to be similar. Likewise, Cary sites 9_1 and 9_3 are crosswalks on opposing legs of the same intersection. In both of these examples, the volumes are similar, suggesting that data collected during the pandemic was done so sufficiently after typical travel patterns had resumed such that the pandemic did not impact this study.

Generally, the majority of the Raleigh crossings where yielding was observed were at signalized locations with pedestrian signal heads. This control type may contribute to the relatively high driver yielding and pedestrian compliance rates observed in the Raleigh study area; however, when the yielding rates were compared across the 25 uncontrolled crossings within all three study areas as shown in Figure 4-1, the uncontrolled Raleigh sites still had higher yield rates (53%), on average, than the Cary or Clayton sites (28% and 7%, respectively).

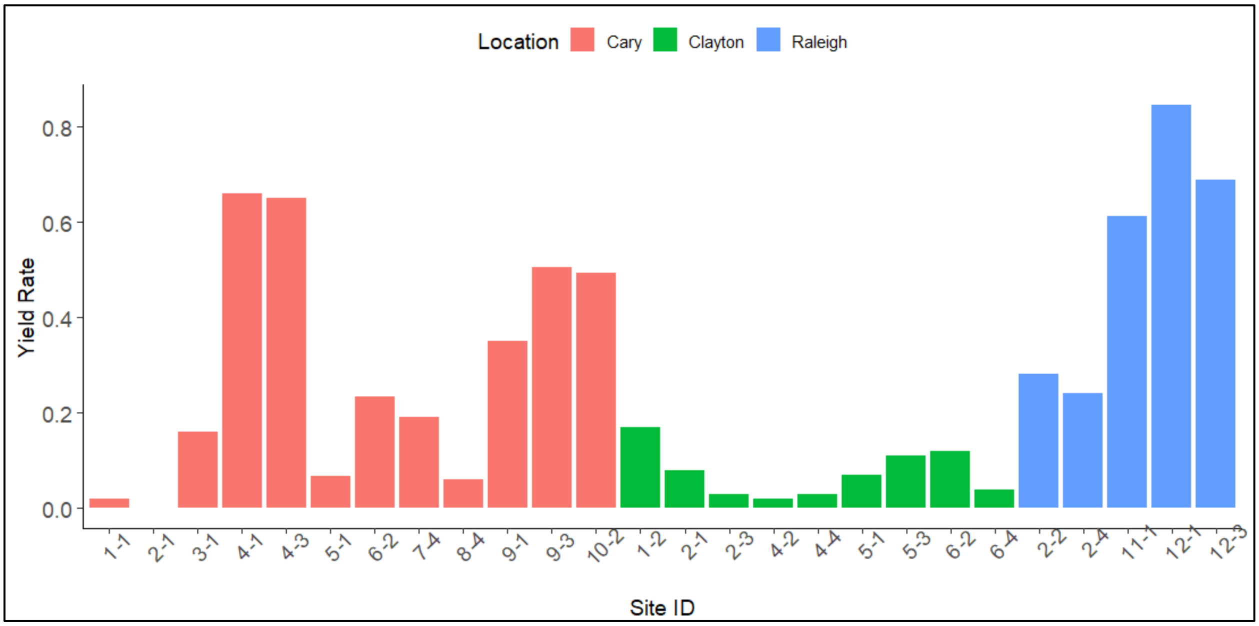

Figure 4-1. Before Condition - Yield rates at uncontrolled crossing sites in each study area. Cary 10_2, Clayton 1_2, and Raleigh 11_1 are the only uncontrolled sites with an HVC.

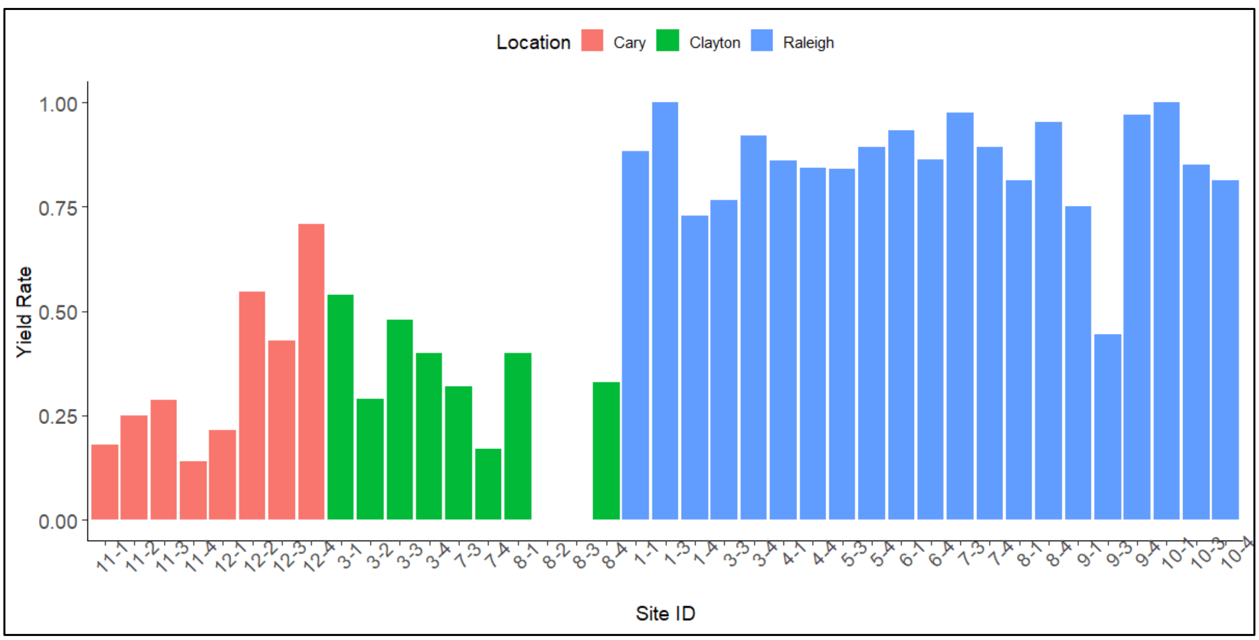

Figure 4-2. Before Condition - Yield rates at signalized crossing sites in each study area. Raleigh 1-4 and Raleigh 5_3 are the only signalized sites with an HVC.

Also, when comparing the signalized sites across all three study areas (Figure 4-2), it is clear that signalization alone does not explain the yield rates. Raleigh's signalized sites saw on average 150% and 193% higher driver yielding rates than Cary or Clayton, respectively.

Only five crosswalks in our study sample were HVCs under Before conditions. Qualitatively, the average yield rate for these HVCs was higher than that of sites with transverse markings or unmarked sites (57%, 56%, and 10%, respectively.) Pedestrian compliance rates averaged 73% for HVC sites, 87% for transverse sites, and 61% for unmarked sites. There may be other external factors effecting average yield rates and average pedestrian compliance rates beyond the marking type alone, and with a low number of HVC sites existing in the Before time period, a statistical comparison across the crossing style groups was not prudent. Assuming that these external factors remain the same in the After period, the change in yield rates between the two periods further explored in Sections 4.3 and 4.5 below.

4.2 After Conditions

Data were re-collected at all study sites at least three months after a subset of the unmarked or transversely marked crosswalks were converted to HVCs. In Raleigh, 20 crosswalks were converted to HVC between March and December 2020. Six of Clayton's crossings were converted to an HVC in September 2020, and seven of Cary's sites were converted in December 2020. Raleigh study area After data were collected across 7 days of field work in April of 2021. Cary data were collected across 9 days of field work in April, May, and June of 2021. Clayton data were collected across 9 days of field work in June and Jul of 2021.

Results from after data collection are summarized for each site in Table 4-4 through Table 4-6. As was noted with the before period dataset, the number of interaction events and number of yields across different sites were observed for varying time durations. However, since the yield rate normalizes this inconsistency, the observation duration is not reported here.

Table 4-4. After Conditions - Raleigh Study Area Results

Site ID	Xwalk Style	Num. Thru Veh (per day)	Num. Turn Veh (per day)	Num. Peds (per day)	Num. Events	Num Yields	Yield Rate (%)	Ped Compliance (%)
1-1	C	1852	1630	330	19	18	95%	89%
1-3†	C	1931	365	62	3	3	100%	63%
1-4	C	7635	661	211	12	11	92%	82%
2-2	U	8021	582	594	66	31	47%	90%
2-4	U	8003	558	368	68	26	38%	91%
3-3	T	30533	2062	216	44	42	95%	98%
3-4	T	6589	2331	314	21	14	67%	89%
4-1	T	25113	3758	271	43	41	95%	99%
4-4	T	7409	1677	119	11	10	91%	99%
5-3	C	2664	2104	213	50	46	92%	87%
5-4	T	9314	1002	302	34	30	88%	97%
6-1	T	3975	1206	334	37	34	92%	98%
6-4	T	9210	2547	407	44	43	98%	96%
7-3	C	8891	1983	213	52	49	94%	92%
7-4	C	8976	939	305	38	36	95%	90%
8-1	C	8697	2351	135	50	44	88%	100%
8-4	C	8989	2035	197	52	50	96%	98%
9-1†	T	1044	504	136	5	4	80%	74%
9-3	T	1045	1135	59	13	9	69%	80%
9-4	T	10167	1184	64	56	51	91%	98%
10-1†	T	836	404	59	1	1	100%	87%
10-3†	T	864	984	47	7	6	86%	84%
10-4	T	9812	849	72	19	17	89%	94%
11-1	C	3483	75	71	69	47	68%	57%
12-1	T	8835	480	105	72	52	72%	81%
12-3	T	8829	200	44	71	49	69%	79%

C = continental, T = transverse, U = unmarked. Six sites highlighted grey were converted to an HVC. Sites marked with a dagger (†) indicate less than ten events were observed and were removed from subsequent analyses.

Table 4-5. After Conditions - Cary Study Area Results

Site ID	Xwalk Style	Num. Thru Veh (per day)	Num. Turn Veh (per day)	Num. Peds (per day)	Num. Events	Num Yields	Yield Rate (%)	Ped Compliance (%)
1-1	C	7401	80	17	52	12	23%	64%
2-1	C	581	167	116	40	16	40%	94%
3-1	C	10131	362	135	55	15	27%	78%
4-1	T	10983	560	209	71	48	68%	83%
4-3	T	11013	1005	372	44	32	73%	52%
5-1	C	874	857	59	36	12	33%	62%
6-2	C	506	219	42	28	17	61%	79%
7-4	C	780	302	134	48	19	40%	70%
8-4	C	360	771	107	28	11	39%	56%
9-1	T	11196	543	171	76	38	50%	68%
9-3	T	11196	930	383	76	45	59%	51%
10-2	C	5813	65	245	50	25	50%	56%
11-1	T	8855	11834	377	50	18	36%	93%
11-2	T	11487	3675	27	48	15	31%	83%
11-3	T	8729	2121	186	50	26	52%	87%
11-4	T	11664	10310	66	52	19	37%	89%
12-1	T	5778	2411	186	38	19	50%	74%
12-2	T	9759	3824	303	50	29	58%	95%
12-3	T	5651	7262	588	50	23	46%	70%
12-4	T	9657	5816	314	50	23	46%	82%

C = continental, T = transverse, U = unmarked. Seven sites highlighted grey converted to an HVC.

Table 4-6. After Conditions - Clayton Study Area Results

Site ID	Xwalk Style	Num. Thru Veh (per day)	Num Turn Veh (per day)	Num. Peds (per day)	Num. Events	Num Yields	Yield Rate (%)	Ped Compliance (%)
1-2‡	C	2052	240	6	46	12	26%	75%
2-1	C	11052	812	86	46	19	41%	98%
2-3	C	11052	668	44	52	21	40%	90%
3-1	C	11040	735	71	24	20	83%	96%
3-2	C	276	1512	203	40	30	75%	89%
3-3	C	11040	1167	44	42	30	71%	79%
3-4	C	276	443	66	14	8	57%	93%
4-2‡	U	2136	174	6	54	3	6%	50%
4-4	U	2118	305	15	49	3	6%	40%
5-1	U	1997	269	44	48	4	8%	52%
5-3	U	1997	461	20	55	8	15%	54%
6-2	U	663	1763	59	26	11	42%	23%
6-4	U	663	1763	59	21	4	19%	23%
7-3	T	9230	6339	42	50	43	86%	79%
7-4	T	1929	464	36	12	8	67%	83%
8-1	T	9355	6571	201	50	41	82%	34%
8-2	T	380	615	419	10	9	90%	97%
8-3	T	9719	1988	217	44	33	75%	97%
8-4	T	339	7910	176	52	46	88%	94%

C = continental, T = transverse, U = unmarked. Six sites highlighted grey converted to an HVC. Sites marked with a double dagger (‡) indicate less than ten pedestrians were observed and were removed from subsequent pedestrian compliance analyses.

4.3 Comparative Analysis

Comparisons of the before and after datasets explore how driver yielding or pedestrian compliance changed after a subset of the crossing sites were converted to an HVC. Since observations at some sites were collected before and during the pandemic, possible impacts on traffic, pedestrian volume, and driver yielding behavior due to the COVID-19 pandemic or other population-level impacts are also explored.

Three primary questions framed the results and analyses laid out in this section:

1) What is the impact of the crosswalk marking style on driver yield rates?
2) What is the impact of the crosswalk marking style on pedestrian compliance rates?
3) How does an increase in saturation of HVCs in an area impact the effectiveness of those HVCs existing originally?

In addition to these three research questions, we endeavored to understand the combined impact of different factors of interest on driver yield rate. We developed regression models to express yield rates through these factors mathematically, which are described at the end of this chapter in section 4.5.

4.3.1 Impact of Marking Style on Changes in Driver Yield Rates

Figure 4-3 through Figure 4-5 shows before-after comparisons of the driver yield rates by site within each study area. In each figure, the background shades indicate a site's crosswalk marking style and which sites were converted to an HVC. The **yellow** background means the crosswalk already had an HVC in the before period, and it did not change in the after period. Sites with a **red** background denotes they either had no marking or a transverse marking which did not change. Sites with a **green** background means they converted to an HVC between the two periods (e.g., the treatment group.)

For some sites with particularly low volumes of traffic at the time that the staged crossings were conducted, the number of observed interactions between drivers and the staged pedestrian is low. Eight of the 65 sites had less than ten events (a somewhat arbitrarily chosen level) in either the before or after period and were removed from the dataset. The five sites in Raleigh and three in Clayton that were removed is likely due to the sites being too low of a volume for motor vehicles during the staged crossing trials, even after attempting to collect additional data through another field visit. For example, Raleigh's site 9_3 (signalized) likely had a low number of events due to the timing of when the turning motor vehicles were arriving within the cycle (later in the cycle) which made it difficult for the staged pedestrian to properly initiate their crossing protocol. Because drawing any useful conclusion is difficult for sites with so few observations, we removed those from the subsequent analyses. This removal should not significantly impact the comparison of different marking styles since most of these sites belong to the control group category, which has the largest pool of sites.

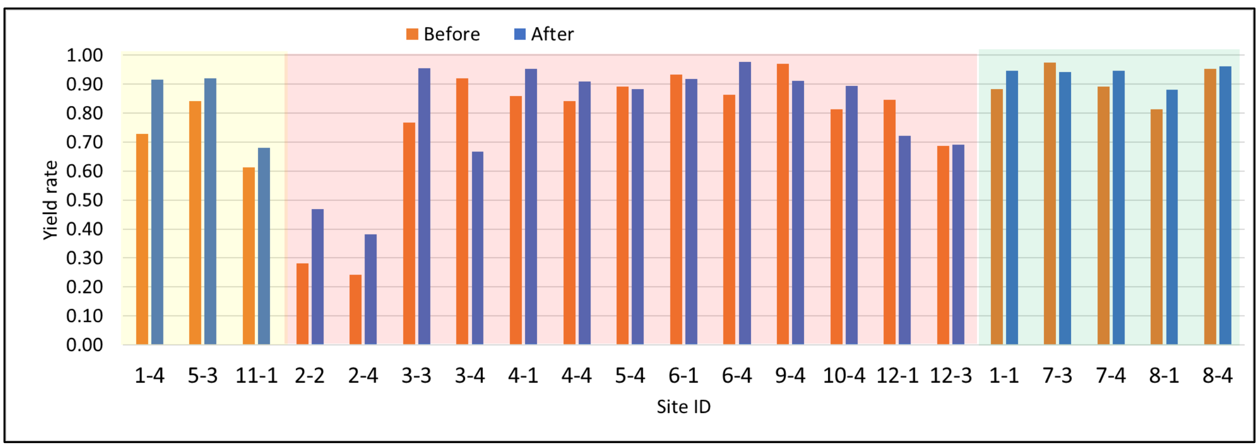

Figure 4-3. Raleigh yield rates by site comparing before (orange bar) to after (blue bar) periods.

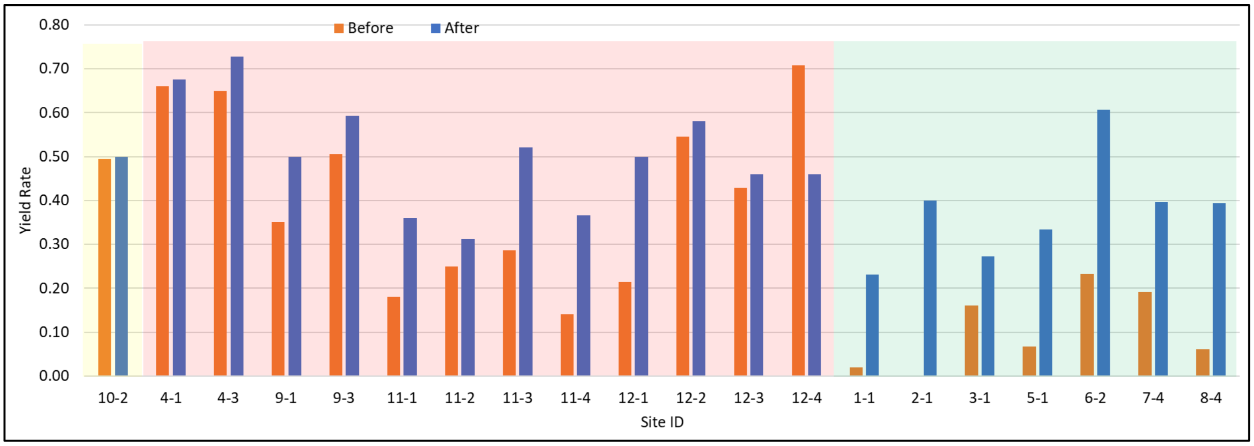

Figure 4-4. Cary yield rates by site comparing before (orange bar) to after (blue bar) periods.

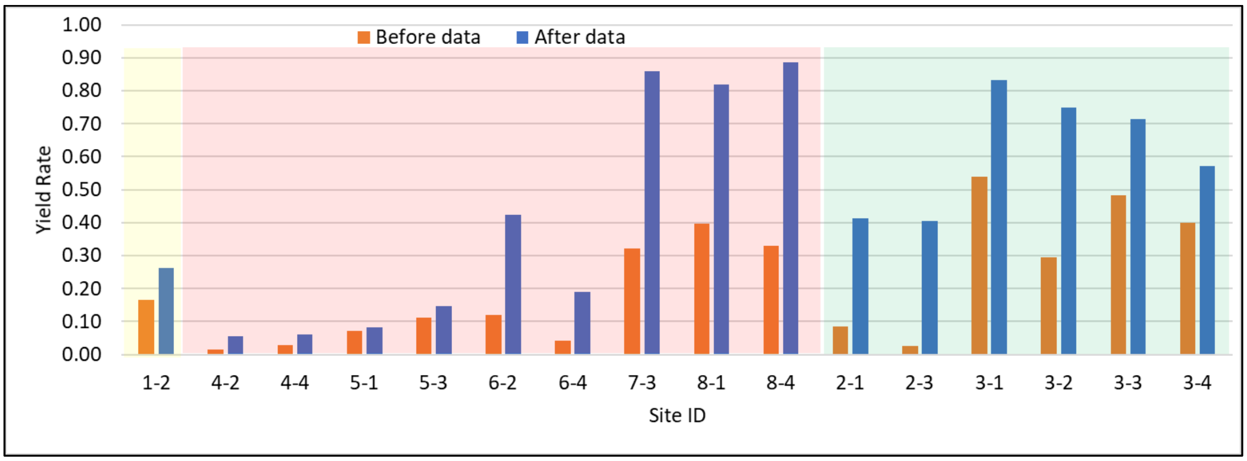

Figure 4-5. Clayton yield rates by site comparing before (orange bar) to after (blue bar) periods.

Key observations from Figure 4-3 through Figure 4-5 are listed below.

- Regardless of their marking style and location, most crosswalks exhibited an increase in yield rate in the after period. Four sites showed a decrease of more than 5% in yield rate (Raleigh sites 3_4, 9_4, 12_1, and Cary site 12_4).
- Overall, the crosswalks with the green background (i.e., those changed to an HVC) show a higher increase in the change in yield rates than the rest. Detailed analyses are demonstrated further below related to this finding.
- Raleigh has many crosswalks with a yield rate in both periods above 0.9. Possibly, drivers in that area frequently interact with pedestrians and develop a natural tendency to yield to them.

For the analyses shown in this section, the sites are divided into two categories:

- Experiment or treatment group: sites where the crosswalk was changed to an HVC
- Control group: sites where the crosswalk remained the same in both before and after conditions, i.e., they either remained an HVC, a transverse marking, or no marking.

The increase in yield rates in the after period relative to the before period for each crosswalk *i* ($\Delta Y_i = Y_{i(after)} - Y_{i(before)}$) is compared between these two groups.

There are several ways of creating these groups. One can create those from the entire dataset across all three study areas and regardless of other characteristics at each of the 55 sites, the effects of which would then be mixed. One can also create the groups from subsets of the total dataset based on these factors such as traffic control type (e.g., signalized versus uncontrolled.) Thus, we would have more control over these factors, but the number of sites in each group would diminish.

After marking style, traffic control type was considered the most critical factor that may also influence driver yield rate. Even though only free-flowing vehicles (either at uncontrolled locations or where turning vehicles had concurrent green signals with the pedestrian's WALK signal) were targeted where drivers could independently choose to yield the staged pedestrian (i.e., not in a platoon), the research team considered that the type of traffic control at given crossing could also influence driver yielding behavior. Hence, the hypothesis test was conducted for three sets of data: i) all sites ii) sites at signalized intersections, and iii) sites at uncontrolled locations to determine if there were any differences in how the experiment group performed compared to the control group after controlling for traffic control type.

The null and alternative hypotheses are as follows:

$$Null\ hypothesis, H_0: \overline{\Delta Y}_{\text{exp}} = \overline{\Delta Y}_{\text{con}},$$

$$Alternative\ hypothesis, H_1: \overline{\Delta Y}_{\text{exp}} > \overline{\Delta Y}_{\text{con}}.$$

Here, the subscripts "exp" and "con" mean experiment and control groups, respectively.

Two-sample *t*-tests were conducted to test this hypothesis on each of the three sets of data. We adopted the *p*-value approach, i.e., the null hypothesis is rejected if the *p*-value of the test is less than 0.05—a commonly used threshold.[43] There are two options for this test, one assuming equal variance and the other unequal variance. A two-sample *F*-test[44] showed that the variances are equal between the control and treatment groups for all the datasets.

Table 4-7 shows the hypothesis test results for the dataset that includes all sites where the mean change in yield rates across the sites in the treatment group were compared to that in the control group. Table 4-8 and Table 4-9 are its companions for subsets of yield rate data from only the signalized and uncontrolled locations, respectively.

Table 4-7: Hypothesis Test: All Sites Driver Yield Rate Dataset

Metrics	Treatment	Control
Mean increase in yield rate	0.218	0.105
Variance	0.022	0.028
Number of sites	18	39
Hypothesized Mean Difference		0
Degrees of freedom		55
t statistic		2.48
p-value		0.008

On average, drivers yielded 21.85% more after a site was converted to a high-visibility marking, which is a statistically significant difference from the change in yield rate observed at the sites where crosswalk markings remained the same. Even after adjusting for the increase seen in the control group, converting an unmarked or transversely marked site to an HVC is likely to increase driver yielding by 11% on average.

Table 4-8: Hypothesis Test: Signalized Sites Driver Yield Rate Dataset

Metrics	Treatment	Control
Mean increase in yield rate	0.146	0.127
Variance	0.025	0.042
Number of sites	9	22
Hypothesized Mean Difference	0	
Degrees of freedom	29	
t statistic	0.24	
p-value	0.4	

Table 4-9: Hypothesis Test: Uncontrolled Sites Driver Yield Rate Dataset

Metrics	Treatment	Control
Mean increase in yield rate	0.284	0.075
Variance	0.009	0.009
Number of sites	9	17
Hypothesized Mean Difference	0	
Degrees of freedom	24	
t statistic	5.4	
p-value	0.00006	

Traffic control type is regulated for the hypothesis tests shown in Table 4-8 and Table 4-9. As the third row of these tables show, the number of sites in each cohort becomes very few as the dataset is classified by this factor; however, the underlying data upon which the change in mean yield rates was calculated at the 31 signalized sites is based on a total of over 2,200 observations, and at the 26 uncontrolled sites it is based on over 2,600 observations. While the treatment group exhibits a higher increase yield rate than the control group for the sites at signalized intersections (Table 4-8), the mean increase is not statistically different between the two cohorts. A possible explanation is that most of the signalized intersection sites are in Raleigh, where high yield rates were observed at most sites under the before condition. There was little to no change in yield rates observed in the after period in Raleigh — even at the sites that were converted to an HVC. Moreover, because the yield rate at many of the signalized intersections in Raleigh was already close to 1 (i.e., 100% of motorists yielding to pedestrians), there was little to no room for the yield rate to increase.

On the contrary, Table 4-9 shows that the increase in yield rate for uncontrolled sites is significantly higher for the treatment group than the control group. The conversion to a high visibility marking seems to have a more pronounced effect on at these types of sites than on those at signalized intersections.

The sample size issue for subsets of the data limited our ability to explore any further subgroups by site to account for the effect of other factors, such as study area or posted speed limit. Low sample size also inhibited the research team's ability to further split the treatment group into sites where unmarked crossings converted to HVCs to compare to sites where transverse markings converted to HVCs to determine any substantive differences in changes in yield rates. Therefore, Table 4-10 below is provided as another way to summarize changes in before-after average yield rates for informational purposes only and is not meant to draw robust, statistically meaningful conclusions.

Table 4-10. Summary of Changes in Average Yield Rates By Crosswalk Marking Style Conversion

Conversion Type	No. of Sites	Before Avg. Yield Rate	After Avg. Yield Rate	Change in Avg. Yield Rate
Unmarked to HVC (treatment)*	5	8.6%	33.8%	25.2%
Unmarked before & after (control)*	8	11.4%	22.6%	11.2%
Transverse to HVC (treatment)	13	50.9%	71.5%	20.5%
Transverse before & after (control)	26	59.1%	69.6%	10.5%
HVC before & after (control)	5	56.8%	65.6%	8.8%

As denoted by the asterisk, the unmarked sites (treatment and control groups) were all at uncontrolled crossing locations, while transverse sites (treatment and control groups) and HVC sites (control only) were at a mix of signalized and uncontrolled locations. Across each treatment group, the value of the change in yield rate was greater than the value of its control group.

4.3.2 Impact of Marking Style on Pedestrian Compliance

Figure 4-7 through Figure 4-9 shows the before-after comparisons of the pedestrian compliance rate at each site within each study area. In each figure, the same background shades are used to indicate which sites are in the treatment group (green background = sites converted to an HVC), and those in the control group (yellow background = HVC sites in before condition that remained so, red = sites with either no marking or transverse lines that remained so). Only sites where at least 10 or more pedestrians per day were observed through the video reduction work are included in further analyses on pedestrian compliance below. Cary site 1-1, and Clayton sites 1-2 and 4-2 had less than 10 pedestrians per day (a somewhat arbitrarily chosen level) and were removed from the dataset prior to analysis. For the two Clayton sites, the low pedestrian volume may be due to their proximity to a school, which was not in session when the after data were collected. The low volume observed at the Cary site in before conditions may be due to natural variability in pedestrian volume (only 17 pedestrians per day were found in the after condition), given its residential neighborhood location. Clayton site 6-4 was also removed, due to an insufficient field of view to see the entire crosswalk in the before condition, when meant the video analyst could see sufficient pedestrian activity to collect counts but not to discern whether a given person crossing was within or outside of the crosswalk per protocol.

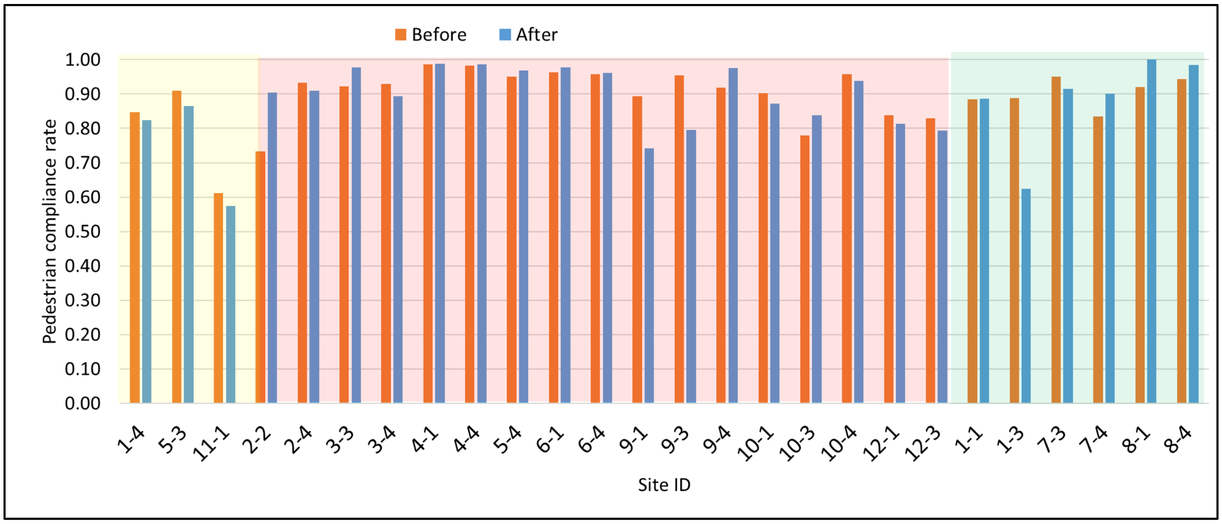

Figure 4-6. Raleigh pedestrian compliance rates by site comparing before (orange bar) to after (blue bar) periods.

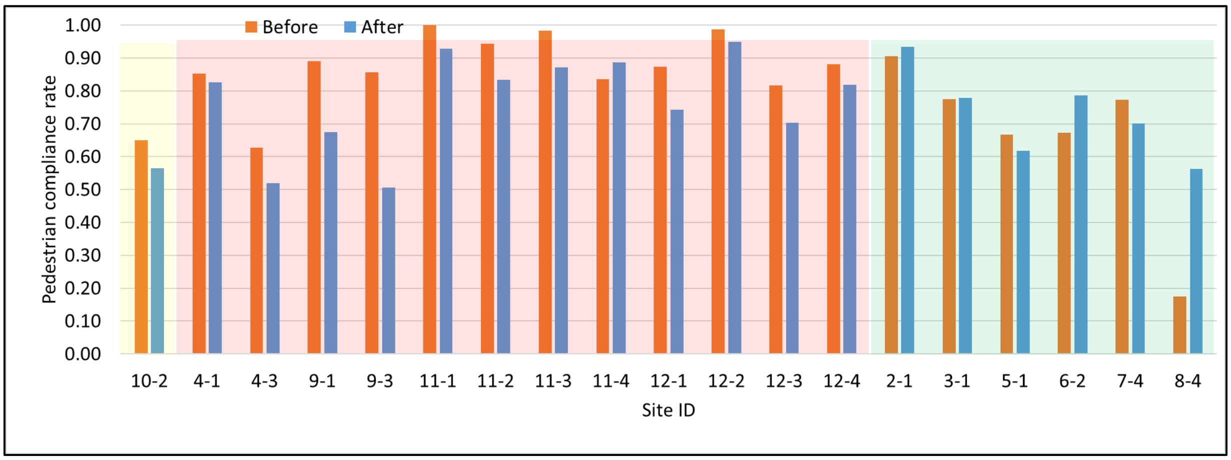

Figure 4-7. Cary pedestrian compliance rates by site comparing before (orange bar) to after (blue bar) periods.

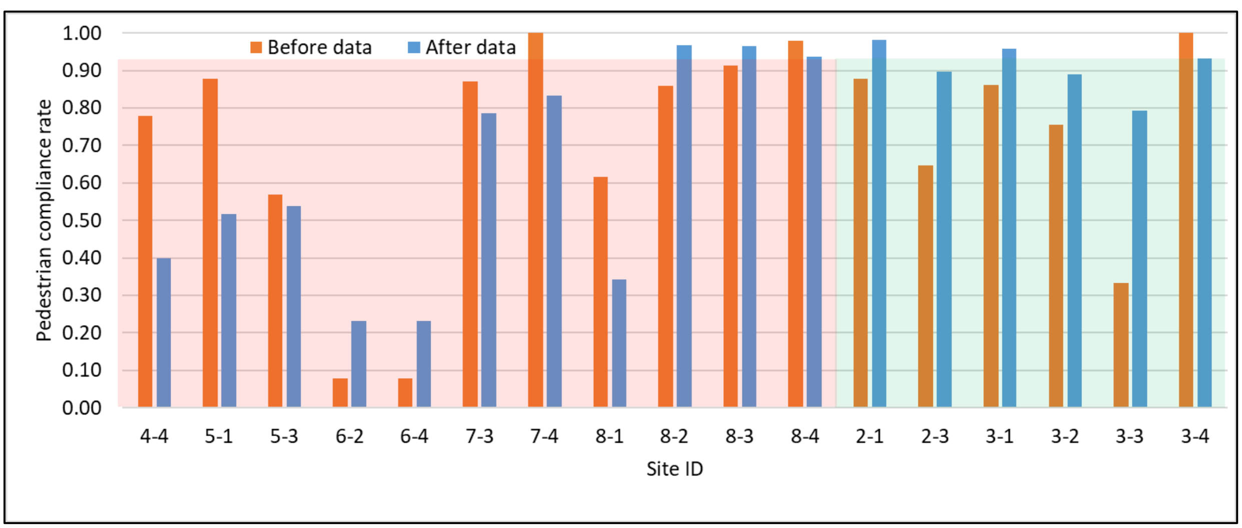

Figure 4-8. Clayton pedestrian compliance rates by site comparing before (orange bar) to after (blue bar) periods.

Key observations from Figure 4-7 through Figure 4-9 are listed below.

- Regardless of marking style, sites showed little change in pedestrian compliance rates on average, with a slight decrease of 2.14%.
- Overall in the before period, pedestrian compliance was higher on average in Raleigh (89.3%) than either Cary or Clayton (79.9% and 75.16%, respectively.) This general trend held in the after period.
- The after to before compliance rate ratio was between 0.7 to 1.23 for the Raleigh sites. However, some sites in Cary and Clayton exhibited a substantial change. It multiplied more than twice at site 8-4 in Cary. On the contrary, it almost halved at site 4-4 in Clayton.
- Overall, the crosswalks with the green background (i.e., those changed to an HVC) show a higher increase in pedestrian compliance rate than the rest. Detailed analyses are demonstrated in the following section related to this finding.

Analyses to understand the impact on pedestrian compliance used the same two categories (experiment and control group) as was defined and used above to explore changes in yield rates. The increase in pedestrian compliance in the after period relative to the before period for each site *i* ($\Delta P_i = P_{i(after)} - P_{i(before)}$) is compared between these two groups. Like the yield rate analysis, the data were further divided by the traffic control types. The same hypothesis test approach was adopted for ΔP as we did for yield rate, with the expectation that converting sites to HVCs would increase pedestrian compliance at those sites.

Table 4-11 shows the hypothesis test results for the dataset that includes all sites across all three study areas where the mean change in pedestrian compliance rates across sites in the treatment group were compared to that in the control group.

Table 4-11. Hypothesis Test: All Sites Pedestrian Compliance Rate Dataset

Metrics	Treatment	Control
Mean increase in pedestrian compliance rate	0.071	-0.056
Variance of yield rate	0.028	0.0150
Number of sites	18	44
Hypothesized Mean Difference		0
Degrees of freedom		60
t statistic		1.671
p-value		0.0008

On average, pedestrian compliance increased by 7.1% after a site was converted to a high-visibility marking, which is a statistically significant difference (*p*-value < 0.05) from the change in pedestrian compliance rate observed at the sites where crosswalk markings remained the same.

Table 4-12. Hypothesis Test: Pedestrian Compliance Rate – Signalized Sites Dataset

Metrics	Treatment	Control
Mean increase in pedestrian compliance rate	0.051	-0.043
Variance	0.033	0.007
Number of sites	10	30
Hypothesized Mean Difference		0
Degrees of freedom		10
t statistic		1.571
p-value		0.074

Table 4-13. Hypothesis Test: Pedestrian Compliance Rate – Uncontrolled Sites Dataset

Metrics	Treatment	Control
Mean increase in pedestrian compliance rate	0.096	-0.08
Variance	0.025	0.032
Number of sites	8	15
Hypothesized Mean Difference		0
Degrees of freedom		21
t statistic		2.34
p-value		0.015

The traffic control type is regulated for the hypothesis tests shown in Table 4-12 and Table 4-13. As the third row of these tables show, the number of sites in each cohort becomes very few as this factor divides the dataset; however, the underlying data upon which the change in the mean pedestrian compliance rate was calculated is based on a total of over 18,000 observations across 39 signalized sites and 7,000 observations across 23 uncontrolled sites. The treatment group exhibits a higher increase in compliance rate than the control group for both traffic control types. While Table 4-12 and Table 4-13 show that the increase in compliance rate for is significantly higher for the treatment group than the control group at both types of locations, the conversion to a high visibility marking seems to have a more pronounced effect at uncontrolled sites than on those at signalized intersections.

4.4 Effect on Driver Yield Rates as Study Area Increases in Saturation of HVCs

Another important question regarding the prevalence in use of HVCs is whether increasing the number of HVCs within a community may dilute the effectiveness of the high visibility marking, in general, in inducing drivers to yield. For this analysis, we focused on the change in yield rate for the sites that were already an HVC in the before condition relative to the increase in saturation levels of HVCs within the study areas as a whole. The average saturation of HVCs for each of the three study areas calculated using the population of crossings from each study area (see Table 3-1), including the sample of sites at which observational field data were collected.

Recall that each study area had very few HVCs already in use in the before period based on the population inventory conducted: there were 5 in Raleigh, 5 in Cary, and 1 in Clayton within the population of crossings (Table 3-1). From these 11 sites five were used to observe driver yielding behavior (3 in Raleigh, 1 in Cary, and 1 in Clayton). The first column of Table 4-14 is the average percent change in yield rate across these sampled sites for each study area. The second and third columns are the number of HVCs total in the before and after periods, respectively, within each study area. In other words, Cary's study area had 5 crossings with HVCs before; 7 sites were converted to high-visibility, so in the after period, they now have 12 HVC sites. These columns also show the saturation level of HVCs within each study area, represented in parentheses as a proportion of the total number of crossings. The last column is the percent change in these saturation levels, calculated from the second and third columns for each study area.

Table 4-14: Change in Driver Yield Rate at Existing HVCs in Relation to Percent Change in Saturation of HVCs within a Study Area

Study Area	Average percent change in yield rate for existing HVCs* $\frac{(Y_{after}-Y_{before})}{Y_{before}} * 100\%$	Num. of population HVCs - before period (% saturation)	Num. of population HVCs - after period (% saturation)	Percent change in HVC saturation $\frac{Col\ 4 - Col\ 3}{Col\ 3} * 100\%$
Raleigh	17.7%	5 (7.1%)	25 (35.7%)	403%
Cary	1.1%	5 (8.1%)	12 (19.4%)	140%
Clayton	56.5%	1 (1.7%)	9 (15.8%)	829%

*Y_{before} and Y_{after} are the yield rates in the before and after period, respectively.

The data in Table 4-14 do not reveal any steady pattern between the percent change in yield rate and the total number of HVCs within an area; however, as the percent change in saturation of HVCs increases in a given area, it appears that average yielding rates at existing HVCs improve. The overall percentage of HVCs was very limited in all three study areas, even in the after period where the maximum saturation level achieved in any study area was still less than 40% of the population of crossings. Further research is needed to determine whether yield rates begin to decline at HVCs as an area's saturation level increases to a percentage higher than 50%, but a cautious conclusion that can be drawn from this study is that the increase of the saturation of HVCs was not found to negatively impact the effectiveness of such a marking. In other words, the research did not find any dilution of effectiveness at the existing HVCs studied as more HVCs were installed in the study areas.

4.5 Modeling Driver Yielding Behavior

The results presented in section 4.3 above are helpful for demonstrating the effect of changing the crosswalk style and of traffic control type on driver yield rate. However, these tests cannot demonstrate how other site characteristics played a role on the yielding tendency of drivers. This section presents the regression models that were developed to reveal the importance of observable factors on yield rate. Like any other model, these models can be used to estimate the yield rate for a crosswalk. However, the user must be cautioned that the number of data points for each category of the factors is very limited. Furthermore, many unobserved factors may have impacted the yielding behavior of drivers.

4.5.1 Description of the Variables

In these models, the before and after periods' data for a site where the marking style was converted to high visibility were treated as separate data points. The reason is that the value for one of the input variables, *crosswalk marking type*, is different for that crosswalk in the two periods. For each of the remaining sites, the average yield rate of the two periods was used since all the input variables were the same for them in the two periods.

The other potential input (i.e., independent) variables are further described in Table 4-15. Recall that these data were collected for each site as part of the study area inventory process (section 3.3.1) or through observational data in the field or through video reduction. Posted speed limits were considered for the streets both parallel to and across the crosswalks. To get better accuracy of how crossing distance influences driver yielding, crossing length was measured from curb face to curb face using satellite images in Google Maps, in lieu of using the number of lanes data described in the study area inventory.

Table 4-15 shows the variables that were used in the model development process. The first one is the response variable, and the rest are predictors. This list is important for reproducing the model. For the categorical variables, the number of data points (i.e., the number of crosswalks) for each level are shown as well. Evidently, several variables' levels have very few data points, such as $Control\ type\ =\ Signalized\ for\ drivers\ only$ and $Area\ type\ =\ CBD$. Hence, testing the interactions of the different variables was not performed due to limited degrees of freedom.

Table 4-15: Description of the Variables

Variable name	Type	Level (for categorical variables)	Number of associated crosswalks (for categorical variables)
Yield rate (response)	Numeric	-	-
Control type	Categorical	Signalized for drivers only	6
		Signalized for both drivers and pedestrians	33
		Uncontrolled	26
Parallel PSL	Categorical	25 mph	43
		35 mph	22
Across PSL	Categorical	25 mph	45
		35 mph	20
Crossing length (ft)	Numeric	-	-
Marking style	Categorical	High visibility marking	22
		No marking	8
		Transverse marking	35
Thru traffic volume (v/hr)	Numeric	-	-
Turn traffic volume (v/hr)	Numeric	-	-
Pedestrian crossing volume (crossing/hr)			
Pedestrian compliance rate	Numeric	-	-
Area type	Categorical	CBD	4
		Suburban corridor	12
		Suburban residential	7
		Urban center	27
		Urban residential	15

4.5.2 Linear Regression Model without Location Type Variable

Before feeding the variables to the linear regression development tool, it is important to address possible correlations between pairs of variables. For each pair of numeric variables, we estimated the Pearson Correlation Coefficients, and for pairs of categorical variables, we used Crammer's V. See details on the correlation between variables in Appendix C, which led to the removal of "area type" from the model. Table 4-16 shows the linear regression model developed *without* the Location type variable in the input. Both the stepwise and backward elimination techniques generated this same model. These techniques sequentially add or eliminate the potential variables by testing their statistical significance at each iteration. [45] The *R*-squared and the residual standard error of this model are, respectively, 0.78 and 0.14 (27% of the mean observed yield rate).

Table 4-16: Linear Regression Model for Yield Rate - Location Type Omitted

Variable Name	Levels for categorical variable	Coefficient	Significant? (α=0.05)
Intercept		0.788	Yes
Control type	Signalized for drivers only (reference)	-	-
	Signalized for both drivers and pedestrians	0.139	No
	Uncontrolled	-0.262	Yes
Parallel PSL	25 mph (reference)	-	-
	35 mph	0.145	Yes
Crossing length (ft)		-0.005	Yes
Marking style	High visibility marking (reference)	-	-
	No marking	-0.274	Yes
	Transverse marking	-0.111	Yes
Pedestrian crossing volume (per hour)		0.008	Yes
Thru vehicle volume (per hour)		0.0002	Yes
Turning vehicle volume (per hour)		-0.001	Yes

Below are the highlights of the linear regression model in Table 4-16.

- The coefficient signs for most of the categorical variables are interpretable. Negative coefficients mean that driver yielding decreases with a given variable, while positive coefficients mean that driver yield increases with a given variable. The value of the coefficient describes the magnitude of its impact. For example, both Transverse and No marking types show negative coefficients, implying a lower yield rate at unmarked crosswalks or those marked with the basic style compared to the reference type, which is the high visibility marking. The coefficient value for Transverse marking is higher than that for No marking, suggesting that while drivers are less likely to yield at basic crosswalks compared to HVCs, they are even more less likely to yield where there is no marking at all
- Uncontrolled has a negative coefficient, whereas Signalized control for pedestrians and drivers has a positive coefficient. This suggests that drivers are less likely to yield to pedestrians at an uncontrolled location compared to a signalized one, and that driver yielding increases at signalized locations that also includes pedestrian heads.
- The effect of the PSL on the street parallel to a crosswalk on driver yield rate is difficult to understand, especially given that the model development technique did not find the Across PSL

to be a significant variable. According to this model, a 35 mph PSL has an increasing effect on yield rate relative to a 25 mph PSL, which would mean drivers are more likely to yield to pedestrians when they approach a cross street that's posted as 35 mph compared to one posted at 25 mph. One possible explanation is that drivers on the uncontrolled approaches of a two-way stop-controlled intersection may be looking to ensure the 35 mph cross street traffic has stopped; likewise, drivers turning left from the 35 mph street on a permissive green at a signalized intersection may accept a more cautious gap in the oncoming through traffic before turning.

- Crossing length shows a lessening effect on yield rate, suggesting that the higher the crossing length, the lower the yield rate (if everything else remains constant). This is consistent with other research that shows that drivers are less likely to yield to pedestrians on multilane facilities (4 or more) compared to 2-lane streets.
- The positive coefficients for pedestrian crossing volume and through vehicle volume can be a reflection of the Location type's effect. For instance, drivers are more prepared to yield to pedestrians near CBDs where pedestrian activities are more common (e.g., such as in Raleigh location) than in residential areas (e.g., Cary location). The negative coefficient of turning movement volume shown in Table 4-16 is difficult to explain. This may be an artifact of the high number of signalized sites contributing to more turning movement yield events in our dataset, where drivers making a turn on a permissive control (e.g., green ball or flashing yellow) are focused on turning through a gap in oncoming traffic and clearing the intersection rather than yielding to a pedestrian.
- The model exhibits acceptable goodness of fit since the *R*-squared is reasonably high (0.78). Its standard error is about 27% of the mean observed yield rate. It is higher than expected and can be attributed to the lack of enough samples from each level of the categorical variables.

4.5.3 Linear Regression Model with Location Type Variable

The study areas themselves (i.e., Raleigh, Cary, and Clayton) should not be used as a potential input for generalizability. However, to get an idea of how these locations can explain much variation in the data, an additional model was developed with this input and compared against the primary one above.

Table 4-17 shows the linear regression model that was developed *with* the Location type variable (e.g., the three study areas) in the input. Both the stepwise and backward elimination techniques generated this same model. Note that the model with the Location variable cannot be applied to data from areas other than these three. The main purpose of developing this model is to compare the changes in model form and performances relative to the previous model. The *R*-squared is 0.86 and the residual standard error is 0.11 (21% of the mean observed yield rate)

Table 4-17: Linear Regression Model for Yield Rate - Location Type Included

Variable Name	Levels for categorical variable	Coefficient	Significant? (α=0.05)
Intercept		0.818	Yes
Location	Cary (reference)	-	-
	Clayton	-0.032	No
	Raleigh	0.362	Yes
Control type	Signalized for vehicles only (reference)	-	-
	Signalized for both vehicles and pedestrians	0.018	No
	Uncontrolled	-0.252	Yes
Crossing length (ft)		-0.005	Yes
Marking style	High visibility marking (reference)	-	-
	No marking	-0.305	Yes
	Transverse marking	-0.066	Yes

Below are the highlights of the linear regression model in Table 4-17.

- $Location = Raleigh$ is the variable with the highest absolute coefficient value. The positive sign of the coefficient implies that a crosswalk in Raleigh has a substantially higher yield rate than a similar crosswalk in Cary or Clayton.
- The parallel PSL, through and turning vehicle volume, and pedestrian crossing volume are not statistically significant variables in this model. The remaining predictors and their coefficient signs are the same in both models.
- This model has a lower standard error (0.11) and higher R-squared (0.86) than the first model without the Location variable. It implies that a certain portion of the variation in the observed yield rate cannot be explained without the Location variable. Most likely there are some cultural or demographic effects on drivers' yielding behavior that are different across these study areas which are not explained through any of the remaining predictors.

5 Conclusions

This project had two primary aims: 1) to understand how HVCs impact driver yielding rates, controlling for other variables, and 2) to determine whether increasing the usage of HVCs would dilute their effectiveness at special emphasis areas, such as where they are typically deployed. A secondary objective was to also consider how pedestrian compliance is impacted by HVCs. As such, more in-depth analyses were conducted to address the primary aims. Comparisons of the treatment group (where a set of unmarked or transverse crossings were converted to HVCs) with the control group (where a set of crossings were either transverse, continental, or unmarked and remained the same) across before and after periods revealed changes in yield rates and pedestrian compliance. The development of a regression model further explored how other factors like speed limit, crossing length, pedestrian and vehicle volumes, and control type also influenced driver yielding along with crosswalk marking style.

A comparative analysis of the before-after dataset found that on average driver yielding increased by 22% at sites that were converted to HVCs, which was a statistically significant difference from the change in yield rate observed at the sites that where the crosswalk remained the same. After adjusting for changes also observed in the control group, this study found that converting a crosswalk to an HVC is associated with an increase of driver yielding by 11%. The increase in yielding was most prominent at unmarked crossings that were converted to an HVC (25%); however, sites where transverse lines were modified to HVCs also saw a marked increase in yielding rates (20.5%). Part of this increase may be given that the 5 unmarked sites selected by agencies to install an HVC were the poorest performing sites for driver yielding in the before period.

Given that 31 out of the 58 sites used in the driver yielding comparative analysis were at signalized locations, we also wanted to understand how the usage of HVCs related to the intersection control type. Upon looking at subset of control and treatment site groups at signalized locations, we found that there was no significant difference in the increase in yielding rates for the treatment-signalized sites compared to their control group. More than half of the signalized sites studied were in Raleigh, though, which as a study area had a much high average driver yield rate in the before condition (79%) than the other two study areas (Cary: 30.7%, Clayton: 21.44%), so there may not have been much room for improvement. Further research is needed to investigate the benefits of HVCs at signalized locations. However, converting crosswalks at uncontrolled sites to HVCs proved to significantly increase the change in yield rates by 28%.

By modeling driver yielding behavior, this project further tested how other site characteristics play into driver yielding. The regression model development exercise tested a variety of categorical and numerical factors to determine which were significant in predicting driver yielding. Model results showed that uncontrolled locations, longer crosswalk lengths, unmarked or transversely marked crosswalks, and increases in turning vehicle volumes each have a lessening effect on drivers yielding to pedestrians in a crosswalk. Crossings with HVCs, increasing through vehicle volume, increasing pedestrian volume, or signal controls for both drivers and pedestrians have an increasing effect of inducing driver yields.

In general, pedestrian compliance rate also increased significantly at the treated sites. On average, pedestrians were 6.6% more likely to cross at the crosswalk than outside of it after it was converted to an HVC. While this is a modest increase, based on the pedestrian volumes observed during the study period at these sites (averaging 151 pedestrians per day per treatment site across before and after time periods), that translates into approximately 10 more people using the crosswalk per site per day.

Answering the question of how an increase in the prevalence of HVCs may impact the effectiveness at existing HVCs proved difficult, in large part because HVCs are currently used very sparingly in North Carolina. This, combined with reliance on local agency support to convert a significant number of crossings to HVCs within the study period meant that the overall increases in saturation rates of HVCs across the three study areas varied from 11.3% to 29% from the before to after period, with a maximum of a 35.7% saturation level achieved in Raleigh in the after period. Further research is needed to determine whether yield rates begin to decline at HVCs as an area's saturation level increases to a percentage higher than 40%, but a cautious conclusion that can be drawn from this study is that the increase of the saturation of HVCs was not found to negatively impact the effectiveness of such a marking at existing sites in any of the study areas, given that the change in yield rates at the existing HVC sites sampled did not decrease from the before to after time period. Further, when considering the increases in HVC saturation within each study area along with the summary results found related to changes in yielding rates at the sampled crossings, it appears that more HVCs in a given area might have some positive effect on yielding behavior at all crossings and not only at those marked with the HVC style. This is based on a general trend observed when analyzing the before-after data which showed an average increase in yield rates across both control and treatment groups. Based on these research findings, using an HVC style more prevalently does not appear to dilute their effectiveness and, indeed, their use may result in drivers yielding more to pedestrians at crosswalks, thereby improving safety for people traveling on foot.

6 Implementation & Technology Transfer Plan

Based on the findings from this research, it appears that there are insufficient safety reasons to restrict the use of HVCs to midblock locations, crossings where pedestrians are not expected, or to places where vulnerable populations such as children or the elderly would use the crosswalk. Indeed, while there were sampling limitations, this research suggests that HVCs are a better-performing marking style than not marking a crosswalk or marking it with transverse lines when using driver yielding as the measure of effectiveness when signal control is not accounted for. When considering differences of effectiveness at signalized locations, HVCs do not perform any worse. Further, the research found no dilution of effectiveness at existing high-visibility crossings as the number of HVCs within a given area increased.

There are several actions that NCDOT could take based on these research findings. These are presented in order from most extreme to least:

1) Consider modifying the standard drawing for crosswalks on state roads to replace the transverse marking style with an HVC style as the default. Forthcoming guidance from FHWA further supports this notion at uncontrolled locations based on similar research that evaluated differences between driver yielding rates at paired transverse and HVC sites. The FHWA study found that HVCs generally perform better than transverse markings except where motor vehicle operating speeds are greater than 30 mph or in a "grid" context such as a downtown where other environmental cues may indicate to drivers to expect pedestrians.[46] One section of the FHWA guide further asks, "Are basic markings still suitable in some locations?" and responds by generally say, "HVC markings [are recommended] everywhere an agency has determined to mark a crosswalk." This statement is then layered with additional recognition that even if an agency has determined HVCs may still be more cost effective, there may be times when marking with transverse style is sufficient, such as at signalized intersections where the crosswalk marking is not the primary cue alerting drivers to the potential presence of pedestrians nor assigning right of way. Key consideration, then, should be given to where drivers still need a highly visible indicator of an HVC at a signalized location to cue them in to expect pedestrians at – perhaps where yielding compliance is poor. While our research found no significant increase in yield rates where HVCs were used at signalized locations, most of our signalized sites were in Raleigh, which had overall better yielding rates and may be biased.

The FHWA research did not differentiate between HVC patterns, but there are a few different HVC styles to consider, which are discussed in the FHWA guide to be published in 2022.[47] A lifecycle cost analysis is recommended to determine whether the bar pair, continental, or ladder pattern would be most suitable as a new standard for NCDOT.

Our research found that several local agencies in North Carolina are moving toward the use of HVCs as their default pattern. This trend was found to echo nationally via the FHWA study, where many state and local agencies interviewed across the U.S. use an HVC as their standard marking style.[48] Shifting toward an HVC pattern as the standard crosswalk marking for NCDOT may also provide more consistency to both drivers and pedestrians, particularly in cities where the default is to use HVCs. Providing consistency can mitigate potential confusion that may arise about whether transverse lines at a crosswalk mean something different than longitudinal bars, when there really should be no difference in interpretation.

2) Even if NCDOT chooses to keep the existing standard transverse style as the default for crosswalk markings, the agency could modify practices that currently limit the use of HVCs to special emphasis areas like midblock crossings to support their use more broadly. For example, this study showed that driver yielding improved at uncontrolled sites when they were converted to an HVC. Further, the research found no downside to using HVCs more prevalently. NCDOT should consider requiring HVCs to be used at all uncontrolled crossings, including midblock locations.

3) Consider updating the NCDOT *Pedestrian Crossing Guide* and flowchart to recommend HVCs as the preferred marking style for outcomes to Steps 3 and 4 (Additional / Alternative Treatments or Pedestrian Hybrid Beacon Assessment) that also include:
   - Geometric improvements
   - Supplemental warning signs, markings, actuated beacons or RRFBs
   - Pedestrian Hybrid Beacons (PHBs)

   These crossing locations are unsignalized or midblock locations where marking a crosswalk alone is considered insufficient for safety reasons due to the number of lanes, speed of vehicles, traffic volume, pedestrian volume, and/or pedestrian delay.

Any updates made to NCDOT standards, policies, or practices will need to be disseminated to others to ensure uptake in implementation. This may be conducted through a simple memorandum distribution to key staff; however, it is beneficial for local agencies and private consultants who design roadways and marking plans for proposed projects on NCDOT roads to also know about any changes in acceptable crosswalk markings. Therefore, it is recommended that a training course be developed and delivered that explains any updates on where HVCs should be used on NCDOT roads, why they are preferred in such locations, where additional resources may be found on the topic, and other factors that may be considered when determining which crosswalk marking style is appropriate.

Finally additional work may be necessary to systematically update existing crossing locations to an HVC where appropriate. NCDOT will need a plan to integrate these modifications through maintenance and resurfacing schedules. This will call for an inventory analysis of all existing crossing locations, filtering for sites that meet the criteria to be converted to an HVC, and prioritizing sites over a predetermined time period to be updated.

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8 Appendices

A. Study Sites

RALEIGH

- 1. Edenton & West st (S)
- 1. Edenton & West St (W)
- 1. Edenton & West St (N)
- 2. Edenton & Harrington (W)
- 2. Edenton & Harrington (E)
- 3. Edenton & Dawson (W)
- 3. Edenton & Dawson (S)
- 4. Edenton & McDowell (W)
- 4. Edenton & McDowell (N)
- 5. Edenton & Salisbury (W)
- 5. Edenton & Salisbury (S)
- 6. Edenton & Wilmington (W)
- 6. Edenton & Wilmington (N)
- 7. Edenton & Blount (W)
- 7. Edenton & Blount (S)
- 8. Edenton & Person (W)
- 8. Edenton & Person (N)
- 9. Edenton & Bloodworth (S)
- 9. Edenton & Bloodworth (W)
- 9. Edenton & Bloodworth (N)
- 10. Edenton & East St (S)
- 10. Edenton & East St (W)
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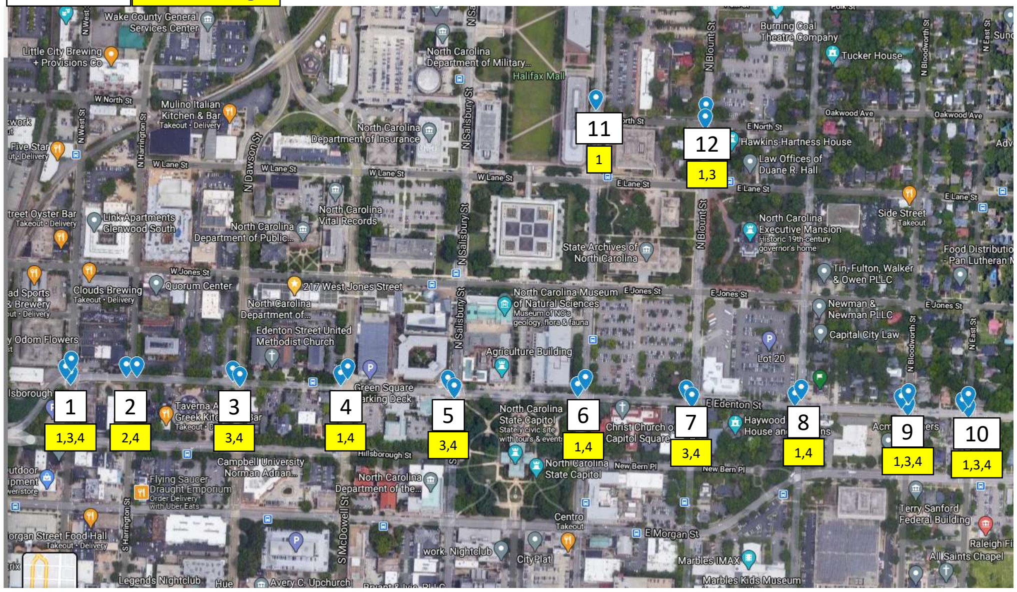
- 12. N Blount St (S)

12 Sites | 26 Crossings



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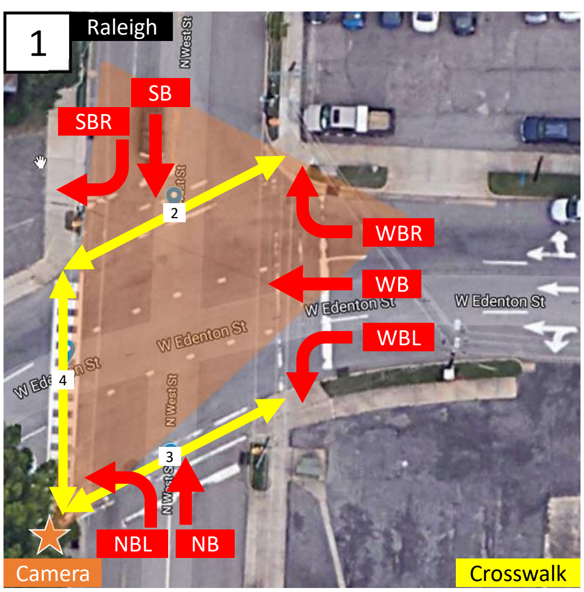

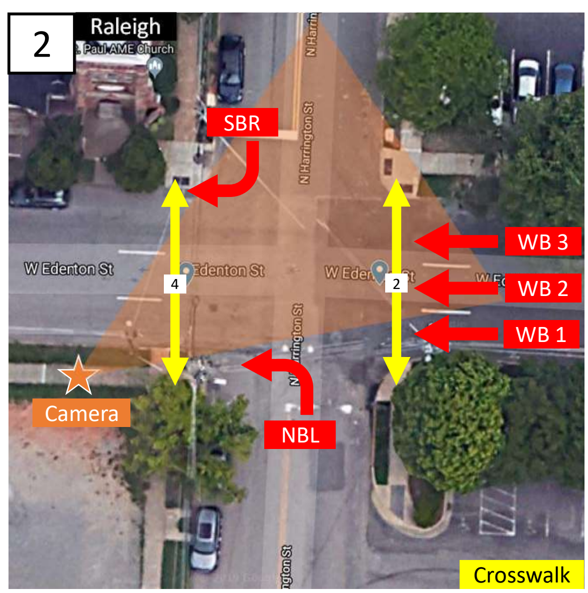

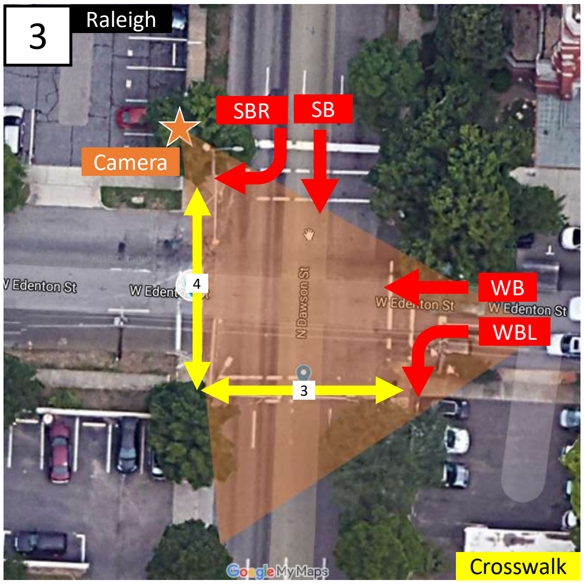
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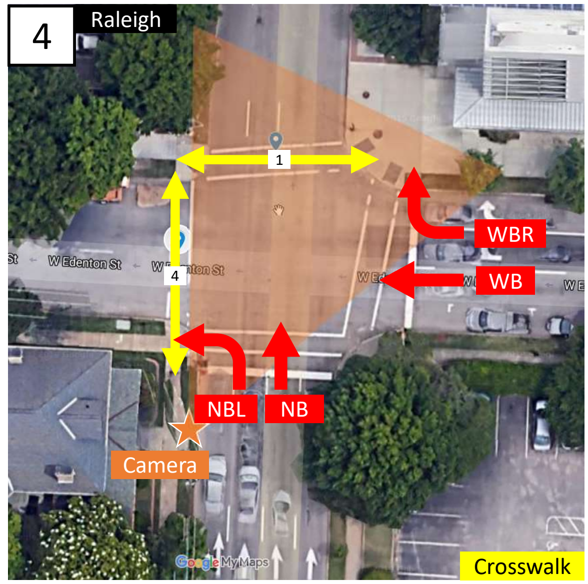
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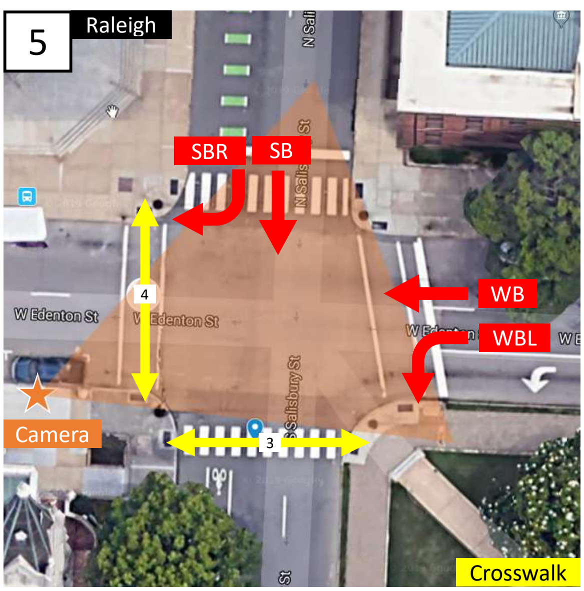
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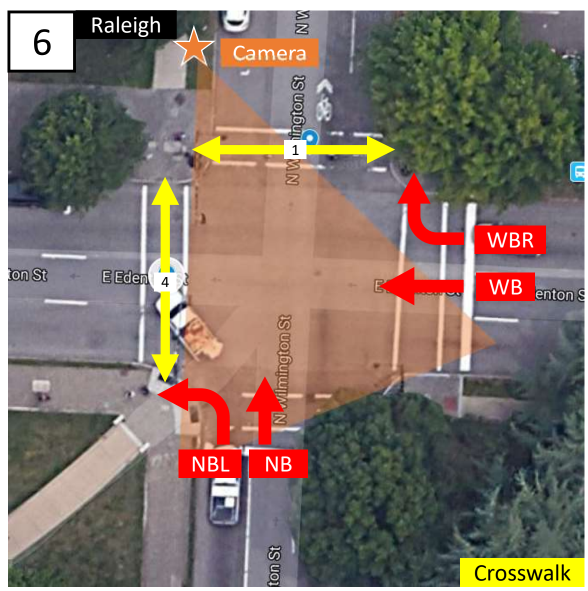
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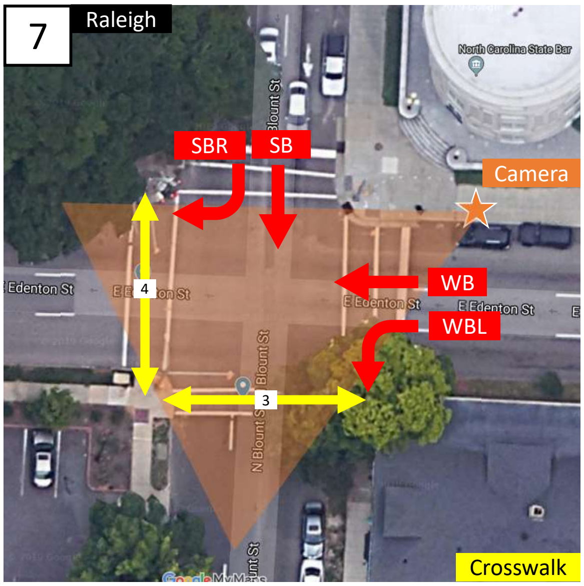
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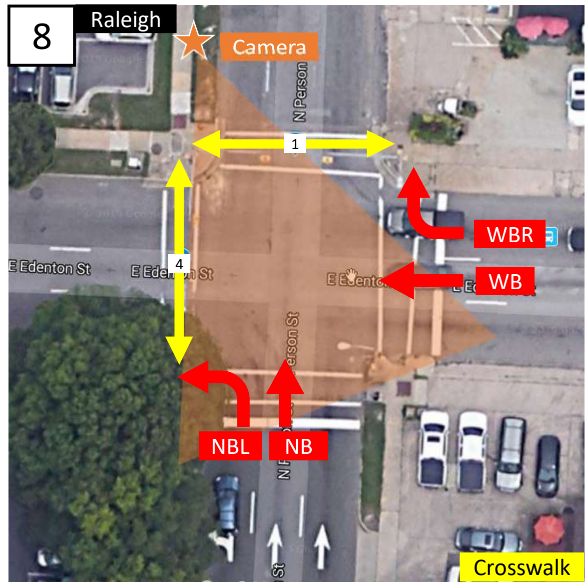
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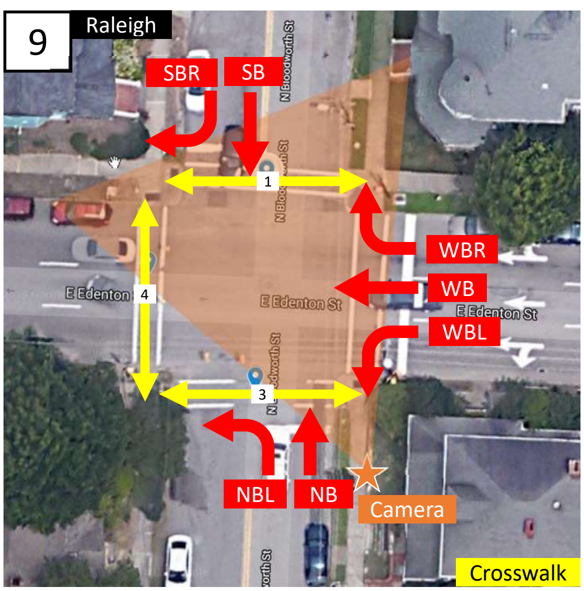
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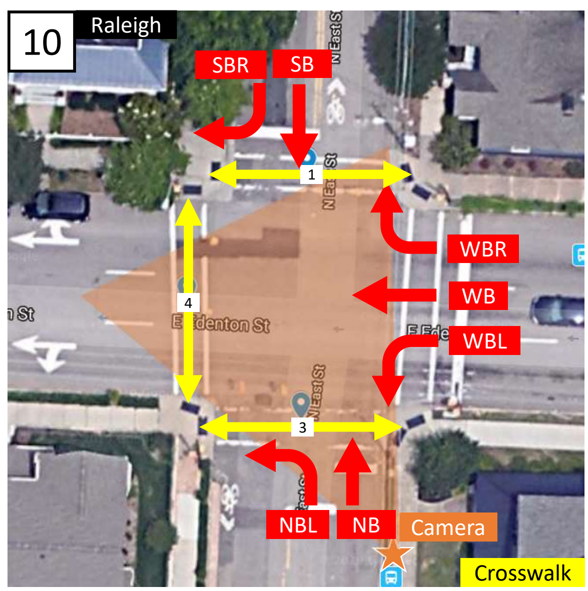
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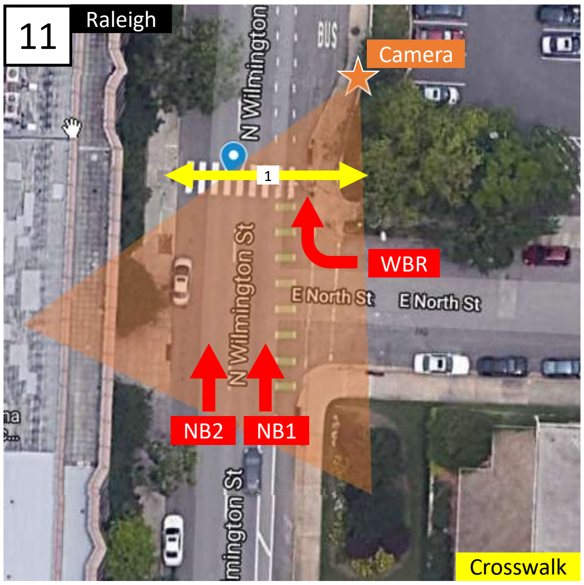
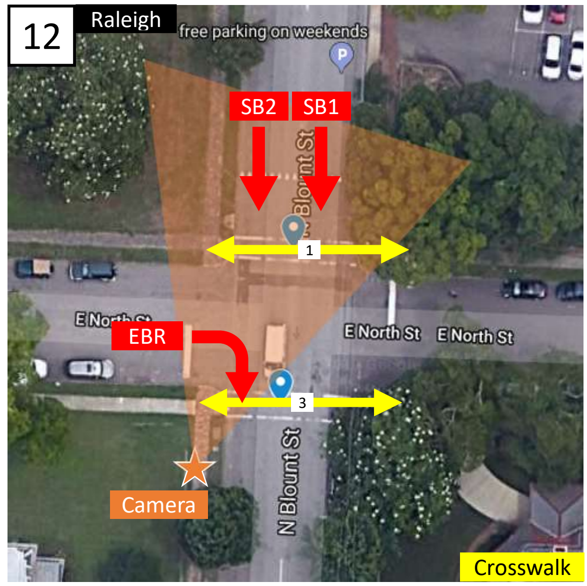
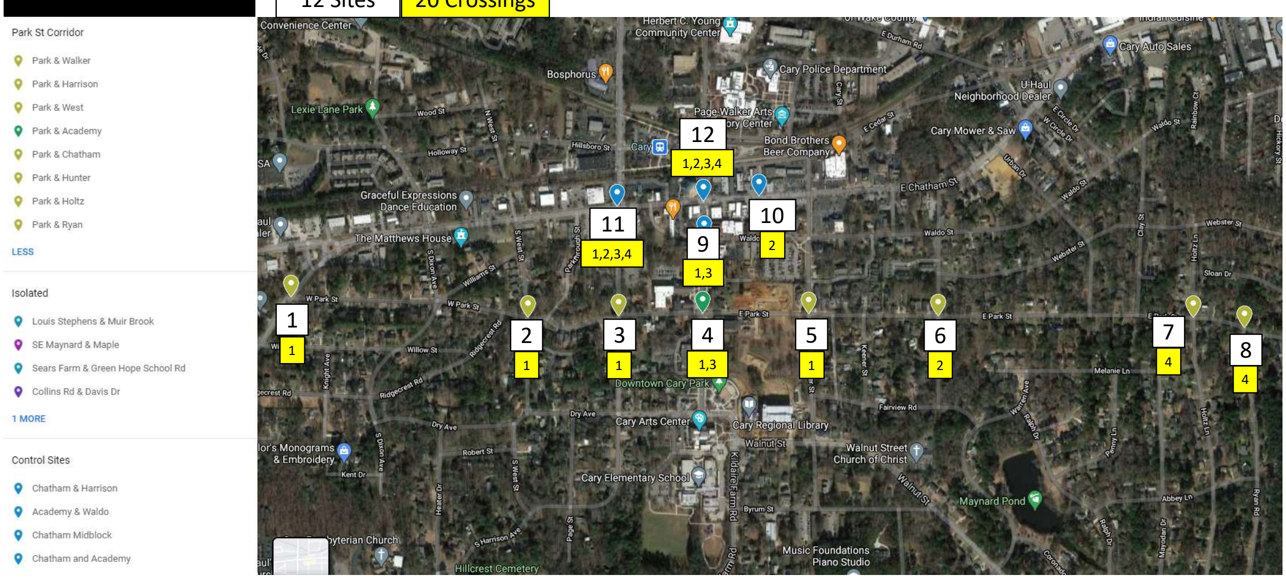




CARY

12 Sites | 20 Crossings



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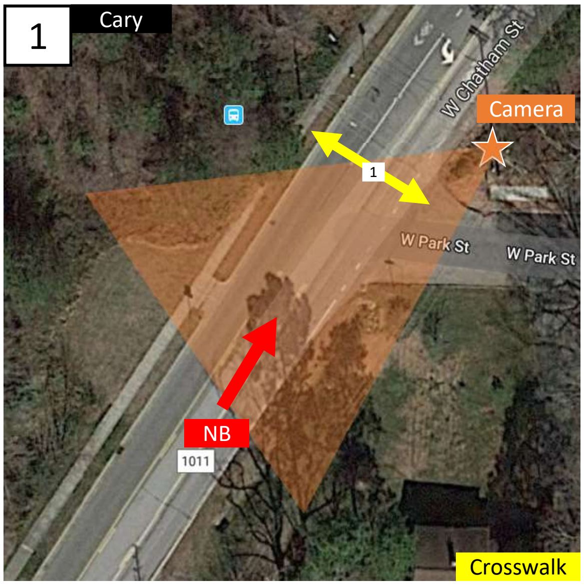
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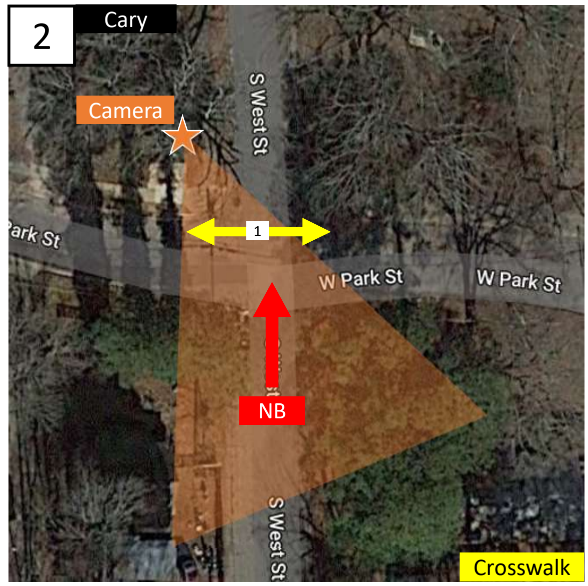
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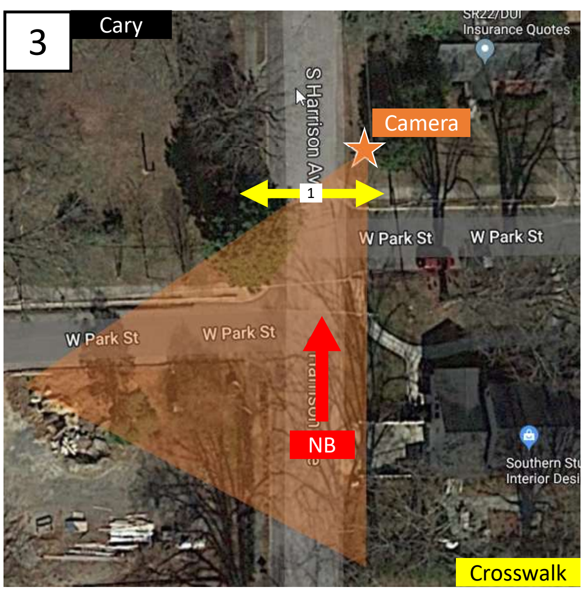
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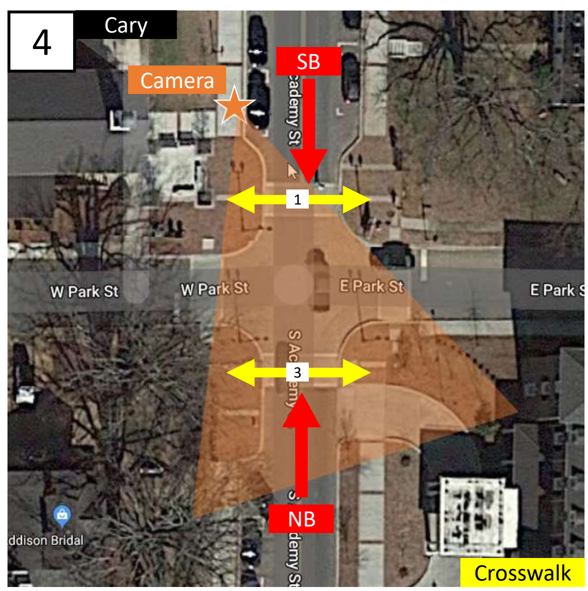
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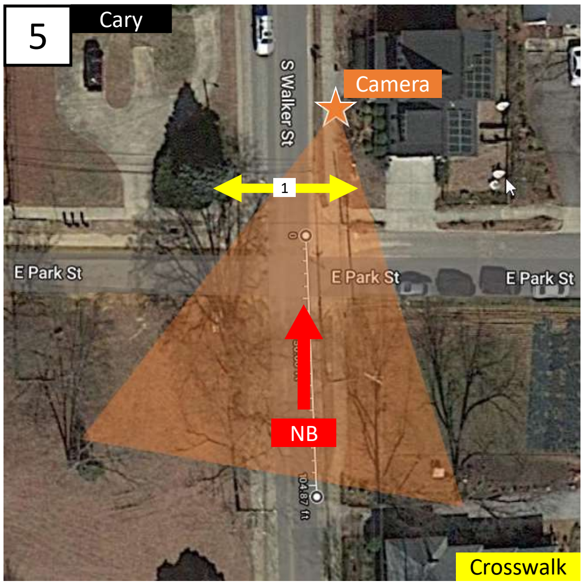
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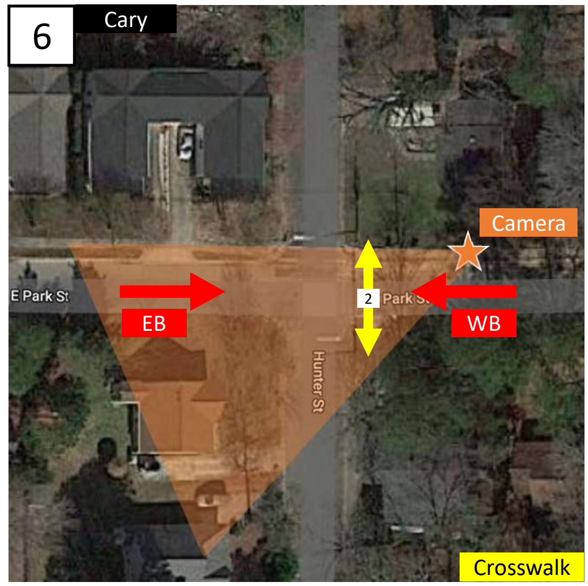
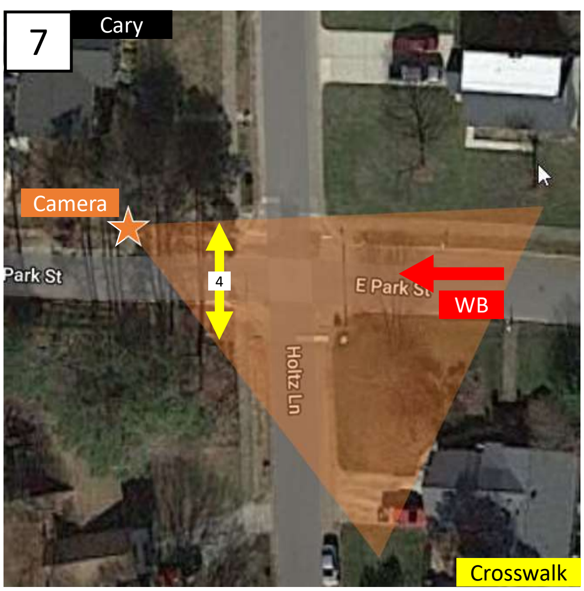
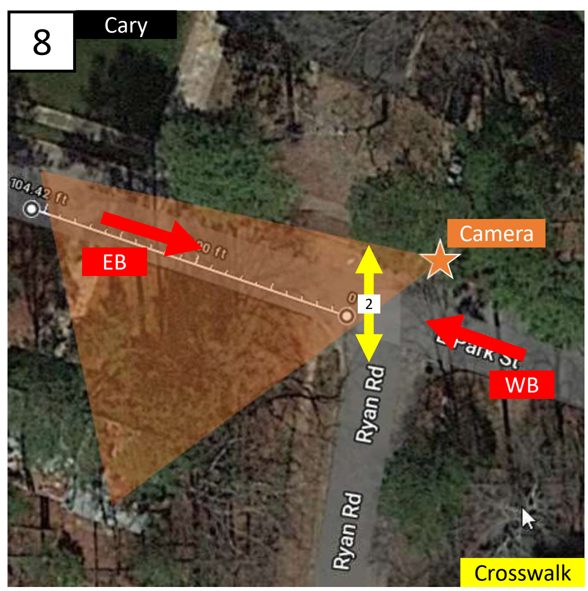
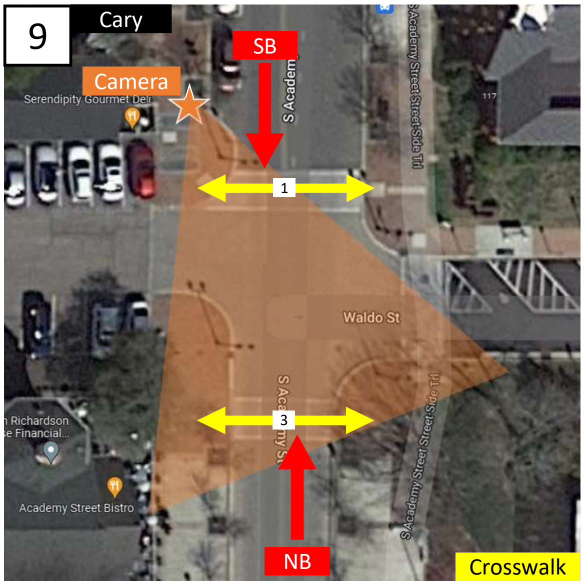
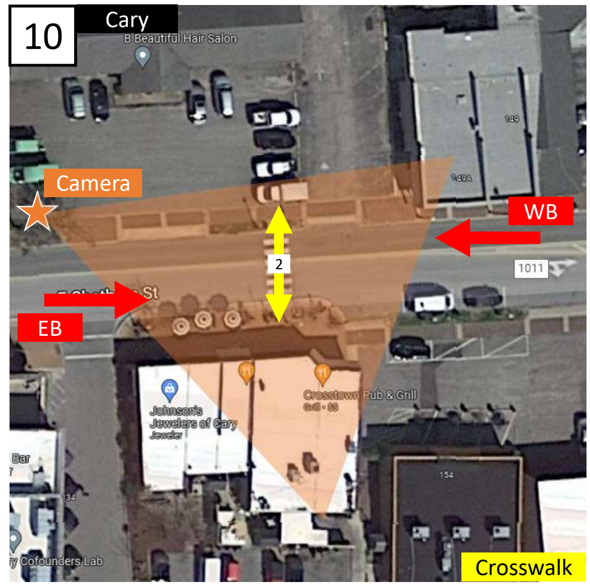
E Park St
NB
Crosswalk

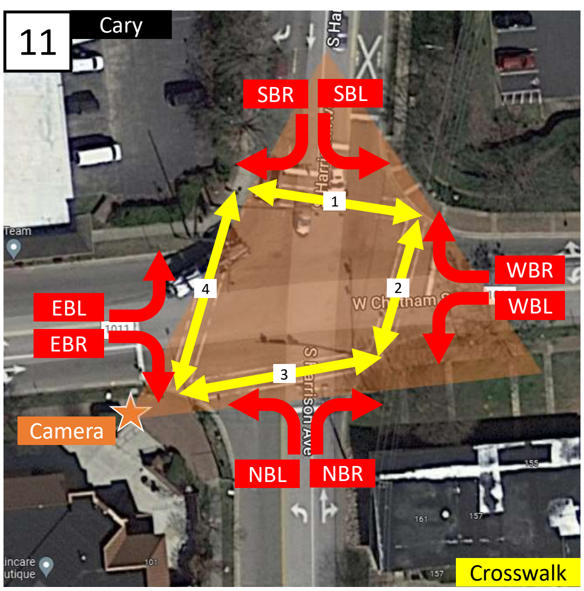

6
Cary
Camera
E Park St
EB
2
WB
Hunter St
Crosswalk

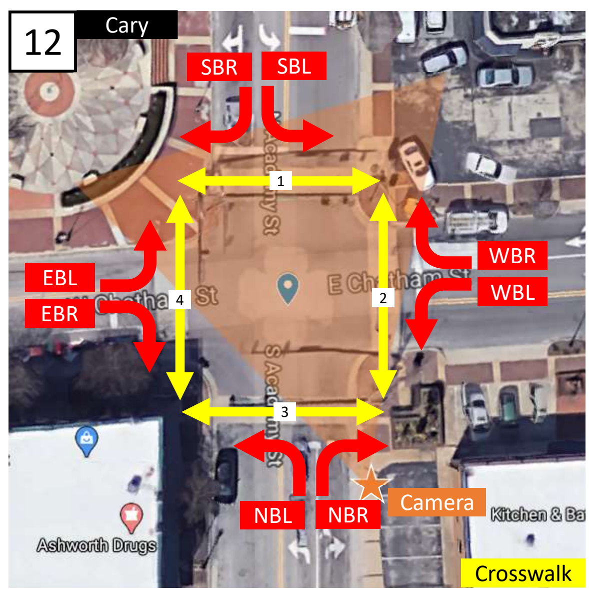

7
Cary
Camera
Park St
4
E Park St
WB
Holtz Ln
Crosswalk


8
Cary
Camera
EB
2
WB
Ryan Rd
Ryan Rd
Crosswalk


9
Cary
SB
Camera
Serendipity Gourmet Deli
S Academy
1
Waldo St
3
S Academy St
S Academy Street Side Trl
Richardson
Financial...
Academy Street Bistro
NB
Crosswalk


10
Cary
B Beautiful Hair Salon
Camera
WB
2
1011
EB
Crosstown Pub & Grill
Johnson's Jewelers of Cary
Cofounders Lab
Crosswalk


11
Cary
SBR
SBL
1
4
2
WBR
WBL
EBL
EBR
W Chatham St
3
S Harrison Ave
Camera
NBL
NBR
Crosswalk


12
Cary
SBR
SBL
1
WBR
WBL
EBL
EBR
4
2
E Chatham St
S Academy St
3
NBL
NBR
Camera
Ashworth Drugs
Crosswalk

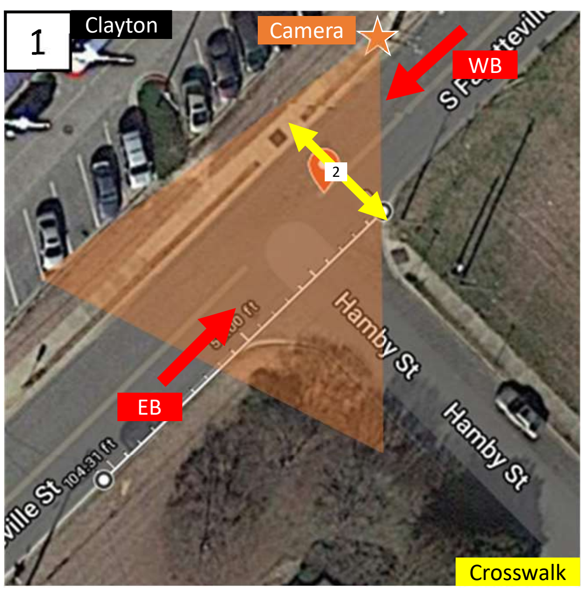
CLAYTON

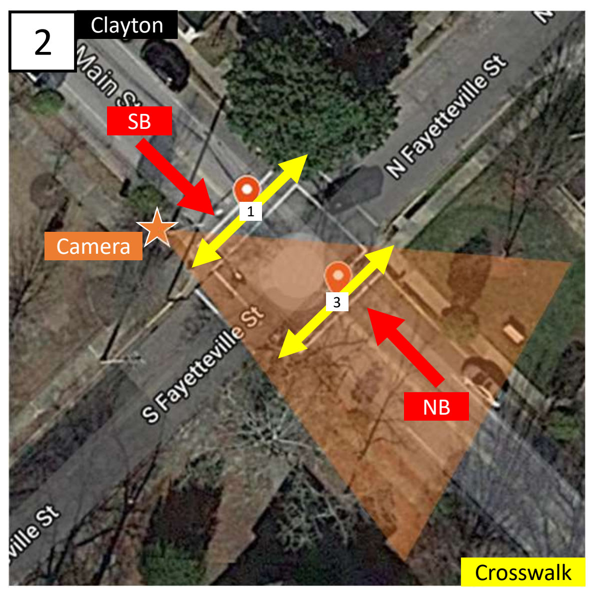
8 Sites | 19 Crossings

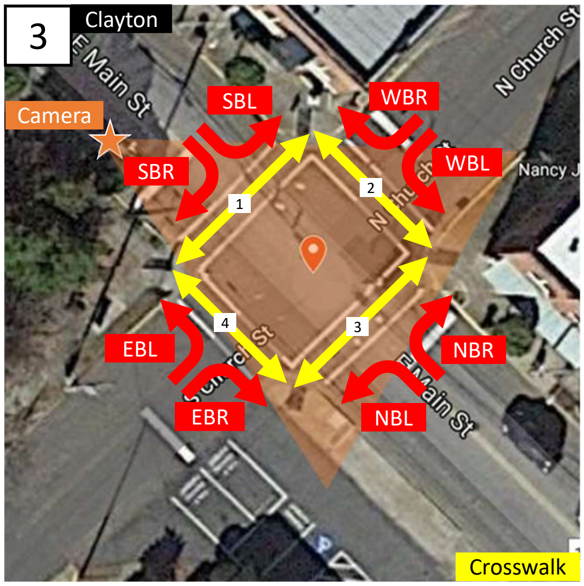
- W Main & Fayetteville
- E Main & Fayetteville
- Fayetteville @ Hamby
- Main & Church (all 4)
- Main & O'Neil (all 4)
- 2nd & Church (W)
- 2nd & Church (E)
- 2nd & O'Neil (N)
- 2nd & O'Neil (S)
- Main & Lombard (all 4)
- Fayetteville & Blanche (S)
- Fayetteville & Blanche (N)

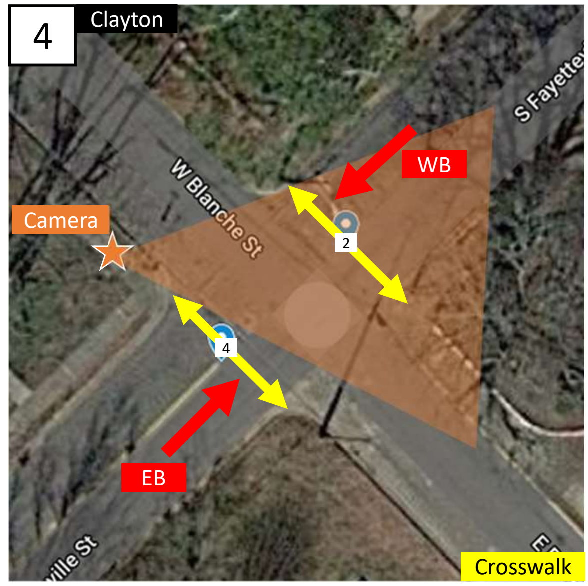
LESS

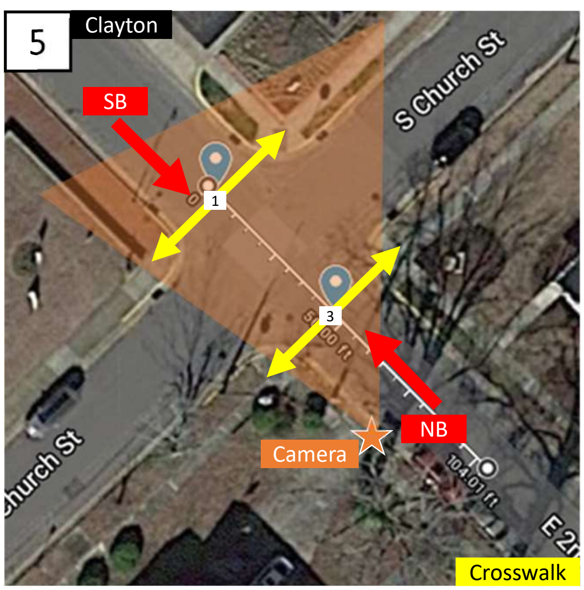
https://www.google.com/maps/@35.6513863,-78.4613672,908m/data=!3m1!1e3!4m2!6m1!1s1ep81ptM7u30TAUBtCaJZJVIERuCrmhzG

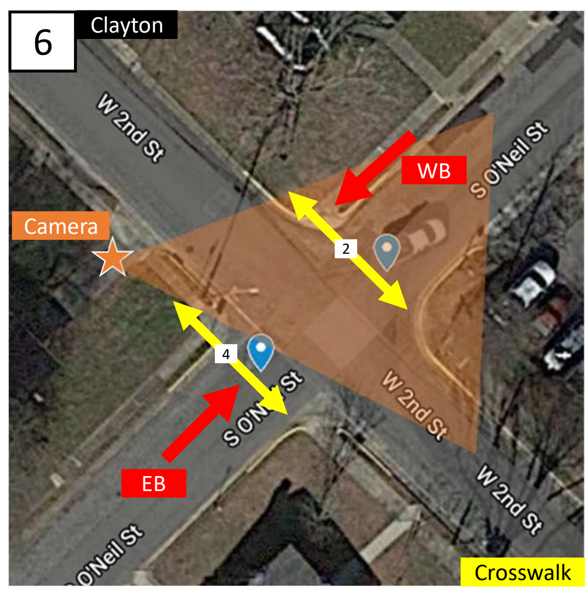


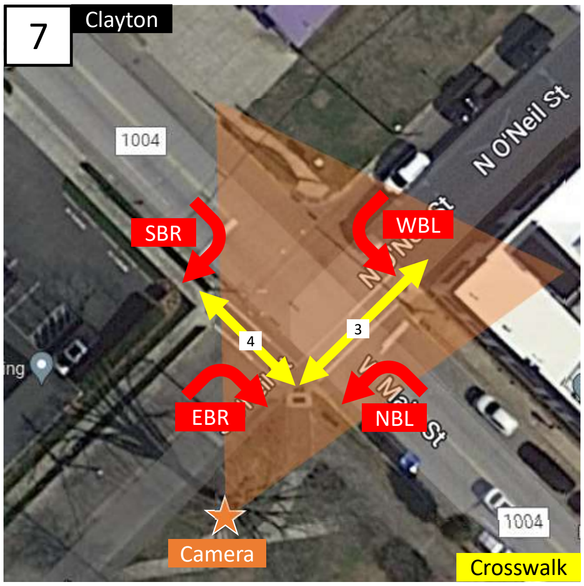


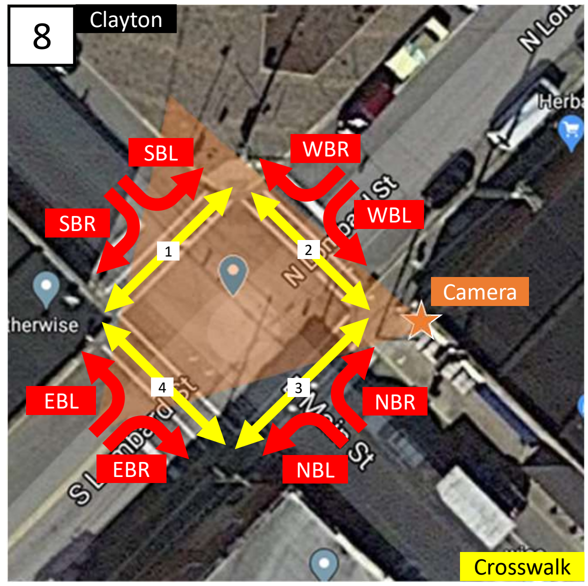

3
Clayton
Camera
SBL
WBR
WBL
SBR
EBL
NBR
EBR
NBL
1
2
3
4
E Main St
N Church St
Crosswalk


4
Clayton
WB
Camera
EB
W Blanche St
S Fayette
2
4
Crosswalk


5
Clayton
SB
NB
Camera
S Church St
1
3
Crosswalk


6
Clayton
WB
Camera
EB
W 2nd St
S O'Neil St
2
4
Crosswalk


7
Clayton
1004
N O'Neil St
SBR
WBL
4
3
EBR
NBL
Camera
1004
Crosswalk


8
Clayton
SBL
WBR
SBR
WBL
1
2
Camera
EBL
4
3
NBR
EBR
NBL
Crosswalk

Crosswalk

B. Video Reduction Protocol

video data was captured across 2 weekdays (Tues, Wednesday, or Thursday) to generate an accurate picture of pedestrian compliance and volumed data per site. Reduction hours were between 0600 and 2200 on either day, to avoid low-volume periods in the late evening and early morning. Table 8-1 and Table 8-2 list the total number of hours of video analyzed at each “Before” and “After” site up to 16 hours. Bad video footage, corrupted files or other issues prevented a full 16 hours’ worth at some sites.

Table 8-1. Before Summary: Hours of Video Reduced by Intersection by Site

Location	Intersection	Site 1	Site 2	Site 3	Site 4
Raleigh	Edenton & West	15.75		15.75	15.75
Raleigh	Edenton & Harrington		14.50		14.50
Raleigh	Edenton & Dawson			14.75	14.75
Raleigh	Edenton & McDowell	13.75			13.75
Raleigh	Edenton & Salisbury			12.75	12.75
Raleigh	Edenton & Wilmington	14.75			14.75
Raleigh	Edenton & Blount			12.25	12.25
Raleigh	Edenton & Person	15.00			15.00
Raleigh	Edenton & Bloodworth	15.50		15.50	15.50
Raleigh	Edenton & East	15.25		15.25	15.25
Raleigh	Wilmington & North	14.25			
Raleigh	Blount & North	15.75		15.75	
Cary	W Chatham St & W Park St	14.50			
Cary	S West St & W Park St	15.00			
Cary	S Harrison Ave & W Park St	15.75			
Cary	S Academy St & W Park St	16.00		16.00	
Cary	S Walker St & E Park St	14.50			
Cary	Hunter St & E Park St		16.00		
Cary	Hotlz Ln & E Park St				16.00
Cary	Ryan Rd & E Park St				16.00
Cary	S Academy & Waldo St	16.00		16.00	
Cary	E Chatham St		14.75		
Cary	S Harrison Ave & E Chatham St	16.00	16.00	16.00	16.00
Cary	S Academy St & E Chatham St	16.00	16.00	16.00	16.00
Clayton	S Fayetteville & Hamby		15.25		
Clayton	E Main & S Fayetteville	15.75		15.75	
Clayton	E Main & N Church	16.00	16.00	16.00	16.00
Clayton	S Fayetteville & E Blanche		16.00		15.50**
Clayton	E 2nd & S Church	16.00		16.00	
Clayton	W 2nd & S O'Neil		16.00		
Clayton	W Main & S O'Neil			16.00	16.00
Clayton	E Main & N Lombard	16.00	16.00	16.00	16.00

**16 hours of vehicle counts, 15.5 hours of pedestrian counts

Table 8-2. After Summary: Hours of Video Reduced by Intersection by Site

Location	Intersection	Site 1	Site 2	Site 3	Site 4
Raleigh	Edenton & West	15.50		15.50	15.50
Raleigh	Edenton & Harrington		16.00		16.00
Raleigh	Edenton & Dawson			15.00	15.00
Raleigh	Edenton & McDowell	15.50			15.50
Raleigh	Edenton & Salisbury			15.00	15.00
Raleigh	Edenton & Wilmington	15.50			15.50
Raleigh	Edenton & Blount			16.00	16.00
Raleigh	Edenton & Person	15.25			15.25
Raleigh	Edenton & Bloodworth	15.75		15.75	15.75
Raleigh	Edenton & East	16.00		16.00	16.00
Raleigh	Wilmington & North	16.00			
Raleigh	Blount & North	16.00		16.00	
Cary	W Chatham St & W Park St	16.00			
Cary	S West St & W Park St	16.00			
Cary	S Harrison Ave & W Park St	16.00			
Cary	S Academy St & W Park St	16.00		16.00	
Cary	S Walker St & E Park St	13.75			
Cary	Hunter St & E Park St		16.00		
Cary	Hotlz Ln & E Park St				13.75
Cary	Ryan Rd & E Park St				16.00
Cary	S Academy & Waldo St	16.00		16.00	
Cary	E Chatham St		16.00**		
Cary	S Harrison Ave & E Chatham St	16.00	16.00	16.00	16.00
Cary	S Academy St & E Chatham St	16.00	16.00	16.00	16.00
Clayton	S Fayetteville & Hamby		16.00		
Clayton	E Main & S Fayetteville	16.00		16.00	
Clayton	E Main & N Church	16.00	16.00	16.00	16.00
Clayton	S Fayetteville & E Blanche		16.00		16.00
Clayton	E 2nd & S Church	16.00		16.00	
Clayton	W 2nd & S O'Neil		16.00		
Clayton	W Main & S O'Neil			16.00	16.00
Clayton	E Main & N Lombard	14.00	16.00	16.50	15.00

**Due to camera malfunction, some of this footage was captured outside the 0600-2200 window.

At each intersection of interest, the crossing sites to be sampled were reviewed one at a time, and the following data points were extracted from the video:

- Through Vehicles: The number of through-movement vehicles that passed through the crosswalk, in either direction.

- Turning Vehicles: The number of turning vehicles that turned through the crosswalk, in any direction.

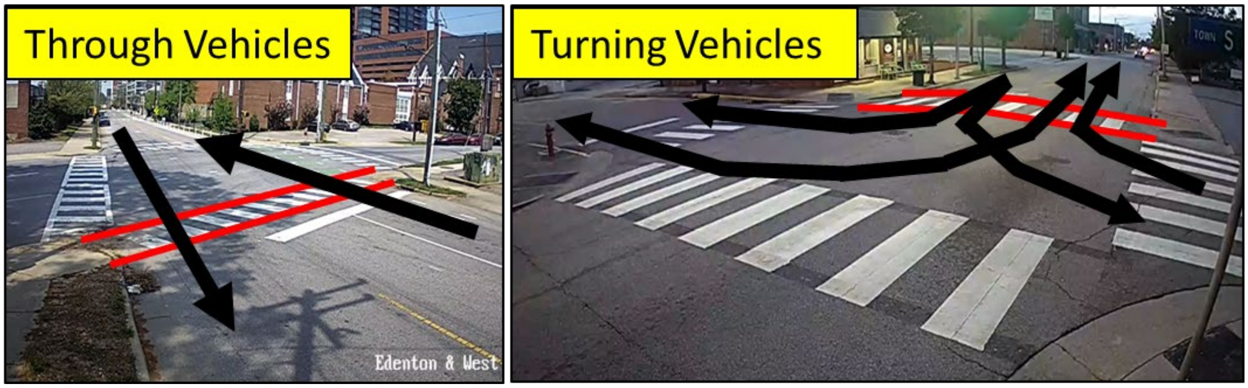


Figure 8-1.Street view images showing which through and turning vehicles were counted in relation to their paths through a given crosswalk site.

- Compliant Pedestrians: The number of pedestrians that crossed along the crosswalk and remained within five feet of the outer edge of the crosswalk for the entire crossing.
    - At unmarked crosswalks, the five-foot boundary rule was relaxed. Measuring from the imaginary centerline of where a marked crosswalk would be, pedestrians within approximately 10 ft of the imaginary centerline were considered compliant.
- Noncompliant Pedestrians: The number of pedestrians falling into any of the following categories:
    - At marked crosswalks: Pedestrians crossed outside of a five-foot "buffer" extended to either side of the marking.
    - At unmarked crosswalks: Pedestrians that crossed outside of the imaginary boundary of a 10 ft crosswalk.
    - At two adjacent crossings: in rare circumstances, one pedestrian may be counted as noncompliant for two sites during the same crossing movement. This occurred if a pedestrian essentially crossed diagonally through an intersection, as shown in Figure 8-2.

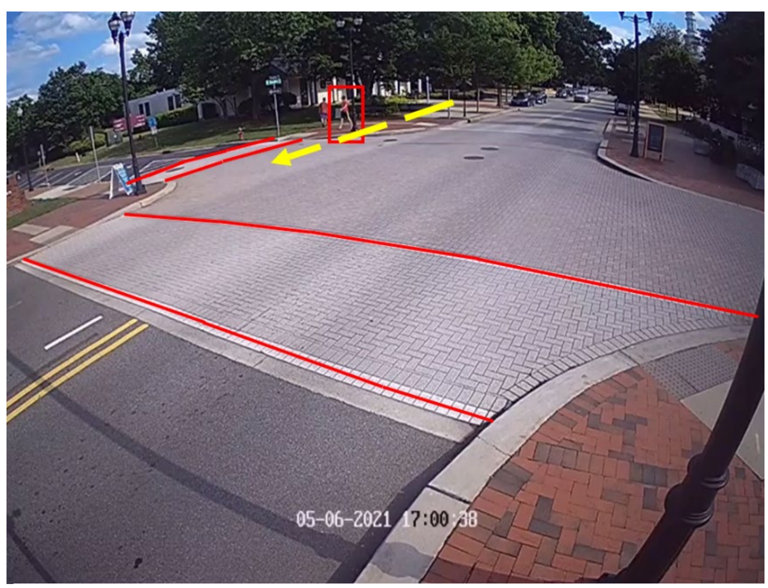
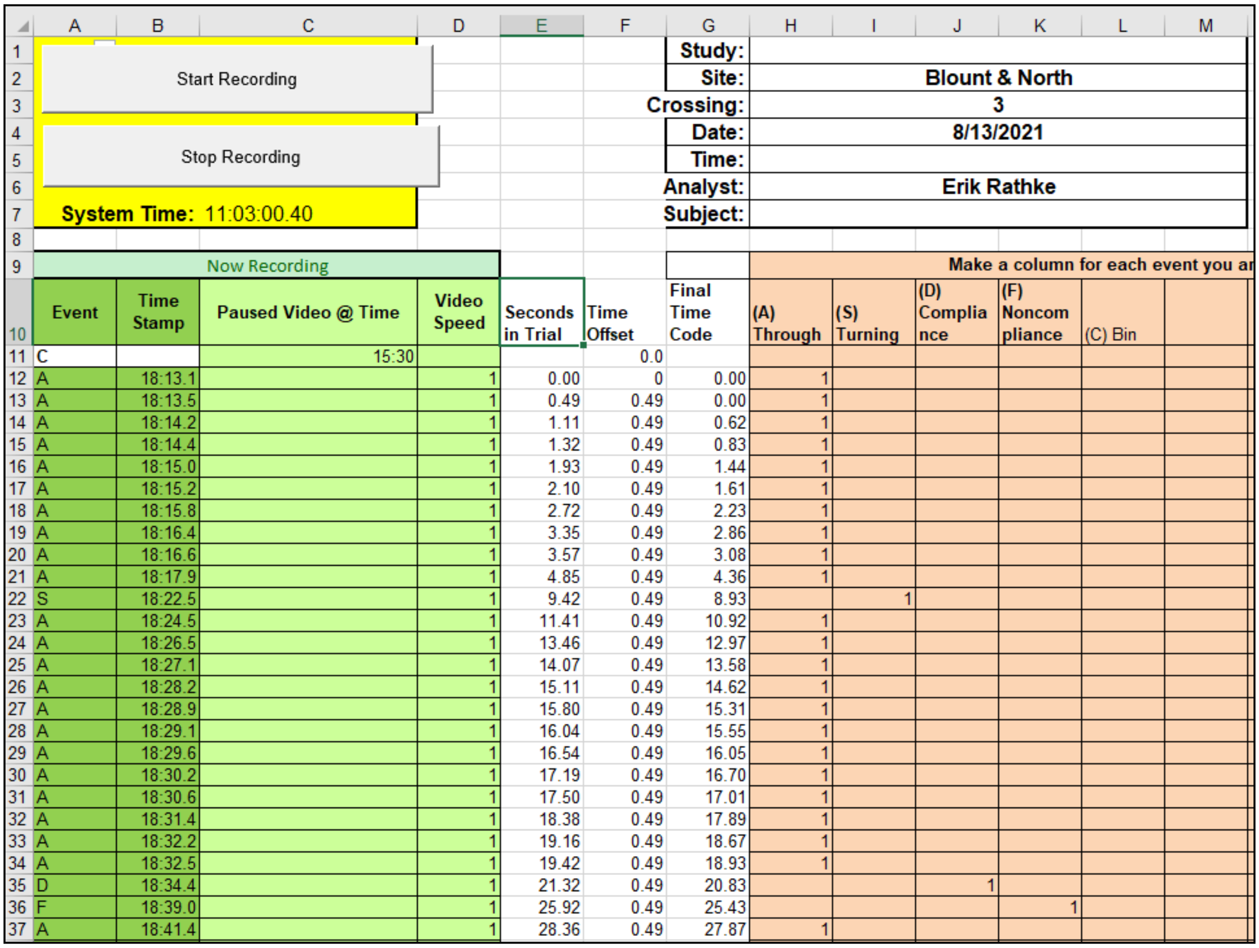


Figure 8-2. Street view of two perpendicular crosswalk sites that meet at the same corner. Yellow dashed arrow indicates travel path of pedestrian crossing two legs of intersection through one crossing movement.

Each count was aggregated into 15-minute bins. Data analysts used an Excel data-entry macro to reduce the video data into a machine-readable format, then used a processing script to aggregate the macro entries. A screenshot from the Excel data-entry program is shown below.



Row	Event	Time Stamp	Paused Video @ Time	Video Speed	Seconds in Trial	Time Offset	Final Time Code	(A) Through	(S) Turning	(D) Compliance	(F) Noncompliance	(C) Bin
11	C		15:30			0.0						
12	A	18:13.1		1	0.00	0	0.00	1				
13	A	18:13.5		1	0.49	0.49	0.00	1				
14	A	18:14.2		1	1.11	0.49	0.62	1				
15	A	18:14.4		1	1.32	0.49	0.83	1				
16	A	18:15.0		1	1.93	0.49	1.44	1				
17	A	18:15.2		1	2.10	0.49	1.61	1				
18	A	18:15.8		1	2.72	0.49	2.23	1				
19	A	18:16.4		1	3.35	0.49	2.86	1				
20	A	18:16.6		1	3.57	0.49	3.08	1				
21	A	18:17.9		1	4.85	0.49	4.36	1				
22	S	18:22.5		1	9.42	0.49	8.93		1			
23	A	18:24.5		1	11.41	0.49	10.92	1				
24	A	18:26.5		1	13.46	0.49	12.97	1				
25	A	18:27.1		1	14.07	0.49	13.58	1				
26	A	18:28.2		1	15.11	0.49	14.62	1				
27	A	18:28.9		1	15.80	0.49	15.31	1				
28	A	18:29.1		1	16.04	0.49	15.55	1				
29	A	18:29.6		1	16.54	0.49	16.05	1				
30	A	18:30.2		1	17.19	0.49	16.70	1				
31	A	18:30.6		1	17.50	0.49	17.01	1				
32	A	18:31.4		1	18.38	0.49	17.89	1				
33	A	18:32.2		1	19.16	0.49	18.67	1				
34	A	18:32.5		1	19.42	0.49	18.93	1				
35	D	18:34.4		1	21.32	0.49	20.83			1		
36	F	18:39.0		1	25.92	0.49	25.43				1	
37	A	18:41.4		1	28.36	0.49	27.87	1				

Figure 8-3. Screenshot of data-entry program used when extracting counts from video data of a given site.

C. Model Variable Correlations

The only case where the Pearson correlation coefficient between a pair of numeric variables was higher than 0.4 is between crossing length and turning movement volume; however, this high coefficient is likely attributed to four crosswalks at the same intersection having a very high value for these two variables and thus, leveraging coefficients. Therefore, we decided to keep both variables in the model development process. The matrix of Pearson correlation coefficients for numeric variables are shown in Table 8-3.

Table 8-3. Pearson correlation coefficient matrix for numeric variables

	Crossing length	Pedestrian crossing volume	Pedestrian compliance rate	Thru traffic volume	Turn traffic volume
Crossing length	1.00				
Pedestrian crossing volume	0.32	1.00			
Pedestrian compliance rate	0.35	0.34	1.00		
Thru traffic volume	0.27	0.22	0.37	1.00	
Turn traffic volume	0.61	0.28	0.20	0.25	1.00

We used Crammer's V for determining correlation between each pair of categorical variables. A strong correlation was also found between marking style and area type, location and area type, and area type and control type. Control type also has a moderate correlation (0.68) with marking style; so do the two PSLs with the location variable. Based on these findings, we removed the "area type" variable from the process due to its correlation with marking style and control type. Note that the latter two variables are more generic than the first one. Location name, as mentioned earlier, is not used in the main model, but its importance to explain the variation in yield rates is tested by feeding it to a supplementary model. The matrix of Crammer's V values for categorical variables are shown in Table 8-4.

Table 8-4. Crammer's V matrix for categorical variables

	Marking Style	Control type	Area type	Parallel PSL	Across PSL	Location
Marking Style	1.00					
Control type	0.68	1.00				
Area type	0.73	0.92	1.00			
Parallel PSL	0.41	0.59	0.55	1.00		
Across PSL	0.33	0.48	0.55	0.59	1.00	
Location	0.32	0.66	0.99	0.61	0.67	1.00