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Phase 2 - High Visibility Crosswalk Pedestrian Study: Concept to Countermeasure – Research to Deployment Using the SHRP2 Safety Data

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This study was focused on evaluating the effectiveness that high-visibility crosswalk (HVC) markings have on improving pedestrian safety. Naturalistic driving data was used to analyze vehicle kinematics and driver behavior in relation to the approach and traversal of HVC locations before and after their implementation. Traffic safety surrogates were developed and evaluated in the presence of different marking types, configurations, and for varying driver characteristics. The findings indicate that the placement of pedestrian crossing signs in advance of the HVC significantly improved the safety surrogates, ladder type configurations were the most effective overall in affecting driver behavior including external scanning patterns, and that targeting education and awareness programs towards young and older drivers could prove to be successful in enhancing the effectiveness of HVC implementations. This study, utilizing naturalistic driving data, provides a more comprehensive analysis on the overall effectiveness of all types and implementations of HVCs.</td></tr>
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EXECUTIVE SUMMARY

In the United States, 5,977 pedestrians were killed due to a motor vehicle crash killed in 2017 [(1)]. These pedestrian deaths accounted for 16 percent of all fatalities in motor vehicle crashes. In New York State pedestrian fatalities accounted for 24 percent of the total fatalities on the state's roadways [(1)]. Furthermore, an estimated 193,866 pedestrians were injured due to motor vehicle crashes and required a visit to an emergency medical department [(2)]. Making roadways safer for pedestrians is an important national and statewide goal [(3)]. Numerous studies of pedestrian-vehicle crashes have been conducted [(4,5,6,7,8)] to analyze the frequency and severity of these crashes. A general finding is that pedestrian-vehicle crashes are associated with a lack of driver compliance, that drivers often fail to yield to the pedestrians [(9)], and that pedestrian safety at crosswalks depends mainly on the vehicles' speed and driver reaction time [(10,11,12)]. Various strategies have methods and countermeasures to improve pedestrian safety, such as passive markings and signage (e.g., high-visibility crosswalk markings); traffic calming measures (e.g., roadway narrowing, horizontal shifts, and vertical deflections); and active control devices (e.g., automated pedestrian detection, smart lighting, and high intensity activated crosswalks). These studies also highlight the importance of carefully considering location-specific countermeasures (e.g., whether marked crosswalks should be provided in a specific location).

The present study focuses on the relatively low cost and widely used pedestrian safety strategy of high-visibility crosswalk (HVC) markings. HVCs feature pavement marking styles (textured pavement, longitudinal, bar-pair, continental, or ladder markings) that allow for better crosswalk visibility to the motorists, as compared to conventional pedestrian crossings, especially in cases of high approach speeds. There is an ongoing debate in the traffic safety community regarding the effectiveness and placement of HVC markings. The overall goal of the study is to provide an evaluation of the effectiveness of HVCs in terms of improving pedestrian safety at uncontrolled locations. A summary of the research questions posed in this study are below:

- Are there differences in effectiveness (i.e., improved pedestrian safety) between mid-block and end block uncontrolled HVCs?
- How do different HVC marking designs (e.g., continental HVC, ladder HVC, bar-pair HVC.), impact HVC effectiveness?
- Does the presence of HVCs and associated signage change the eye scan behavior of drivers approaching an HVC?
- Are there any relationships between driver demographics (e.g., age and gender) and changes in driver behavior due to HVC implementations?

The Second Strategic Highway Research Program (SHRP2) Naturalistic Driving Study (NDS) data offer detailed information on the everyday driving behavior of a large number of participants in six test sites across the U.S. including Buffalo, New York; Tampa, Florida; Raleigh, North Carolina; Seattle, Washington; Bloomington, Indiana; and State College, Pennsylvania. This analysis utilizes a sample of the data from five of the six sites, only excluding Bloomington, due to the lack of suitable HVC sites for analysis. In total, driving behavior of SHRP2 NDS participants was analyzed at 18 uncontrolled locations with HVC markings. The data used for the analysis span over the three-year SHRP2 NDS data collection period from 2011 to 2013. The sites were selected based on the availability of sufficient traversal data through the locations both before and after the HVC were installed.

In order to develop a robust and varied data set for analysis five objectives for the inclusion of a HVC were developed. These objectives are summarized below:

- HVC Design: In addition to HVCs with ladder markings, HVCs with continental and bar-pair markings will be included in the analyses.
- HVC Location: All HVCs must be at uncontrolled mid-block or end-of-block crossing locations.
- Number of HVCs to Analyzed: The targeted number for each category of HVCs to be is three of each configuration type.
- Availability of Traversals: Data sample target of approximately 350 traversals through each of the HVC sites with approximately half the traversals occurring prior to HVC installation and half the traversals occurring after HVC installation.
- Nature of the Traversal Data: The goal is to acquire traversals at each HVC location that are equally distributed by driver age and gender.

There are two important aspects of the analysis methodology. The first relates to the way the forward video data were analyzed. The process of analyzing the videos involved the determination of an upstream benchmark point for each intersection location and direction. The benchmark points were selected to represent the approximate location where drivers can see and react to the HVC. They were also selected based on easily identifiable locations in the videos both before and after the HVC was installed (i.e., landmarks such as buildings and light poles were used). Each video was reviewed and the time that the vehicle crossed the benchmark and crosswalk (HVC, when installed) locations were recorded. Additional information was also recorded, such as pedestrian presence, vehicle's lane position, preceding and parked vehicles' presence, the level of obstructed visibility of the HVC, windshield condition and wipers' usage, weather conditions, pavement surface conditions, and lighting conditions. Using the timestamps on the videos, the time-series data were matched with the rest of the trip data. Upon reviewing the forward-facing videos and time-series data, 3,480 traversals were available for analysis. These traversals were undertaken by 183 drivers with the frequency of traversals ranging from 1 trip/participant to 391 traversals/participant. Of the traversals used, HVC was present in 2,019 traversals and was under construction for 269 traversals. While pedestrian presence was identified for 333 traversals, pedestrians were also observed crossing the roads adjacent to the HVC location in 77 traversals.

The statistical analysis employed in this study aimed to identify the in-depth effects of HVCs on modifying driving behavior in terms of improving pedestrian safety. To comprehensively evaluate the effectiveness of HVCs, different HVC positions (mid-block vs. end-of-block) and different HVC marking designs (continental, bar-pair, and ladder.) were considered in the analysis. As no pedestrian-vehicle crashes or conflicts were identified from the forward-facing videos and time-series information of the SHRP2 NDS data, crash surrogate measures were employed to identify and analyze modifications in driving behavior at or near the HVCs. Due to the high-dimensional nature of the NDS data, the presence of panel effects arising from multiple traversals undertaken by each participant, the effect of unobserved characteristics, as well as their unobserved correlations, constituted possible misspecification issues. To account for these issues the correlated grouped random parameters estimation framework was employed. In this context, several correlated grouped random parameters linear regression models were estimated for speed, acceleration, and throttle pedal actuation (TPA) at the benchmark and HVC locations, as well as for the difference between the benchmark and HVC locations. To investigate the likelihood of speed, acceleration, TPA, and brake application decrease between the benchmark and HVC, a correlated grouped random parameters discrete outcome modeling framework was employed, which also accounts for misspecification issues. The following section summarizes the findings of the study.

Overall, the results of the analysis suggest that the presence of HVCs reduce speed, acceleration, and TPA at the benchmark and HVC locations. HVC presence is also found to reduce the speed, acceleration, and TPA difference between the benchmark and HVC locations. The simultaneous presence of HVC and pedestrian signage is found to have a mixed effect in acceleration at the benchmark and HVC locations and to decrease the difference in acceleration between the benchmark and HVC locations. Apart from the presence of HVC, the HVC type (e.g., ladder, bar-pair) and in-block location (mid-block, end-of-block) were also found to affect the vehicles' speed, acceleration, TPA, and brake application.

Ladder type end-of-block located HVCs were found to have a mixed effect on the speed at the benchmark and HVC location although a reduction at either point was found to occur in 97 percent of all traversals. End-of-block located HVCs indicated mixed effects on TPA at the benchmark location, while bar-pair type end-of-block located HVCs increased the TPA at the HVC location, the acceleration at the benchmark and the HVC locations, and the acceleration difference between the benchmark and HVC locations. Bar-pair type HVCs were found to have a decreasing effect on the likelihood of acceleration decrease, whereas ladder type HVCs were found to decrease the likelihood of brake application. End-of-block located HVCs were found to increase the overall likelihood of both acceleration decrease and TPA decrease.

Apart from the HVC-related characteristics, trip and traffic characteristics such as the speed limit in the area where a traversal was undertaken, and the presence of lead and obstructing vehicles, were found to be statistically significant in most of the estimated models. The presence of a lead vehicle and the absence of parked vehicles near the HVC location were also found to decrease the speed difference between the benchmark and HVC location.

Finally, various driver-specific characteristics were also found to be statistically significant in modifying driving behavior at HVC locations. Younger drivers were found to be more likely to increase acceleration at the benchmark location, while older drivers were found to show mixed effects on traversal speed at the benchmark location. Participants' traversal frequency was also found to play a significant role in most of the estimated models. A summary of the notable factors having a statistically significant impact on the safety surrogates can be found below.

This research provides information about driver behavior and characteristics that can be used to improve and optimize HVC implementations. The use of the SHRP2 NDS data provided the opportunity to examine driver behavior in response to HVCs in ways that have not been possible in the past. The evaluation of HVC implementation in the past primarily depended upon the identification of the number of crashes before and after the installation of the HVC, or the comparison of observed crash rates at comparable sites where HVC were not installed; roadside observational studies of driver compliance; number of citations issued before and after the implementation; and surveys to identify any self-reported changes in driver behaviors. These strategies provide a measure of the effectiveness of the HVC to change aggregate driver behavior but fall short in evaluating the effects of the HVC on different groups of drivers. SHRP2 NDS data provided a unique opportunity to have access to detailed driver demographics over a period of time. The use of the SHRP2 NDS data allowed for the examination of other driving behaviors including throttle and brake pedal actuation from the time-series data and eye glance and scanning patterns that were only observable through the interior video data in the SHRP2 NDS equipped vehicles.

Four main recommendations can be drawn from this study.

- First, the placement of pedestrian crossing signs in advance of the HVC was found to significantly improve the safety surrogates associated with the traversals through that location.
- Second, ladder type configurations of pavement markings were shown to be most effective in improving the safety surrogates associated with the traversals through those HVCs as well as increasing external scanning patterns.
- Third, directing specific education and awareness programs towards *young* drivers (less than 25) and *older* drivers (greater than 65) through public service announcements, social media outlets, and other means could prove to be successful in enhancing the effectiveness of HVC implementations.
- A final recommendation for the transportation safety community, in general, is to design the evaluation of HVC implementations into future naturalistic driving data collection programs. A limitation of this study was finding HVC locations that were installed in the SHRP2 NDS test sites during the data collection period. This proved to be a tedious and time-consuming process that ended up limiting the sites available for analysis and in-turn the total number of traversals.

The results of this study are especially timely for New York State (NYS). Currently, the New York State Department of Transportation (NYSDOT) is coordinating with safety partners from the Governor's Traffic Safety Committee, the New York State Department of Health (NYSDOH), the Federal Highway Administration (FHWA), Metropolitan Planning Organizations, and local transportation agencies to develop a Pedestrian Safety Action Plan (PSAP). Strategies in the plan include enforcement, education and engineering actions with the goal to significantly reduce pedestrian crashes in New York. The package of engineering measures outlined in the PSAP includes systemic treatments at locations that contain risk factors associated with pedestrian crashes. Over a five-year period (2016-2020), NYSDOT plans to study and install HVC markings at a number of existing uncontrolled crosswalks and signalized intersections for state-maintained facilities. This research is intended to justify the use of HVC, as well as help NYSDOT utilize the most effective design for these crossings for both the markings as well as other elements such as warning sign placement. Also, many of the pedestrian crashes in NYS occur off-system, on roadways maintained by local jurisdictions. The results of this research will assist NYSDOT in demonstrating the benefits of using HVC markings to local agencies and help develop policy for their use in NYS. Utilizing complete information collected by traditional roadside equipment, in-vehicle sensors, associated driver demographics and characteristics, and crash and citation records could potentially provide more complete analysis of the overall effectiveness of all types and implementations of HVCs.

1. INTRODUCTION

In the United States, 5,977 pedestrians were killed due to a motor vehicle crash killed in 2017 [1]. These pedestrian deaths accounted for 16 percent of all fatalities in motor vehicle crashes. In New York State pedestrian fatalities accounted for 24 percent of the total fatalities on the state's roadways [1]. Furthermore, an estimated 193,866 pedestrians were injured due to motor vehicle crashes and required a visit to an emergency medical department [2]. Making roadways safer for pedestrians is an important national and statewide goal [3]. Numerous studies of pedestrian-vehicle crashes have been conducted [4,5,6,7,8] to analyze the frequency and severity of these crashes. A general finding is that pedestrian-vehicle crashes are associated with a lack of driver compliance, that drivers often fail to yield to the pedestrians [9], and that pedestrian safety at crosswalks depends mainly on the vehicles' speed and driver reaction time [10,11,12]. Various strategies have methods and countermeasures to improve pedestrian safety, such as passive markings and signage (e.g., high-visibility crosswalk markings); traffic calming measures (e.g., roadway narrowing, horizontal shifts, and vertical deflections); and active control devices (e.g., automated pedestrian detection, smart lighting, and high intensity activated crosswalks). These studies also highlight the importance of carefully considering location-specific countermeasures (e.g., whether marked crosswalks should be provided in a specific location).

The present study focuses on the relatively low cost and widely used pedestrian safety strategy of HVC markings. HVCs feature pavement marking styles including textured pavement, longitudinal, bar-pair, continental, or ladder markings that allow for better crosswalk visibility to the motorists, as compared to conventional pedestrian crossings, especially in cases of high approach speeds [13,14]. These HVC configurations are shown in Figure 2. There is an ongoing debate in the traffic safety community regarding the effectiveness and placement of HVC markings [4,13,14,15]. The overall goal of the study is to provide an evaluation of the effectiveness of HVCs in terms of improving pedestrian safety at uncontrolled locations.

Bar Pair | Ladder | Continental

Figure 1. HVC configurations.

Several studies have used several data resources (field traffic data, driving simulation) to evaluate several types of HVCs, such as parallelogram-shaped pavement markings, and advance yield markings for marked midblock crosswalks, to name a few [16,17,18]. However, these studies do not allow for an exploration of the effect of driver's behavioral characteristics, or of time- and location-specific roadway, weather and driving conditions, on pedestrian safety. The naturalistic driving study (NDS) data from the second Strategic Highway Research Program (SHRP2) [19] provide a unique opportunity to analyze such behavioral and environmental characteristics, before and after installation of the HVC. Although no pedestrian-vehicle crashes were observed in the SHRP2 NDS test sites, safety surrogates (i.e., speed, acceleration, TPA, and brake pedal state) can be used for analyses [20,21,22,23,24,25,26,27,28,29]. The NDS data therefore offers a good representation of the drivers' reactions to crosswalk markings and possibly other safety countermeasures.

This study is part of a two-phase research effort. Phase 1 was led by NYSDOT along with CUBRC and the State University of New York at Buffalo (SUNY at Buffalo) and performed for The American Association of State Highway Transportation Officials (AASHTO), funded under the SHRP2 Implementation Assistance Program: "Concept to Countermeasure – Research to Deployment Using the SHRP2 Safety Data". This previous work provided three results of critical importance to the expansion of analyses, namely:

- Evidence of the availability of the necessary SHRP2 NDS data for analysis. As a result of a review of the SHRP2 NDS database more than 13,000 trips made by 813 drivers before and after HVC implementations were identified. This suggests additional sites are available for an expansion of analyses.
- Demonstration of the feasibility of the statistical analysis methodologies. The applicability of a statistical methodology to analyze the relationship between HVCs and pedestrian safety was validated.
- Preliminary statistical analysis results, from a limited sample of the available data, suggested that HVCs are effective in improving pedestrian safety. Specifically, the results indicated that HVCs can reduce drivers' speed and acceleration (and possibly throttle position activation), which in turn has the potential to increase pedestrian safety at uncontrolled intersections or mid-block locations.

The Phase 2 program, conducted by CUBRC and SUNY at Buffalo for NYSDOT, significantly expands the scope and size of the Phase 1 analyses. This was accomplished by identifying additional HVC locations, of different configuration types, and utilizing a much larger sample of trips. This provides a more robust analysis of the measures of HVC effectiveness. The number of primary research questions addressed was also expanded. A summary of the research questions posed in this study are summarized below:

- Are there differences in effectiveness (i.e., improved pedestrian safety) between mid-block and end block uncontrolled HVCs?
- How do different HVC marking designs (e.g., continental HVC, ladder HVC, bar-pair HVC.), impact HVC effectiveness?
- Does the presence of HVCs and associated signage change the eye scan behavior of drivers approaching an HVC?
- Are there any relationships between driver demographics (e.g., age and gender) and changes in driver behavior due to HVC implementations?

To increase the sample sizes available for analysis in this study issues associated with personally identifiable information (PII) were addressed. Instances of PII in the requested data most often derived from the HVC being located within 1-mile of the origin or destination of the NDS driver's trip. These trips were not available for export but can be analyzed within the confines of a secure data center housed at Virginia Tech Transpiration Institute (VTTI) or the Federal Highway Administration (FHWA) Safety Training and Analysis Center (STAC) at the Turner-Fairbank Highway Research Center. In addition to increasing the amount of data analyzed, the scope and size of the analyses were expanded to include the use of driver eye glance data to investigate the effects of HVC markings and signage had on driver behavior. Utilizing pre-HVC installation versus post-HVC installation video and time-series data, differences, if any, were observed in the optical scanning patterns of NDS drivers.

The following sections describe the research approach and data processing procedures, including the identification and selection of HVC sites, descriptive statistics and an overview of the modeling methodology, the model results, an analysis of the eye glance data, and finally a summary of results, conclusion, and recommendations.

2. TEST AREA, DATA, AND PROCESSING

The SHRP2 NDS data offer detailed information on the everyday driving behavior of a large number of participants in six test sites across the U.S. including Buffalo, New York; Tampa, Florida; Raleigh, North Carolina; Seattle, Washington; Bloomington, Indiana; and State College, Pennsylvania. This analysis utilizes a sample of the data from five of the six sites, excluding Bloomington, due to the lack of suitable HVC sites for analysis. The driving behavior of SHRP2 NDS participants was analyzed at 18 uncontrolled locations with HVC markings. The data used for the analysis span was gathered over the three-year SHRP2 NDS data collection period from 2011 to 2013. The sites were selected based on the availability of sufficient traversal data through the locations both before and after the HVC was installed. An example of an aerial view of two of the HVCs is shown in Figure 1.

Figure 2. Aerial views of the two HVC locations used in the analysis.

IDENTIFICATION AND SELECTION OF HVCS

In order to develop a robust and varied data set for analysis five objectives for the inclusion of a HVC were developed. These objectives are summarized below:

1. HVC Design: In addition to HVCs with ladder markings, HVCs with continental and bar-pair markings will be included in the analyses. Since the SHRP2 NDS New York test site only

has HVCs with ladder markings it was necessary to identify HVCs at the other five SHRP2 NDS test sites to include in the analysis.

2. HVC Location: All HVCs must be at uncontrolled mid-block or end-block crossing locations.
3. Number of HVCs to Analyzed: The targeted number (shown in parentheses) for each category of HVCs to be included in the Phase 2 analyses is shown in Figure 3. As noted, the Phase 2 goal is to analyze a total of 18 HVCs. These HVCs will be split equally between mid-block and end-block HVC locations.
4. Availability of Traversals: Data sample target of approximately 350 traversals through each of the HVC sites with approximately half the traversals occurring prior to HVC installation and half the traversals occurring after HVC installation.
5. Nature of the Traversal Data: The goal is to acquire traversals at each HVC location that are equally distributed by driver age and gender.

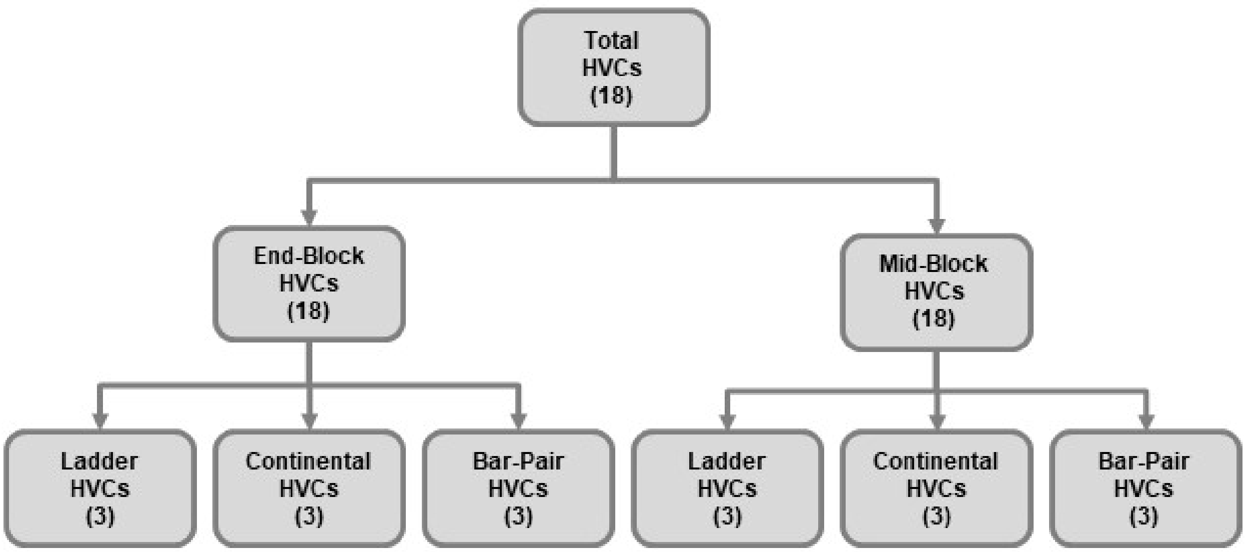

Figure 3. Types of HVCs for analysis.

PROCESS OF IDENTIFYING HVCS FOR INCLUSION

This section describes the process that was employed to select the HVCs to be included in the analysis. This iterative process, shown in Figure 4, involved two tasks to identify the 18 HVCs to be included in the analyses. A summary of the tasks is described below the figure.

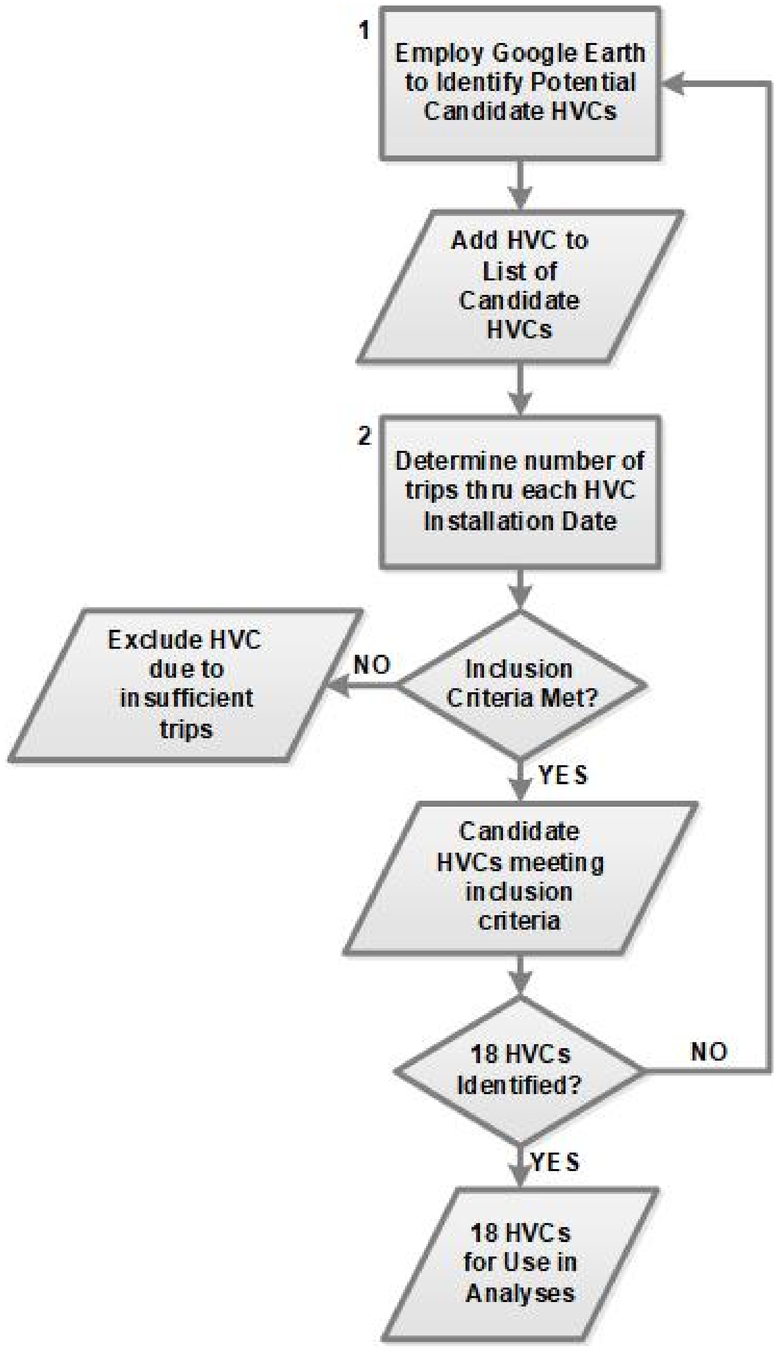

Figure 4. Process to identify HVCs to be included in the analyses.

First, Google Earth imagery was used to identify HVCs at the SHRP2 NDS test sites that met inclusion criteria 1 and 2 (i.e., they were bar-pair, continental or ladder configuration and were at uncontrolled end-block or mid-block locations). Five searches were needed to identify all HVCs of interest. The first of these searches occurred during the Phase 1 project and resulted in the identification of 22 HVCs for possible use in the Phase 2 analyses. These 22 HVCs became the starting point for the HVC identification process. The subsequent searches for new HVCs were required because previously identified HVCs were eliminated from consideration since they did not meet inclusion criteria 4 and 5 (i.e., traversals available in the SHRP2 NDS database were insufficient to support the effectiveness analyses).

Second, each of the HVCs identified in the first task were examined to determine the HVC installation date so that the requirement of sufficient trips before and after the installation could be met. This was done in a three-step process. If available, historical Google Earth images were used to establish an approximate installation date. If the images were not available, video from the forward-facing camera of the SHRP2 NDS vehicle were acquired for several trips through the HVC location and used to establish the HVC installation date. The number of trips through each of the HVC locations and the number of participants making those trips was determined using the 'Trip Density Maps' available on the VTTI InSight website.

Table 1 identifies the 49 HVCs that were identified, evaluated, and included or excluded from the analysis. The reasons for the exclusion of the HVCs are also provided.

Table 1. List of all HVCs identified and evaluated for inclusion.

HVC ID	Test Site	HVC Street Location	HVC Configuration	HVC Block Location	Installation Date	HVC Status	Exclusion Reason
1	NY	Elm / Eagle	Ladder	End-of-Block	Jun-12	Include	-
2	NY	Oak / Eagle	Ladder	End-of-Block	Jun-12	Include	-
3	NY	Main St, Hamburg	Ladder	Mid-Block	-	Exclude	[A]
4	NY	Delaware Ave.	Ladder	Mid-Block	-	Exclude	[A]
5	FL	S. Miller Rd	Zebra	End-of Block	-	Exclude	[D]
6	FL	North 50th St	Ladder	Mid-Block	Jun-12	Include	-
7	FL	North 50th St	Ladder	Mid-Block	Jun-12	Include	-
8	IN	E. 3rd St	Continental	End-of-Block	-	Exclude	[A]
9	NC	Pullen Rd.	Continental	End-of-Block	Aug-12	Include	-
10	FL	S. Howard Ave	Continental	End-of-Block	-	Exclude	[A]
11	NC	E. Cameron Ave	Continental	Mid-Block	-	Exclude	[A]
12	IN	E. 2nd St	Continental	Mid-Block	-	Exclude	[A]
13	NC	E Rosemary St	Continental	Mid-Block	May-11	Include	-
14	WA	Green Lake Way N	Bar-Pair	End-of-Block	May-11	Include	-
15	WA	S. McClellan St	Bar-Pair	End-of-Block	Jan-13	Include	-
16	WA	University Way NE	Bar-Pair	End-of-Block	Mar-13	Include	-
17	WA	25th Ave NE	Bar-Pair	Mid-Block	-	Exclude	[A]
18	WA	22nd Ave. NE	Bar-Pair	Mid-Block	-	Exclude	[A]
19	WA	Beacon Ave. S	Bar-Pair	Mid-Block	Sep-11	Include	-
20	WA	Beacon Ave. S	Bar-Pair	Mid-Block	-	Exclude	[A]
21	NY	Union Rd	Ladder	End-of-Block	Jun-13	Include	-

HVC ID	Test Site	HVC Street Location	HVC Configuration	HVC Block Location	Installation Date	HVC Status	Exclusion Reason
22	PA	E. Pollack Rd	Continental	End-of-Block	Oct-11	Include	-
23	PA	S. Allen St	Continental	End-of-Block	Jun-12	Include	-
24	FL	S. 78 St.	Continental	End-of Block	-	Exclude	[A]
25	FL	North Blvd.	Ladder	Mid-Block	-	Exclude	[A]
26	FL	N. 40th St.	Continental	End-of-Block	-	Exclude	[A]
27	FL	Telfair Rd.	Ladder	Mid-Block	-	Exclude	[A]
28	FL	W. Snow Dr.	Continental	End-of Block	-	Exclude	[A]
29	WA	NE 65th St	Bar-Pair	End-of Block	-	Exclude	[A]
30	WA	Phinney Ave.	Bar-Pair	End-of Block	-	Exclude	[A]
31	WA	NE Pacific St	Bar-Pair	End-of-Block	-	Exclude	[C]
32	WA	116 Ave, SE	Bar-Pair	Mid-Block	-	Exclude	[A]
33	WA	E. Pike	Bar-Pair	End-of-Block	-	Exclude	[A]
34	WA	Ravenna Ave.	Bar-Pair	End-of Block	-	Exclude	[A]
35	NC	W. Rosemary St	Ladder	End-of-Block	-	Exclude	[A]
36	NC	W. Cameron St.	Ladder	End-of-Block	-	Exclude	[A]
37	NC	S. Greensboro St.	Continental	End-of-block	-	Exclude	[A]
38	NC	Blackwell St.	Continental	Mid-Block	-	Exclude	[A]
39	NC	E. Morgan St.	Continental	End-of Block	-	Exclude	[A]
40	IN	N. Fee Lane	Continental	Mid-Block	-	Exclude	[A]
41	IN	Countryside LN.	Continental	End-of-Block	-	Exclude	[A]
42	PA	Waupelani Dr.	Continental	End-of-Block	Jun-12	Include	-
43	IN	N. College Ave	Continental	Mid-Block	TBD	Exclude	[A]
44	WA	SW 320th St	Bar-Pair	Mid-Block	Jul-11	Include	-
45	WA	SW 348th St	Bar-Pair	Mid-Block	Jul-11	Include	-
46	FL	S. Village Dr.	Ladder	Mid-Block	Jul-13	Include	-
47	NC	N. Mangum St	Continental	End-of-Block	TBD	Exclude	[A]
48	NC	W. Franklin St	Continental	Mid-Block	Mar-11	Include	-
49	IN	10th St.	Continental	Mid-Block	TBD	Exclude	[A]

The following provides definitions of the Table Headings as well as notes included in the Table.

- HVC ID – Arbitrary number to uniquely identify each of the identified HVCs
- HVC Test Site – SHRP2 NDS test site State in which the HVC is located
- HVC Street Location – Street (mid-block) or Streets (end-of block) HVC is on
- HVC Configuration – continental, ladder, zebra, bar-pair

- HVC Block Location – Mid-Block, End-of-Block
- Installation Date – Approximate date of HVC installation based upon inspection of historical Google Earth images or vehicle forward video
- HVC Status – HVC inclusion or exclusion status
- Reason for Excluding the HVC -
    - [A] - HVC installed prior to SHRP2 NDS as determined by Google Earth Historical imagery or inspection of traversal forward videos
    - [B] - HVC installed after SHRP2 NDS as determined by Google Earth Historical imagery or inspection of traversal forward videos
    - [C] – Atypical HVC design (e.g., 'Y' – configuration)
    - [D] - Decision to eliminate zebra configuration HVCs

As noted in Table 1, the primary reason for the exclusion of HVCs concerns the HVC installation date. In order to include the HVC in the Phase 2 analyses, the HVC installation must have occurred during the SHRP2 NDS data collection activities so traversals before and after HVC installation are available. Figure 5 shows the timelines for data collection at each of the 6 SHRP2 NDS test sites indicated by blue bars. The numbers in parentheses indicate the total number of vehicle months of data collected at each site. Also shown on each bar are 'white' lines indicating the quartiles associated with the data collection at each site. Thus, for the NY test site:

- 25% of the data was collected and 75% remained to be collected by April 2012
- 50% of the data was collected and 50% remained to be collected by mid-August 2012
- 75% of the data was collected and 25% remained to be collected by mid-March 2012

The closer the HVC installation date is to the 50% quartile date, the higher the probability that pre- and post-HVC installation traversal data will be available. Using similar reasoning, a) the earlier the HVC installation date is before the 25% quartile date the lower the probability that pre-HVC installation traversal data will be available and b) the later the HVC installation date is after the 75% quartile date the lower the probability that post-HVC installation traversal data will be available.

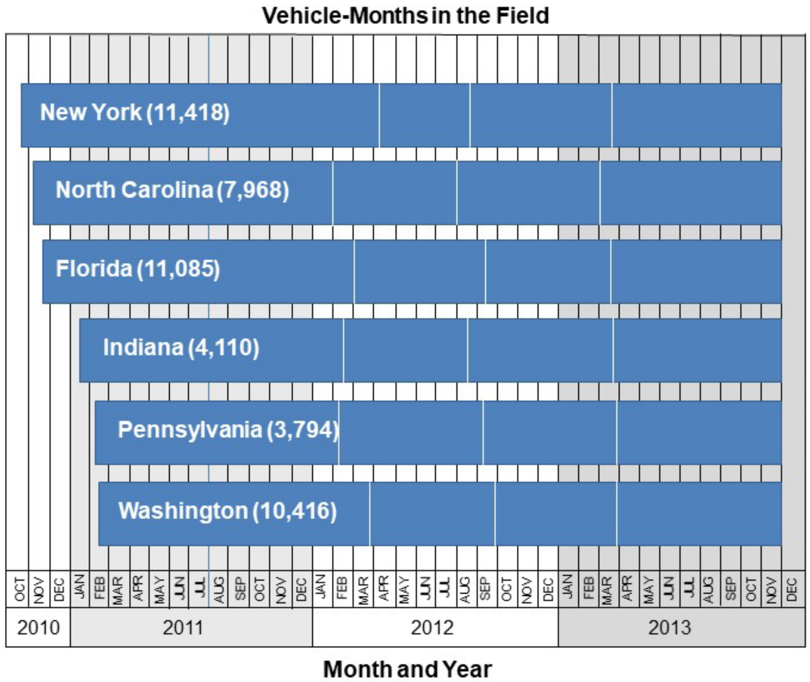

Figure 5. Data collection at each of the 6 SHRP2 NDS test sites.

Figure 6 shows the installation dates (shown as 'yellow triangles) for the 16 HVCs selected for inclusion in the analyses. The HVCs are identified by the HVC numbers employed in Table 1. An iterative process was designed to identify HVCs to be used in the analyses. Forty-nine HVCs were identified and evaluated to obtain the 18 HVCs required for the analyses.

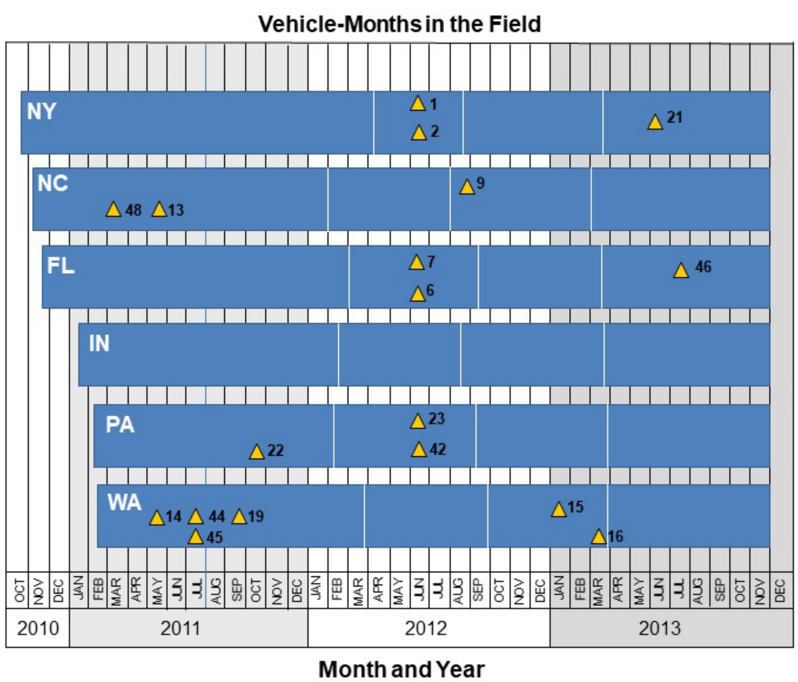

Figure 6. HVCs included in analyses versus installation dates.

METHODS AND APPROACH

There are two important aspects of the analysis methodology. The first relates to the way the forward video data were analyzed. The process of analyzing the videos involved the determination of an upstream benchmark point for each intersection location and direction. The benchmark points were selected to represent the approximate location where drivers can see and react to the HVC. They were also selected based on easily identifiable locations in the videos both before and after the HVC was installed (i.e., landmarks such as buildings and light poles were used). Each video was reviewed and the time that the vehicle crossed the benchmark and crosswalk (HVC, when installed) location was recorded. Additional information was also recorded, such as pedestrian presence, vehicle's lane position, preceding and parked vehicles' presence, the level of obstructed visibility of the HVC, windshield condition and wipers' usage, weather conditions, pavement surface conditions, and lighting conditions. Using the timestamps on the videos, the time-series data were matched with the rest of the trip data. It should be noted that the on-board vehicle equipment recorded information at 60 Hz intervals; however, the exact values of variables at the benchmark and crosswalk (HVC, when installed) locations were not always provided in the time-series data. To that end, using the timestamps data from the videos and the closest (in time) reported information, the exact values were linearly interpolated. Due to the insignificant time difference between the two reported values and the interpolated value (less than 1×10^{-1} sec), the effect of the possible interpolation error on the calculated values is negligible.

Data Processing of Video Files

Benchmark points for all locations were determined based on the available visibility of the HVC location from the benchmark point and the stopping sight distance. The main criterion in determining the benchmark location was the identification of the distance, across which drivers will be able to recognize and react to the HVC; to that end, the benchmark point was located 50 m before the crosswalk for all sites. Figure 7 through Figure 19 illustrate the benchmark and crosswalk points for selected HVC locations.

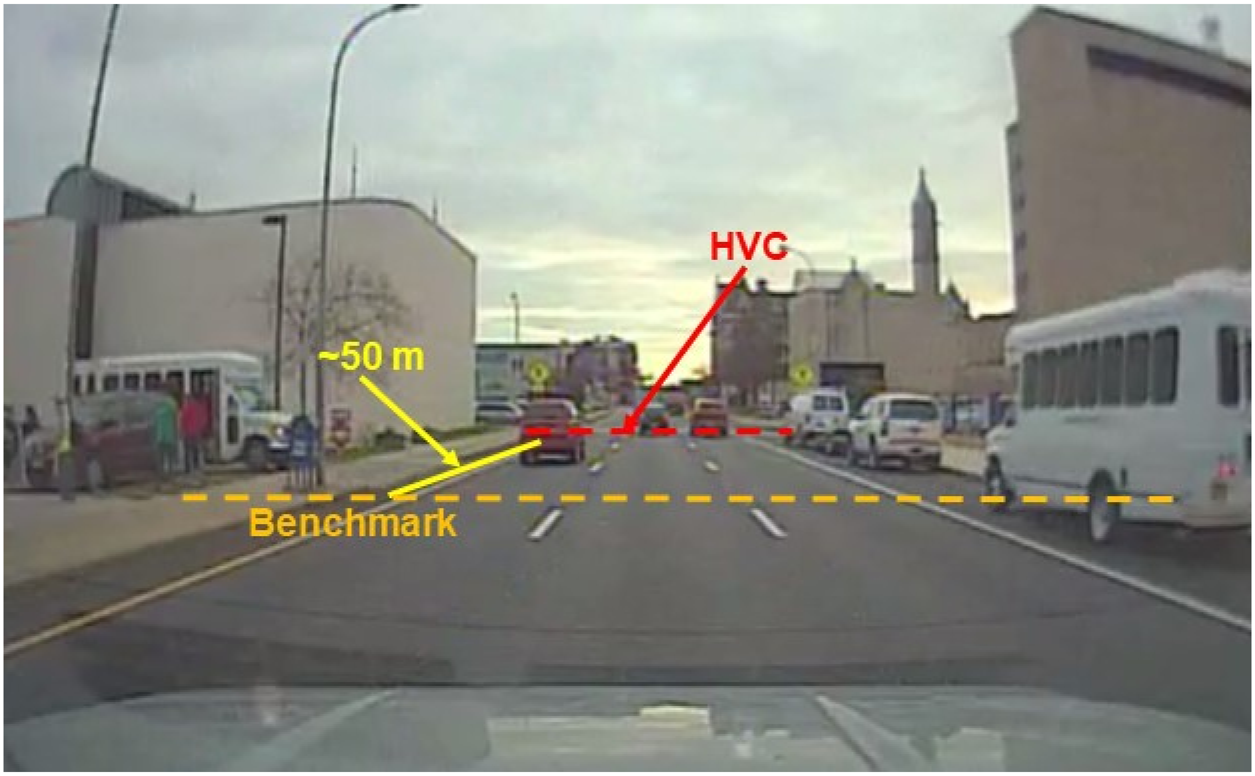

Figure 7. HVC 2: Forward facing video with benchmark and HVC points.

Figure 8. HVC 3: Forward facing video with benchmark and HVC points.

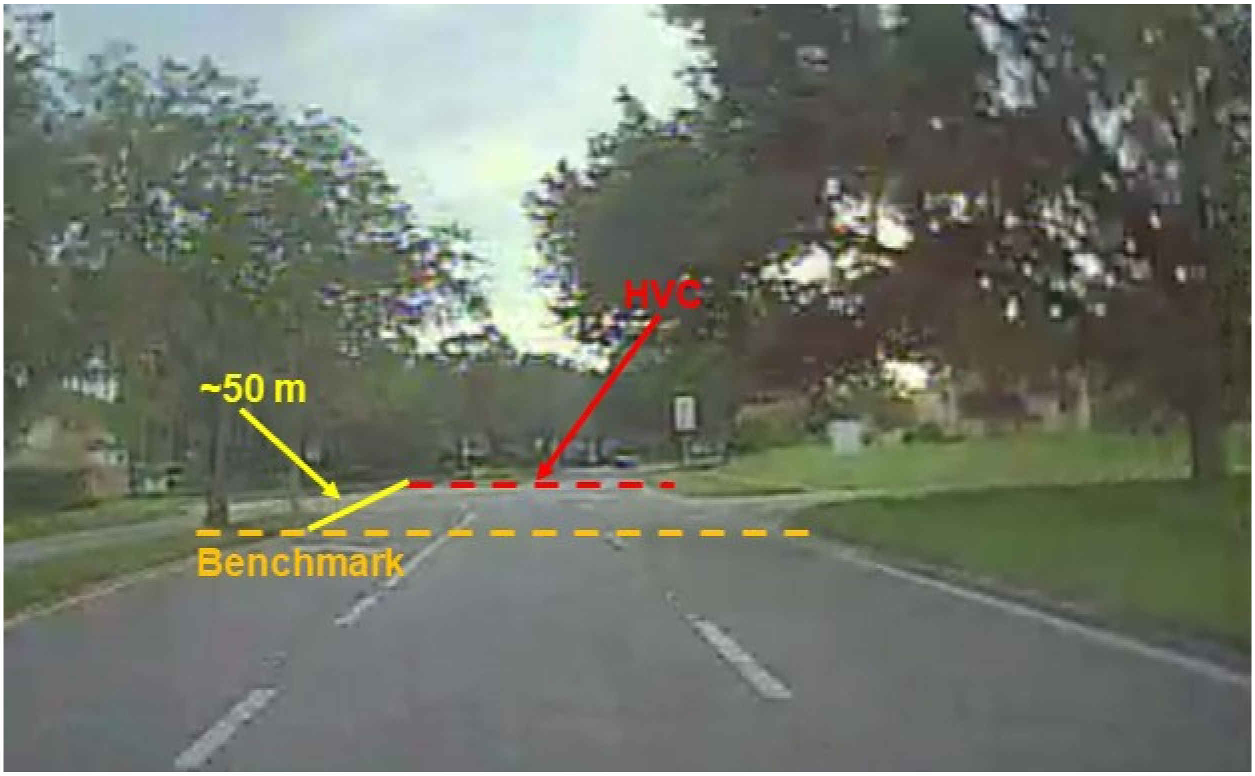

Figure 9. HVC 4: Forward facing video with benchmark and HVC points.

Figure 10. HVC 5: Forward facing video with benchmark and HVC points.

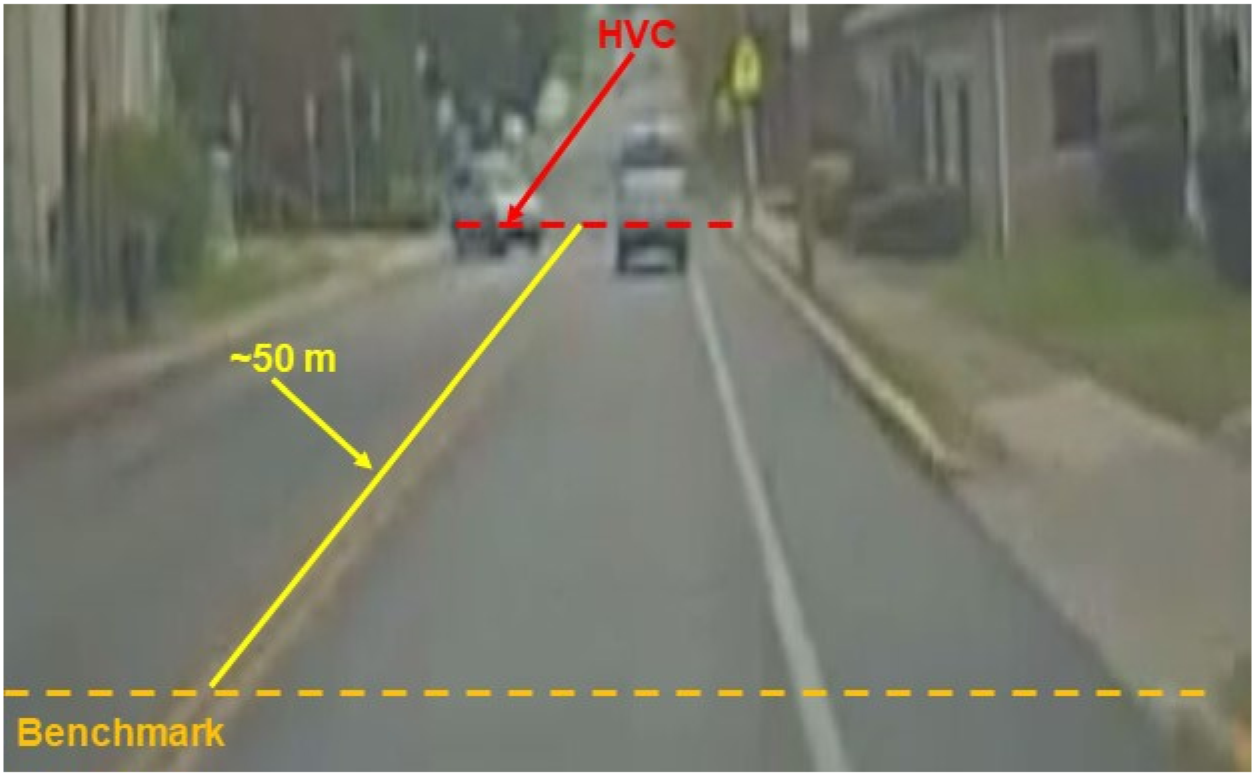

Figure 11. HVC 7: Forward facing video with benchmark and HVC points.

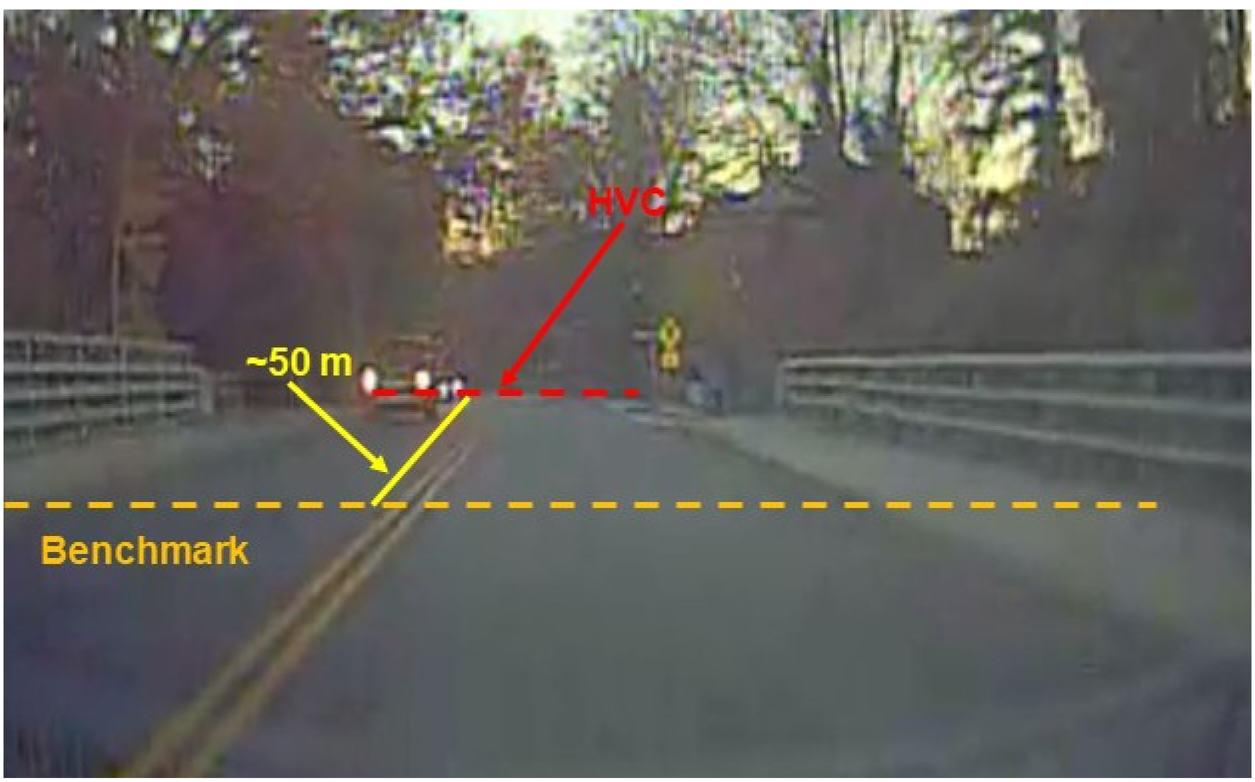

Figure 12. HVC 8: Forward facing video with benchmark and HVC points.

Figure 13. HVC 11: Forward facing video with benchmark and HVC points.

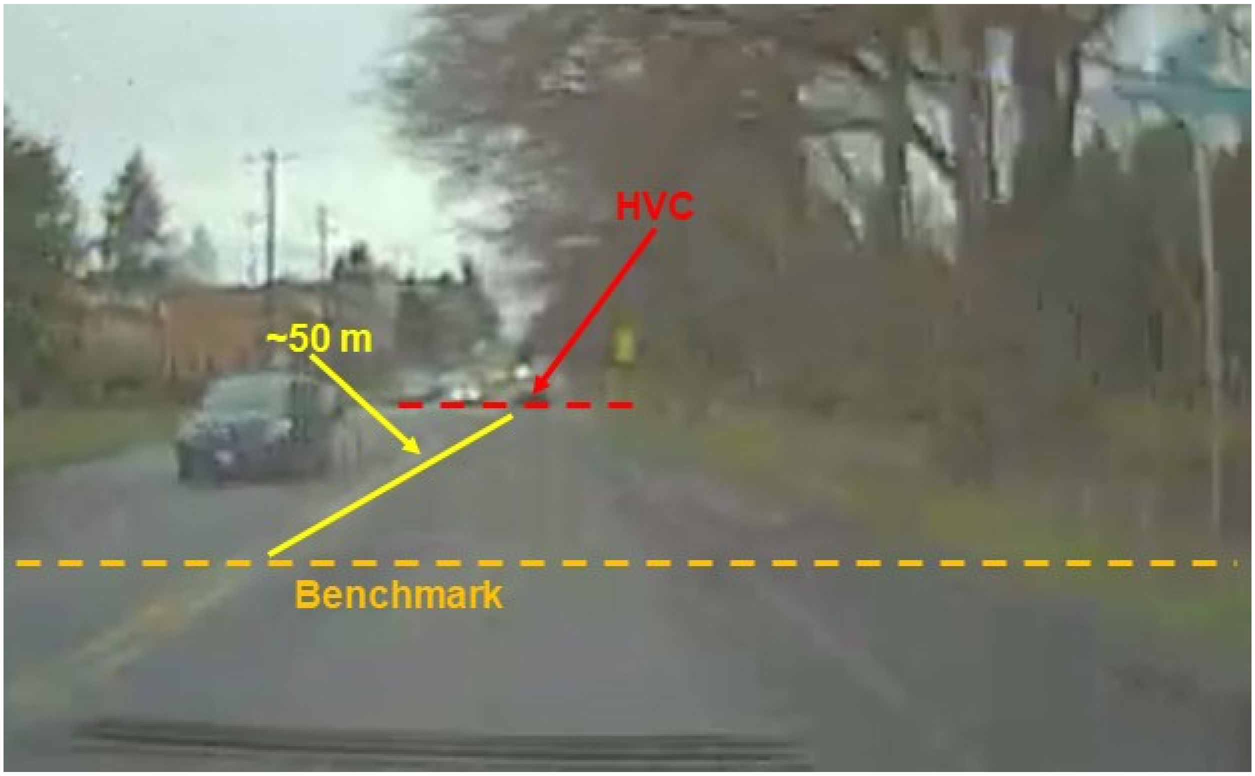

Figure 14. HVC: Forward facing video with benchmark and HVC points.

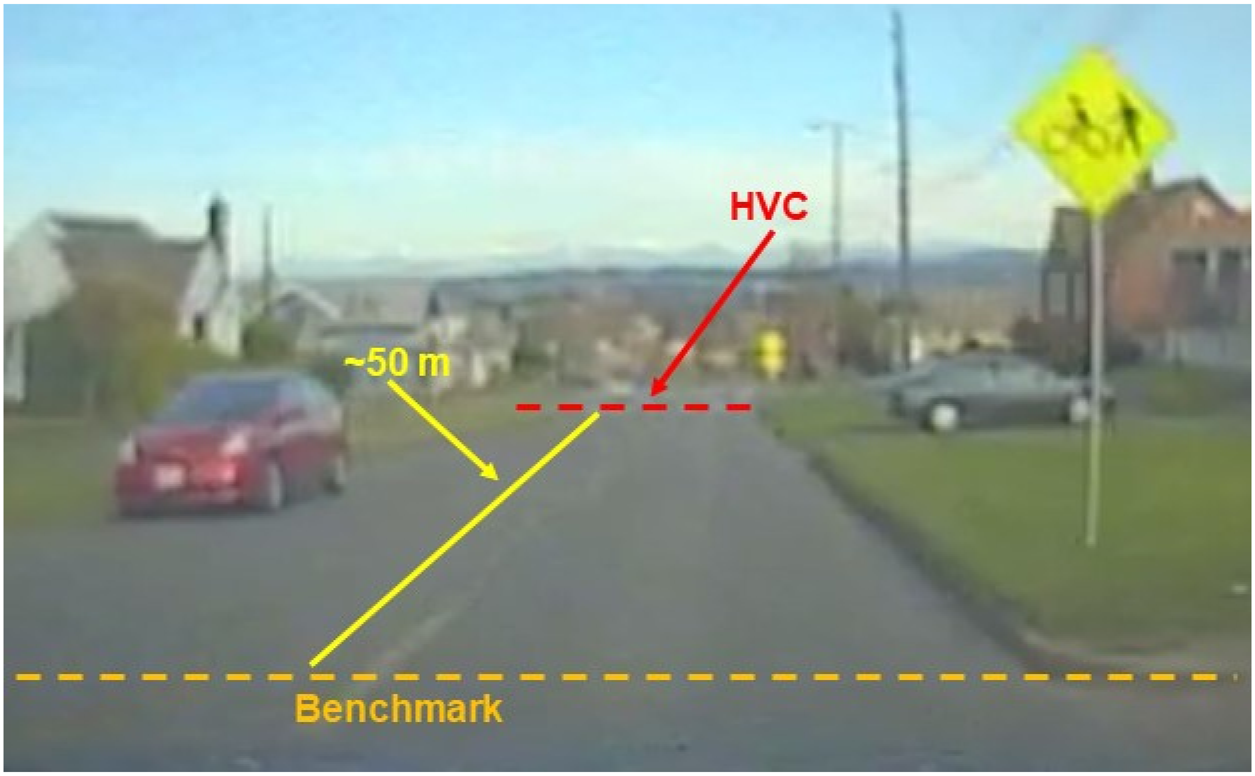

Figure 15. HVC 14: Forward facing video with benchmark and HVC points.

Figure 16. HVC 15: Forward facing video with benchmark and HVC points.

Figure 17. HVC 16: Forward facing video with benchmark and HVC points.

Figure 18. HVC 17: Forward facing video with benchmark and HVC points.

Figure 19. HVC 18: Forward facing video with benchmark and HVC points.

At the beginning of the video the following information is observed:

- The number of lanes in the direction of travel of the vehicle as observed from the forward-facing video. For example, in Figure 20, the road in the direction of travel has one through lane. Thus, the number of lanes in this case is coded "1".
- The relative position of the lane in which the vehicle is traveling. If the vehicle is traveling in the left lane, then a value of "1" is assigned to the variable to reflect the relative lane position. For the center and right lanes, the values of "2" and "3" are assigned respectively.

The video is paused at the benchmark and the following are noted:

- The timestamp on the video screen at the benchmark point. This is provided in the lower-left corner of the screen. Figure 20 illustrates the location of the timestamp obtained from a forward-facing video from a traversal made at HVC 18.

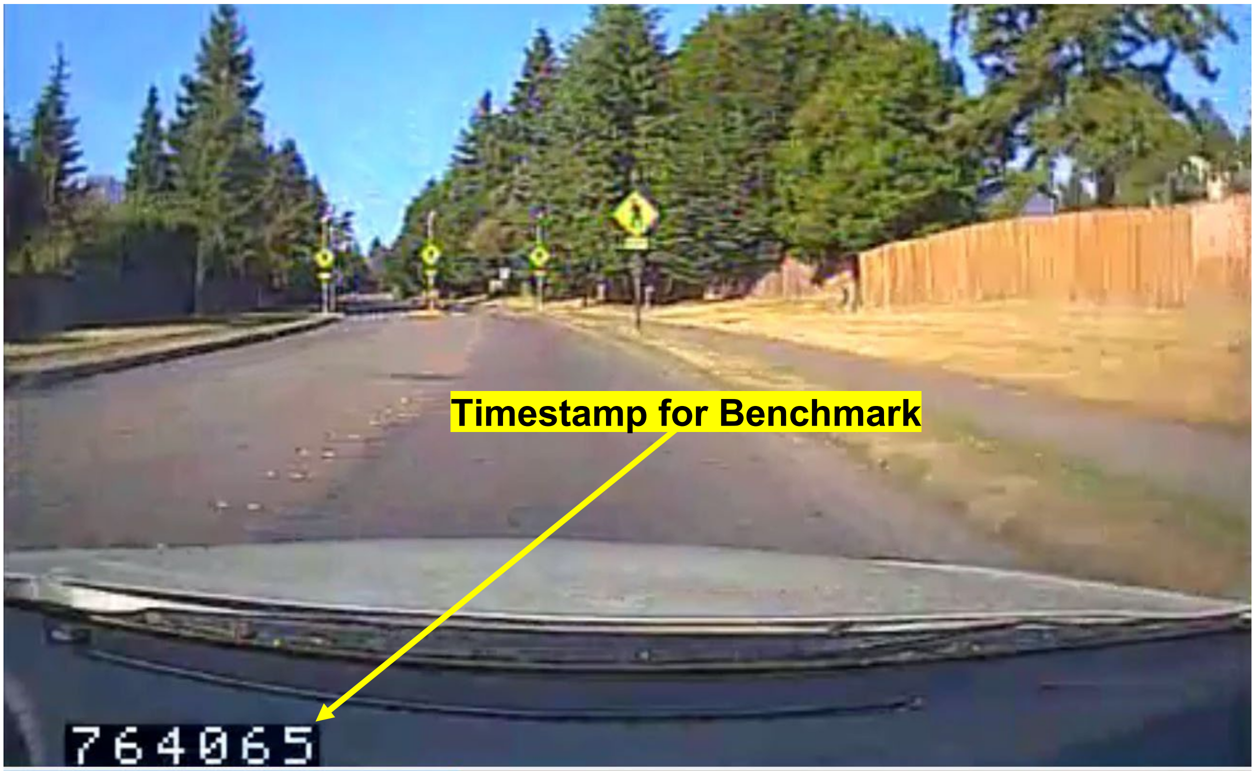

Figure 20. Illustration of timestamp for benchmark.

- The number of on-street parked vehicles visible from the benchmark point. For example, in Figure 21, the number of parked vehicles visible at the benchmark is three. It can also be observed that all three vehicles are passenger cars.
- The number of non-passenger vehicles (other than passenger cars) visible from the benchmark point.
- The presence of lead vehicle as observed from the benchmark point. For example, in Figure 23, a lead vehicle is observed; in this case, the variable indicating the presence of a lead vehicle will assume value of “1”.
- The number of vehicles obstructing the view of the HVC from the benchmark point are also observed. For example, in Figure 29, a passenger vehicle is present in the lane to the left of the travel lane; thus, the variable reflecting the number of passenger cars obstructing the view will take the value of “1”.
- The number of non-passenger car vehicles obstructing the view of the crosswalk is noted.

Next, the video is paused at the start of the HVC location. At this point, the following are noted:

- The timestamp at the HVC location.
- The construction state of HVC. If a HVC is not present then “0” is assigned to the corresponding variable (as seen in Figure 21). If the HVC is fully constructed then “1” is assigned to the specific variable (as seen in Figure 22). If HVC is under construction, the value “2” is assigned (as seen in Figure 23).

Figure 21. Illustration of HVC fully constructed in HVC site 13.

Figure 22. Illustration of HVC fully constructed in HVC site 18.

Figure 23. Illustration of HVC under-construction in HVC site 18.

- The presence of the pedestrian sign: This variable takes the value "0" when a pedestrian sign (informing drivers about the presence of pedestrian crossing) is not present; it takes the value "1" when a pedestrian sign is present. For example, in Figure 24, pedestrian signs are present, so the value for the specific variable is "1".

Figure 24. Illustration of presence of pedestrians near HVC site 13.

- The presence of pedestrians who might not be crossing the road but are present at the side of the road: If no pedestrian is present, the corresponding variable is equal to 0; when a pedestrian is present, the variable is equal to 1. If the pedestrian presence cannot be determined, then "-999" is assigned to this variable. As seen in Figure 24, the presence of pedestrians is clearly visible.
- The identification of pedestrians crossing the road anywhere during the trip: The specific variable takes the value "1" if any pedestrian crosses the road anywhere other than the HVC location and "0" if no pedestrian crossings are observed. For example, in Figure 25, a pedestrian is crossing an intersecting road so the value of this variable is "1".
-

Figure 25. Pedestrian crossing adjacent road at HVC site 13.

- The presence of pedestrians crossing the road near or at HVC location: The specific variable takes the value "1" if pedestrians are crossing the road at HVC, "0" if no pedestrians are crossing HVC, and "-999" if pedestrian crossing cannot be identified. For example, in Figure 26, a pedestrian is crossing the road at the HVC location and therefore the value assigned to the variable is "1". In Figure 25, the pedestrian is crossing a road other than the road with HVC and in this case, the value of this variable is "0".

Figure 26. Pedestrian crossing HVC location for a trip in HVC site 13.

Other variables that are observed from the video recordings of traversals are:

- Lane change: If the vehicle stays in its lane throughout the trip then this specific variable is assigned the value “0”. If the vehicle changes lane to the left, then this variable takes the value “1”. If the vehicle changes lanes to the right, then the value is “2”.
- The timestamp at the time of lane change is also noted in cases when lane changes occur. In cases where no lane change occurs, “-999” is assigned to the variable.
- In the case that the vehicle turns at any point during the trip, the timestamp corresponding to the time of the turn completion is recorded. In the case of no turn is completed or undertaken, then the value “-999” is assigned.
- Weather is observed from the forward-facing video, with different weather conditions corresponding to various values of the weather-specific variable; the variable values assigned to different weather conditions are provided below:

    Clear weather = 0,
    Cloudy weather = 1 (refer to Figure 27)
    Rainy weather = 2 (refer to Figure 28)
    Snow = 3 (refer to Figure 29)
    Foggy weather = 4 (refer to Figure 30)

Figure 27. Illustration of cloudy weather (HVC site 13).

Figure 28. Illustration of rainy weather (HVC site 13).

Figure 29. Illustration of snowy weather (HVC site 1).

Figure 30. Illustration of foggy weather (HVC site 13).

- Wiper condition: If the wipers were engaged or not during the trip is noted. The specific variable takes the following values: “0” if wipers are not engaged; “1” if the wipers are engaged on low; and “2” if the wipers are engaged on high.
- Windshield condition is the next variable to be documented. The following values are assigned to windshield condition based on the clarity and visibility of view as observed from the forward view video:

  Excellent = 1
  Very Good = 2
  Good = 3
  Poor = 4
  Very poor = 5
    - Where 1 is when the windshield has clear visibility and 5 is when the visibility of the windshield is almost completely blocked.
    - For example, in Figure 28 the windshield condition would be 3 as the video is blurred, whereas in Figure 23 the windshield condition would be 1 as the video appears very clear.

- The apparent time of day during which the trip is undertaken can be observed from the forward-facing camera. This information can help capture the ambient light conditions of the trip. The following values have been assigned to this variable for various times of the day:

  Day = 1
  Dawn = 2
  Dusk = 3
  Night = 4
    - For example, Figure 30 illustrates night, Figures27 through 29 illustrate trips undertaken during day, and Figure 31 and Figure 32 illustrate dusk and dawn respectively.

Figure 31. Illustration of dusk (HVC site 13).

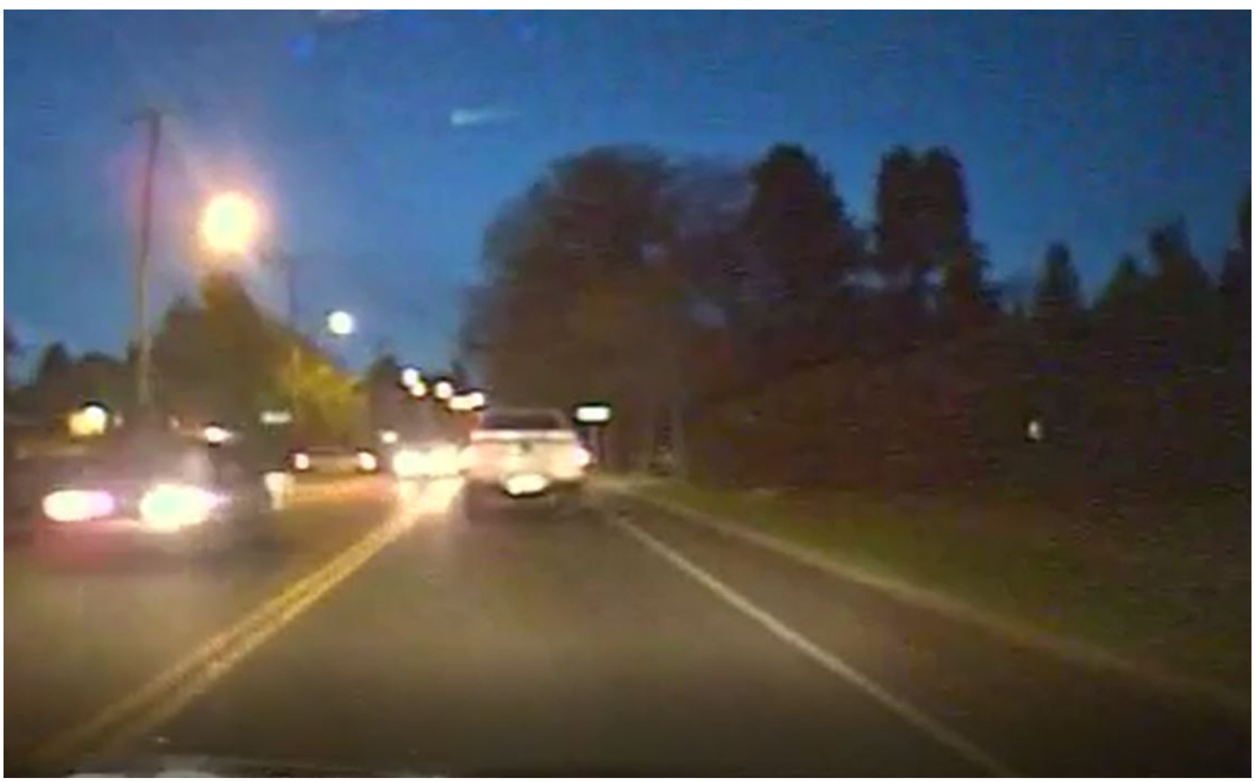

Figure 32. Illustration of dawn (HVC site 13).

Data Processing for Time-Series Files

The first step of the analysis is the extraction of manageable data from the video processing, which involved the determination of a benchmark point for each location and direction. The videos were observed and the times the vehicle crossed the benchmark and HVC locations were recorded. Additional information was also recorded, such as pedestrian presence, vehicle's lane position, preceding and parked vehicles' presence, level of the obstructed visibility of the HVC, windshield condition and wiper usage, weather conditions, pavement surface conditions, and lighting conditions. Using the timestamps on the video, the time-series data were matched with the rest of the trip data. Since the on-board vehicle equipment records information at intervals, the corresponding values at the benchmark and HVC locations were approximated through linear interpolation.
The following measures are observed:

- Acceleration (in X-axis) at benchmark and HVC locations
- Global Positioning System (GPS) speed at benchmark and HVC locations
- Network speed at benchmark and HVC locations
- State of brake pedal at benchmark and HVC locations
- Position of gas pedal at benchmark and HVC locations
- Position of steering wheel at benchmark and HVC locations

The variables included in the time-series data, along with their descriptions, are provided in Table 2.

Table 2. Decription of variables utilised from time-series data.

Variable Name	Description	Units
Timestamp	Time since beginning of trip, in milliseconds	MS
File_Id	File id, called trip id on insight	(Null)
Accel_X	Vehicle acceleration in the longitudinal direction versus time.	G
Speed_GPS	Vehicle speed from GPS	Km/H
Speed_Network	Vehicle speed indicated on speedometer collected From network.	Km/H
Pedal_Brake_State	On or off press of brake pedal	0=Off, 1=On, 2=Invalid Data, 3=Data Not Available
Pedal_Gas_Position	Position of the accelerator pedal collected from The vehicle network and normalized using manufacturer specs	(Null)
Steering_Wheel_ Position	Angular position and direction of the steering wheel from neutral position	Deg

For most trips, the timestamps at benchmark and HVC location do not coincide with the timestamps in time-series data, where the timestamp is usually provided at 100 milliseconds intervals. Information about acceleration (X-axis), speed (both GPS and Network), state of pedal brake (if on or off), position of gas pedal, and position of steering wheel are not available for at all timestamps. To obtain this information, linear interpolation is applied. This process is illustrated in Table 3. Please note that this table illustrates only missing data; in this case, Speed_GPS data are missing.

Table 3. Illustration of interpolation to approximate missing information.

vtti.timestamp	vtti.accel_x	vtti.speed_gps	vtti.speed_gps (interpolated)
603200	0.1102	48.53673	48.53673
603300	0.1276		48.40525
603400	0.1015		48.27376
603500	0.0754		48.14228
603600	0.1218		48.0108
603700	0.1073		47.87932
603800	0.058		47.74784
603900	0.0957		47.61636
604000	0.0899		47.48488
604100	0.0754		47.3534
604200	0.0841	47.22192	47.22192

To approximate values at benchmark locations the timestamps were rounded up and down to the closest 100 milliseconds. For example, if the timestamp at the benchmark is 618279, then the timestamp is rounded down to 618200 and subsequently, rounded up to 618300. Then, the acceleration, speed (GPS and network), brake pedal state, gas pedal position and steering wheel position at 618200 and 618300 are obtained. Then, linear interpolation is applied to obtain the corresponding values at timestamp 618279, when the vehicle was observed to be crossing the benchmark position. Similarly, information at the HVC location is also approximated by linear interpolation. For further illustration of the video and time-series processing, an example is provided in the next section.

Example of the Data Processing

The trip selected here is from HVC site 13 bearing VTTI File ID 53402310 and Event ID 13001. The first step of this process is the processing of the video file. The following information is obtained from this step (as shown in Table 4):

Table 4. Information obtained from video file.

1	Event ID	13001
2	File ID	53402310
3	HVC State	1
4	Ped Sign Present	1
5	Ped Present	0
6	Ped Crossing	0
7	Ped Crossing HVC location	0
8	Lane Position	0
9	Lane Change	0
10	Time of Lane Change (approx.)	-999
11	Leading Vehicle	1
12	Obstructing Vehicles	0
13	Parked Vehicles	3
14	Non-PC Obstructing Vehicles	0
15	Non-PC Parked Vehicles	0
16	Weather	1
17	Wipers	0
18	Windshield Condition	1
19	Time of Day	1
20	Time Done Turning	-999
21	Benchmark Time	618279
22	HVC Time	621682

Information for rows 5,8,11,12-15 and 21 was obtained from the forward-facing video at the benchmark location. This is illustrated in Figure 27. The timestamp at the benchmark can be seen at the lower-left corner of the figure. Presence of pedestrian signs can also be identified. The number of lanes in the direction of travel is 1 and the lane position is 0. The presence of lead vehicle can also be seen from the benchmark location; thus, the variable's value is 1. On the left-hand side of the picture three parked passenger cars can be observed and no obstructing vehicles are present. Also, the number of non-passenger vehicles is zero in this trip.

Other information is obtained from the HVC location. This is illustrated in Figure 27. It can be observed that the HVC is installed, therefore the HVC state variable is 1. No pedestrians are present roadside, and no pedestrians are observed crossing the road. It can also be observed in Figure 27 that the weather is cloudy and windshield wipers have not been activated. The windshield is clear but not to the largest extent possible, so the windshield condition is assigned a value of 1. It is also evident that the trip was undertaken during the day.

Figure 33. Illustration of information obtained at benchmark location.

3. DESCRIPTIVE STATISTICS AND MODELING METHODOLOGY

This section discusses the basic descriptive statistics of the data set used for analysis and the modeling approach taken to understand the effects that the HVCs have on driver behavior. Although 350 traversals were targeted for each location a significantly fewer number of trips were available for suitable locations for analysis (i.e. installation of HVC during SHRP2 NDS data collection). Table 5 provides a breakdown of the number of traversals available for analyses at each of the 18 selected HVC sites. Of note in this table are the traversals with PII which required the data reduction to be conducted in a secure data enclave to be added to the analyses database.

Table 5. Traversals available for analyses at each HVC site.

ID	Site	Location	Type	Block Location	Traversals (Exportable)	Traversals (with PII)	Total
1	NY	Elm / Eagle	Ladder	End-of-Block	474	-	474
2	NY	Oak / Eagle	Ladder	End-of-Block	328	-	328
6	FL	North 50th St	Ladder	Mid-Block	400	-	400
7	FL	North 50th St	Ladder	Mid-Block	50	49	99
9	NC	Pullen Rd.	Continental	End-of-Block	68	68	136
13	NC	E Rosemary St	Continental	Mid-Block	98		98
14	WA	Green Lake Way N	Bar-Pair	End-of-Block	101	-	101
15	WA	S. McClellan St	Bar-Pair	End-of-Block	174	-	174
16	WA	University Way NE	Bar-Pair	End-of-Block	6	198	204
19	WA	Beacon Ave. S	Bar-Pair	Mid-Block	52	91	143
21	NY	Union Rd	Ladder	End-of-Block	79	-	79
22	PA	E. Pollack Rd	Continental	End-of-Block	54	-	54
23	PA	S. Allen St	Continental	End-of-Block	390	-	390
42	PA	Waupelani Dr.	Continental	End-of-Block	25	112	137
44	WA	SW 320th St	Bar-Pair	Mid-Block	6	56	62
45	WA	SW 348th St	Bar-Pair	Mid-Block	344	-	344
46	FL	S. Village Dr.	Ladder	Mid-Block	133	-	133
48	NC	W. Franklin St	Continental	Mid-Block	32	92	124
						Total	**3,480**

DESCRIPTIVE STATISTICS

Upon reviewing the forward-facing videos and time-series data, 3,480 traversals were available for analysis. These traversals were undertaken by 183 drivers with the frequency of traversals ranging from 1 trip/participant to 391 traversals/participant. Of the traversals used, HVC was present in 2,019 traversals and was under construction for 269 traversals. While pedestrian presence was identified for 333 traversals, pedestrians were also observed crossing the roads adjacent to the HVC location in 77 traversals. Figure 34 illustrates the distribution of traversals by weather conditions. The majority of traversals (48%) were conducted in clear weather conditions, while 40% of the traversals were conducted under cloudy weather conditions. Note that very few traversals (17) were conducted under foggy conditions.

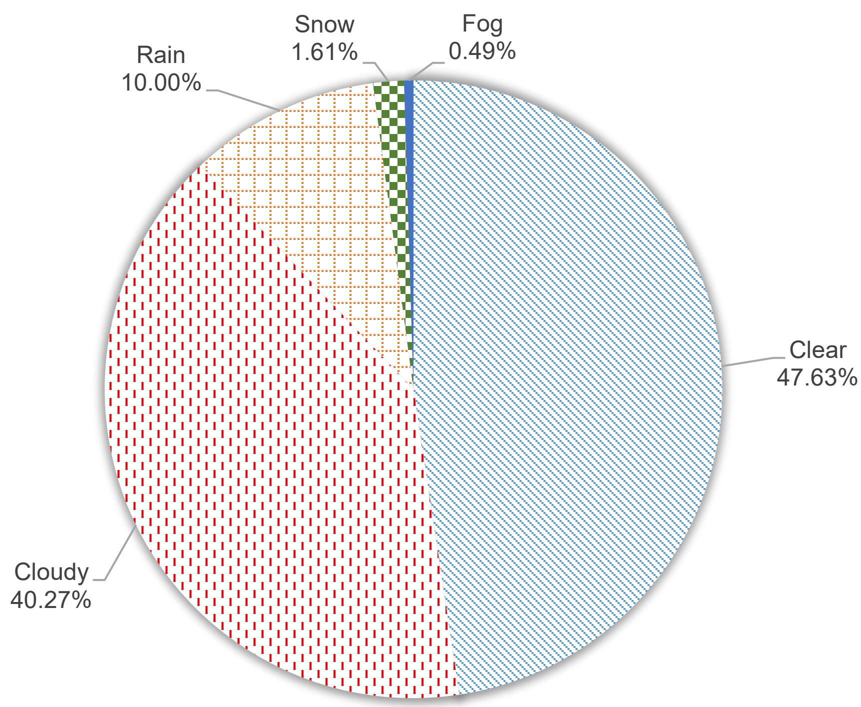

Figure 34. Distribution of traversals by weather conditions.

Figure 35 shows the distribution of traversals by the participant's gender, while Figure 36 illustrates the distribution of traversals by the participants' age group.

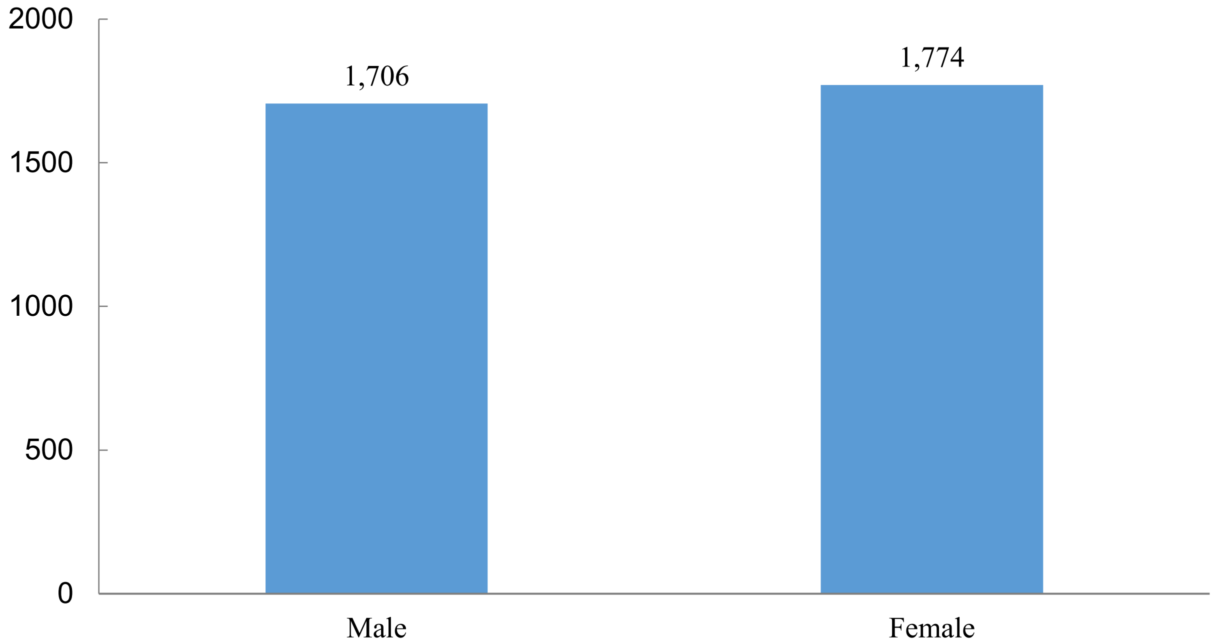

Figure 35. Distribution of traversals by gender.

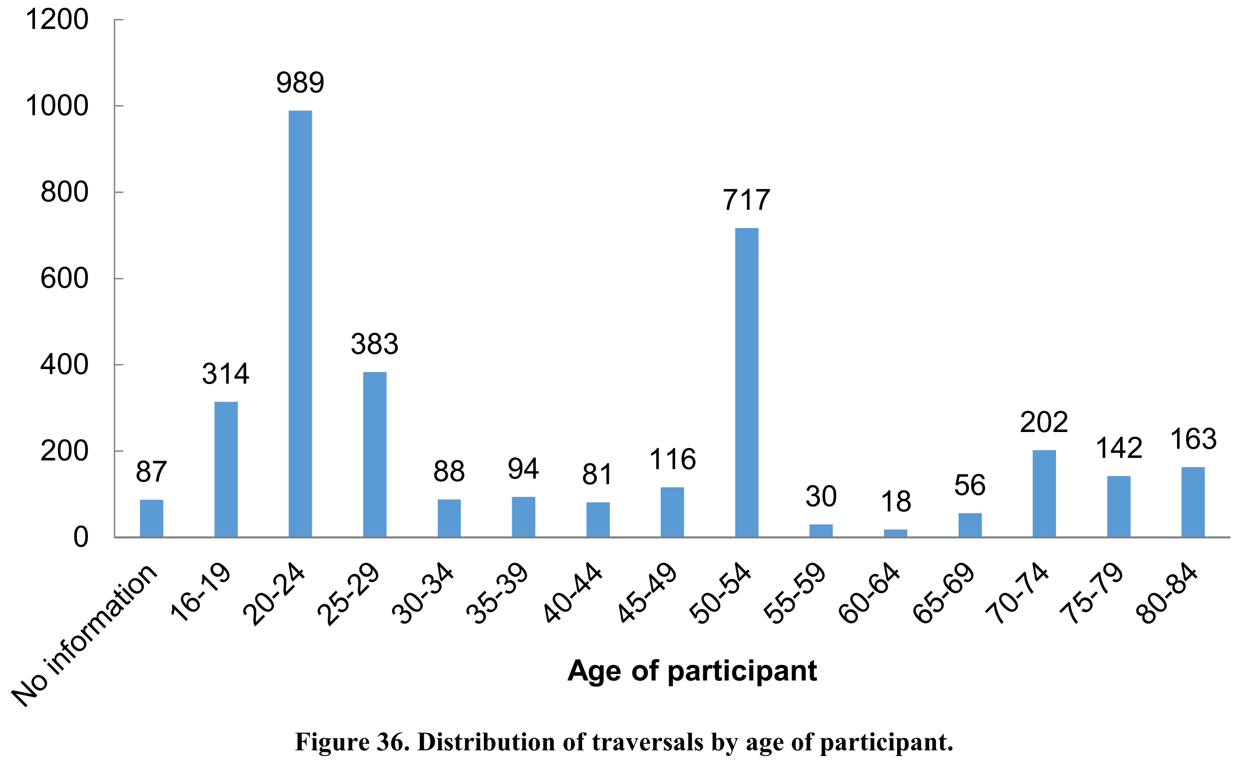

Figure 36. Distribution of traversals by age of participant.

MODELING METHODOLOGY

To understand the effect of HVC on driving behavior, four surrogate measures were used: vehicle speed and acceleration, brake pedal state, and TPA. Changes in surrogate measures due to the HVC presence were then analyzed using: (i) hypothesis testing; and (ii) statistical modeling. The latter allows for the identification of the HVC-specific effect while controlling for roadway and traffic characteristics, driver's trip frequency, trip characteristics (such as time-of-day of the trip), weather conditions, and vehicle characteristics.

Correlated grouped random parameters linear regression models

To identify the effect of the HVC presence on the vehicle speed and acceleration, and on the TPA, correlated grouped random parameters linear regression models were estimated, at benchmark and HVC points, as well as for the differences in vehicle speed, acceleration, and TPA, between the benchmark and HVC points.

To derive an estimable model, we begin with a standard linear regression model, which is defined as (30,31,32,33,34):

$$y_i = \alpha + \boldsymbol{\beta}_i \mathbf{X}_i + \varepsilon_i \quad (1)$$

where, y is the dependent variable (i.e., vehicle speed, acceleration and TPA at benchmark; vehicle speed, acceleration and TPA at HVC points, and the differences in speed, acceleration and TPA between the benchmark and HVC points), which is a function of a constant term α and coefficient $\boldsymbol{\beta}$ times the value of independent variables $\mathbf{X}$ (e.g., HVC, roadway/roadside and weather conditions, and driver/vehicle/trip characteristics) for driver i (i = 1, 2, …, *n*), plus a disturbance term *ε*. The model defined is a linear regression model and the expectation of ε is zero with variance σ^2, as shown in Equation 2 (33):

$$\begin{aligned} E\left[\varepsilon_i \mid \mathbf{X}_i\right] &= 0 \\ E\left[\varepsilon_i \varepsilon_i' \mid \mathbf{X}_i\right] &= \sigma_\varepsilon^2 \mathbf{I}_T \end{aligned} \quad (2)$$

To account for the effect of unobserved heterogeneity (i.e., unobserved factors varying systematically across the observations), a random parameters modeling approach is employed (35,36,37,38,39,40). Because there were traversals performed by the same driver, it is likely that similar unobserved characteristics may be commonly encountered among the driver-specific traversals. Thus, to account for unobserved heterogeneity varying across driver-specific sub-samples of the traversal population (i.e., panel effects), grouped random parameters are estimated. Under this modeling structure, one separate parameter estimate ($\boldsymbol{\beta}$) is estimated for each driver; thereby, all the driver-specific traversals are represented by the same parameter estimates. In this context, the effects of the parameter estimates are allowed to vary across the drivers, as (33,34,38,41,42,43):

$$\boldsymbol{\beta}_i = \boldsymbol{\beta} + \Gamma \mu_i \quad (3)$$

where $\boldsymbol{\beta}_\mathbf{i}$ is the driver-specific vector of random parameters, $\boldsymbol{\beta}$ denotes the vector with the mean values of the random parameters, μ_i is a randomly distributed error term for each driver i (with mean equal to 0 and variance equal to σ^2), and $\mathbf{\Gamma}$ is a triangular coefficient matrix that accounts for cross-parameter correlations in distribution of $\boldsymbol{\beta}_\mathbf{i}$ [(33)]. To account for correlation among random parameters the below diagonal elements of the coefficient matrix can be non-zero. Note that the driver-specific grouped random parameters are assumed to follow a continuous distribution. For the density function of this distribution, a wide variety of the most popular parametric density functions were used (such as normal, log-normal, triangular, uniform and Weibull); herein, the normal distribution was found to provide the best statistical fit, and was used in the model specifications [(33,44)].

A generalized linear regression equation is obtained by inserting Equation 3 in Equation 1:

$$\mathrm{y_i} = \alpha + \boldsymbol{\beta}\mathbf{X}_\mathrm{i} + (\varepsilon_\mathrm{i} + \mathbf{X}_\mathrm{i}\mu_\mathrm{i}) \tag{4}$$

The covariance matrix of disturbances for each driver i is given as [(33)]:

$$\mathbf{\Omega}_{ii} = \sigma^2\mathbf{I}_T + \mathbf{X}_i\mathbf{\Gamma}\mathbf{X}_i' \tag{5}$$

where, $\mathbf{I}$ am an identity matrix, and $\mathbf{\Gamma}$ is the covariance matrix given by $\mathrm{E}\left[\boldsymbol{\mu}_i\boldsymbol{\mu}_i' \mid \mathbf{X}_i\right] = \mathbf{\Gamma}$.

The GLS estimator for estimating parameters is the weighted average of OLS estimators for each group:

$$\hat{\beta} = \left(\mathbf{X}'\mathbf{\Omega}^{-1}\mathbf{X}\right)^{-1}\mathbf{X}'\mathbf{\Omega}^{-1}\mathrm{y}\,. \tag{6}$$

Correlated grouped random parameters binary outcome models

The likelihood of occurrence of speed, acceleration, and TPA decrease between the benchmark and HVC locations, as well as the likelihood of brake application, were investigated through the estimation of discrete outcome (binary logit/probit) models. To account for unobserved heterogeneity and panel effects, correlated grouped random parameters binary logit/probit modeling approach was employed. Upon estimation of the binary logit and probit models, the logit models were found to be statistically superior (as compared to their probit counterparts) for the likelihood of occurrence of speed, acceleration and TPA decrease; while the binary probit model provided a better statistical fit (as compared to its logit counterpart) for the likelihood of brake application.

The linear function A_{in} that determines the occurrence of speed, acceleration, and TPA decrease, or brake application during a traversal *i,* can be defined as [(32)]:

$$\mathrm{A_{in}} = \boldsymbol{\beta}_\mathrm{i}\mathbf{X}_\mathrm{in} + \varepsilon_\mathrm{in} \tag{7}$$

To account for panel effects, unobserved heterogeneity and correlation among pairs of random parameters, individual $\boldsymbol{\beta}$s are estimated for each driver and can vary across traversals undertaken by each driver, as:

$$\boldsymbol{\beta}_i = \boldsymbol{\beta} + \Gamma\delta_i \tag{8}$$

Where, **β** is the mean of the random parameter for driver i, Γ is a Cholesky matrix (including the elements used for computation of standard deviation of random parameters), and δ is a randomly distributed term with mean 0 and variance 1.

The outcome of the dependent variable is binary: 1 for the occurrence of speed, acceleration, and TPA decrease, and 0 for non-occurrence. The binary outcome probability is defined as:

$$P_n(i) = \int \frac{e^{(\boldsymbol{\beta}_{in}+\varepsilon_{in})}}{1+e^{(\boldsymbol{\beta}_{in}+\varepsilon_{in})}} f\left(\boldsymbol{\beta}|\boldsymbol{\varphi}\right) d\boldsymbol{\beta} \tag{9}$$

where, $P_n(i)$ is the discrete binary outcome probability, and $f\left(\boldsymbol{\beta}|\boldsymbol{\varphi}\right)$ introduces random parameters to the probability estimation and is the density function of $\boldsymbol{\beta}$, whose parameter vector is $\boldsymbol{\varphi}$ (in this case, mean and variance of the normal distribution).

To estimate the likelihood of the occurrence of brake application, the binary probit model was employed. Since the outcome of the dependent variable is binary, with 1 indicating the occurrence of brake application and 0 indicating non-occurrence, the probability of outcome 1 for observation n can be estimated as follows [32]:

$$P_n(1) = P(\beta_1 X_{1n} - \beta_2 X_{2n} \geq \varepsilon_{2n} - \varepsilon_{1n}) \tag{10}$$

where, ε_{1n} ε_{2n} and are normally distributed with mean=0 and variances σ_1^2 σ_2^2 and, respectively, with covariance σ_{12}. Since the addition or subtraction of two normally distributed variates produces a normally distributed variate, Equation 10 can be rewritten as:

$$P_n(1) = \Phi\left(\frac{\boldsymbol{\beta}_1 \mathbf{X}_{1n} - \boldsymbol{\beta}_2 \mathbf{X}_{2n}}{\sigma}\right) \tag{11}$$

Where $\sigma = \sqrt{\left(\sigma_1^2 + \sigma_2^2 - 2\sigma_{12}\right)}$ $\Phi(.)$ and is the standardized cumulative normal distribution.

The estimation of mixed effect models, such as the random parameter models estimated for this analysis, is computationally difficult using traditional maximum likelihood methods, and therefore, a simulated maximum likelihood estimation technique was employed herein. In simulation-based maximum likelihood estimation techniques, different values of β are drawn from the density function $f\left(\boldsymbol{\beta}|\boldsymbol{\varphi}\right)$ for a given $\boldsymbol{\varphi}$, and the average of corresponding outcome probabilities (from different βs) is obtained as the outcome probability in Equation 9.

To increase the efficiency of the complex numerical integrations required within the simulation procedure, Halton draws are used. The latter allows sampling of different values of β, which are drawn from the density function $f\left(\boldsymbol{\beta}|\boldsymbol{\varphi}\right)$ for a given $\boldsymbol{\varphi}$. The relevant econometric literature recommends a minimum of 200 Halton draws for obtaining stable random parameters. However, in this study, 1200 Halton draws were found to provide parameter stability and were thus used in model estimation.

4. MODEL RESULTS

In Phase 1, the analysis focused on the vehicle speed, acceleration, and TPA during vehicle traversals of crosswalks before and after HVC installations. It was observed that the HVCs were influential in decreasing speed and acceleration, brake application, and TPA. In Phase 2, the scope of the analysis has been expanded to investigate the effect of different HVC configurations and block-specific HVC locations (mid-block or end-of-block) on driving behavior.

EFFECT OF PRESENCE OF HVC ON SPEED, ACCELERATION, AND TPA

Upon analysis of the traversals performed before and after the installation of HVC at the HVC sites under consideration, it was found that there was a reduction in speed and acceleration at the benchmark and HVC location. However, TPA was found to be decreased at the benchmark and increased at the HVC location. The findings from this initial analysis supported the need to further investigate the speeds, accelerations, and TPAs at the benchmark and HVC locations, and their differences between these two points. The findings are summarized in Table 6.

Table 6. Average Speed, Acceleration and TPA, Before and After HVC Installation

Variable	HVC Installation	
	Before	After
Avg. Speed at Benchmark (km/h)	53.289	51.514
Avg. Speed at HVC (km/h)	53.899	51.688
Avg. Speed Difference Between Benchmark and HVC (km/h)	0.610	0.174
Avg. Acceleration at Benchmark (g)	0.0064	0.0032
Avg. Acceleration at HVC (g)	0.0086	0.0063
Avg. Acceleration Difference Between Benchmark and HVC (g)	0.0022	0.0031
Avg. TPA at Benchmark	13.302	12.852
Avg. TPA at HVC	12.624	13.206
Avg. TPA Difference Between Benchmark and HVC	-0.678	0.354

Linear Regression Models: Speed, acceleration, and TPA

Correlated grouped random parameters linear regression models were developed for vehicle speed, acceleration, and TPA, all at Benchmark and HVC locations, as well as for the difference in speed, acceleration, and TPA between the benchmark and HVC locations. As will be demonstrated subsequently, the location and type of HVC were found to have a statistically significant influence on vehicle speed, acceleration, and TPA. Similarly, correlated grouped random parameters binary outcome models (logit and probit) were also developed to investigate the likelihood of speed, acceleration, and TPA decrease as well as the likelihood of brake application.

Vehicle Speed

Table 7 presents the descriptive statistics of the statistically significant variables (at 0.90 level of confidence) included in the correlated grouped random parameters linear regression models for vehicle speed. Table 8 presents the estimation results of the correlated grouped random parameters linear regression models for vehicle speed (at benchmark and HVC locations, and for the speed difference between the benchmark and HVC locations). Various HVC-, driver- and trip-specific characteristics were observed to influence vehicle speed at benchmark and HVC locations, as well as the difference in speed between the two locations. Correlation matrices for the random parameters identified in the model specifications are also provided in Table 8. Please note that the correlation refers to the possible linear association among the unobserved factors of the pair of random parameters, and not on the linear association between the two parameters.

Several HVC-related variables were found to affect the speed observed at benchmark and HVC locations, and the speed difference between the two locations. Specifically, the presence of HVC and pedestrian signs (at benchmark and HVC) had mixed effects on the vehicle speed at the benchmark location – the vehicle speed at the benchmark location is reduced for 53% of the traversals. The presence of HVC was found to have mixed effects on the vehicle speed at the HVC location – a speed decrease was identified for 46% of the traversals. The presence of HVC was also identified to decrease the speed difference between the benchmark and HVC locations. The ladder configuration of end-of-block located HVCs had mixed effects on the vehicle speed at the HVC location and on the speed difference between the benchmark and HVC locations. Specifically, a speed decrease was observed for 97.90% of the traversals (in the speed difference model) in the presence of ladder type end-of-block located HVCs.

Among the driver-specific characteristics, age and gender were found to have a statistically significant effect on the speed measures. Table 8 shows that drivers over the age of 65 years were associated with a lower speed difference between the benchmark and HVC locations for 75.60% of the traversals. Among the vehicle-specific characteristics, vehicle type (passenger car) and vehicle age were found to have a statistically significant effect on the speed measures. Traffic and roadway characteristics were found to affect the vehicle speed, such as the presence of a lead vehicle and the presence of pedestrians in proximity to the HVC location. The presence of pedestrians was found to reduce the difference in vehicle speed between the benchmark and HVC locations. Traversals that occurred in snowy or rainy weather conditions were found to decrease the speed at the HVC location.

Table 7. Descriptive statistics for vehicle speed.

Variable	Mean	Standard Deviation	Minimum	Maximum
Speed at benchmark location (kmph)	51.754	12.278	2.776	99.287
Speed at HVC location (kmph)	52.100	12.356	0.058	98.904
Speed difference	0.373	5.238	-33.766	32.198
HVC and pedestrian sign indicator (1 if both are present, 0 otherwise)	0.502	0.500	0	1
HVC indicator (1 if HVC is present, 0 otherwise) (Speed at HVC)	0.578	0.494	0	1
HVC indicator (1 if HVC is present, 0 otherwise) (Speed Difference)	0.563	0.496	0	1
HVC position indicator (1 if end-of-block located HVC, 0 otherwise)	0.643	0.479	0	1
HVC type and position indicator (1 if ladder type end-of-block located HVC, 0 otherwise) (Speed at HVC)	0.336	0.472	0	1
HVC type and position indicator (1 if ladder type end-of-block located HVC, 0 otherwise) (Speed Difference)	0.406	0.491	0	1
Pedestrian presence indicator (1 if pedestrian is present near the HVC, 0 otherwise)	0.096	0.294	0	1
Lane position indicator (1 if vehicle is in the center lane of a multilane road, 0 otherwise) (Speed at benchmark)	0.424	0.494	0	1
Lane position indicator (1 if vehicle is in the center lane of a multilane road, 0 otherwise) (Speed at HVC)	0.425	0.494	0	1
Lead vehicle indicator (1 if lead vehicle is present, 0 otherwise) (Speed at Benchmark)	0.499	0.500	0	1
Lead vehicle indicator (1 if lead vehicle is present, 0 otherwise) (Speed at HVC)	0.499	0.500	0	1
Lead vehicle indicator (1 if lead vehicle is present, 0 otherwise) (Speed difference)	0.523	0.500	0	1
Parked vehicle indicator (1 if there is no parked vehicle near the crosswalk, 0 otherwise)	0.619	0.486	0	1
Parked vehicle indicator (1 if there is no parked vehicle near the crosswalk, 0 otherwise) (Speed difference)	0.621	0.485	0	1
Obstructing vehicle indicator (1 if there is 1 or more vehicles obstructing the view to the crosswalk, 0 otherwise)	0.664	0.472	0	1
Vehicle type indicator (1 if passenger car, 0 otherwise)	0.739	0.439	0	1

Variable	Mean	Standard Deviation	Minimum	Maximum
Speed limit indicator (1 if the speed limit is below 30mph, 0 otherwise)	0.588	0.492	0	1
Participant Gender indicator (1 if driver is male, 0 otherwise) (Speed at HVC)	0.487	0.500	0	1
Participant Gender indicator (1 if driver is male, 0 otherwise) (Speed difference)	0.422	0.494	0	1
Participant's age indicator (1 if greater than 50 years old, 0 otherwise)	0.374	0.484	0	1
Participant's age indicator (1 if greater than 60 years old, 0 otherwise)	0.177	0.382	0	1
Participant's age indicator (1 if greater than 65 years old, 0 otherwise)	0.141	0.348	0	1
Weather indicator (1 if weather is rainy or snowy, 0 otherwise)	0.119	0.324	0	1

Table 8. Correlated grouped random parameters linear regression models for vehicle speeds.

Variable	*Speed at Benchmark*		*Speed at HVC*		*Speed difference*	
	Coefficient	t-stat	Coefficient	t-stat	Coefficient	t-stat
Constant	57.417	188.740	61.067	319.740	1.139	3.500
HVC and pedestrian sign indicator (1 if both are present, 0 otherwise)	-0.459	-2.460	-	-	-	-
Standard deviation of parameter distribution	*5.429*	*38.780*	-	-	-	-
HVC indicator (1 if HVC is present, 0 otherwise)	-	-	0.474	2.750	-0.563	-3.300
Standard deviation of parameter distribution	-	-	*5.980*	*58.750*	-	-
HVC position indicator (1 if end-of-block located HVC, 0 otherwise)	-1.961	-8.180	-	-	-	-
HVC type and position indicator (1 if ladder type end-of-block located HVC, 0 otherwise)	-	-	9.196	27.840	-4.995	-1.960
Standard deviation of parameter distribution	-	-	*7.702*	*28.580*	*2.449*	*2.770*
Lane position indicator (1 if vehicle is in the center lane of a multilane road, 0 otherwise)	-6.176	-39.170	-9.213	-44.670	-	-
Standard deviation of parameter distribution	-	-	*7.645*	*31.070*	-	-
Lead vehicle indicator (1 if lead vehicle is present, 0 otherwise)	-4.776	-23.360	-2.374	-6.580	-0.887	-4.820
Standard deviation of parameter distribution	-	-	*3.618*	*43.260*	-	-
Parked vehicle indicator (1 if there is no parked vehicle near the crosswalk, 0 otherwise)	6.523	44.060	-	-	-0.368	-1.900
Gender indicator (1 if driver is male, 0 otherwise)	0.552	2.420	-	-	-0.065	-0.380
Standard deviation of parameter distribution	*9.902*	*30.071*	-	-	*0.503*	*85.380*
Participant's age indicator (1 if greater than 50 years old, 0 otherwise)	1.979	46.100	-	-	-	-
Standard deviation of parameter distribution	*7.893*	*31.765*	-	-	-	-
Participant's age indicator (1 if greater than 65 years old, 0 otherwise)	-	-	-	-	-2.855	-8.890
Standard deviation of parameter distribution	-	-	-	-	*4.123*	*65.230*
Participant's age indicator (1 if greater than 60 years old, 0 otherwise)	-	-	-7.810	-30.130	-	-
Pedestrian presence indicator (1 if pedestrian is present near the HVC, 0 otherwise)	-	-	-3.982	-9.330	-	-
Obstructing vehicle indicator (1 if there is 1 or more vehicles obstructing the view to the crosswalk, 0 otherwise)	-	-	-1.621	-4.040	-	-
Weather indicator (1 if weather is rainy or snowy, 0 otherwise)	-	-	-1.809	-3.300	-	-
Vehicle type indicator (1 if passenger car, 0 otherwise)	-	-	-	-	-0.455	-2.460
Standard deviation of parameter distribution	-	-	-	-	*2.084*	*40.340*

Variable	*Speed at Benchmark*		*Speed at HVC*		*Speed difference*	
	Coefficient	**t-stat**	**Coefficient**	**t-stat**	**Coefficient**	**t-stat**
Speed limit indicator (1 if the speed limit is below 30mph, 0 otherwise)	-	-	-	-	0.696	3.360
Variance parameter, sigma	7.992	204.560	7.630	180.450	4.718	194.220
Number of drivers/Number of traversals	180/3264		181/3266		149/2695	
Number of estimated parameters	15		20		20	
Log-likelihood at convergence	-11191.200		-11077.900		-7861.900	
Log-likelihood at zero	-12816.400		-12845.001		-8286.260	
R^2	0.608		0.661		0.207	
Adjusted R^2	0.606		0.659		0.201	
MAD	5.694		5.359		3.023	
SSE	192896.651		169146.323		58642.375	
MSE	59.098		51.790		21.760	
RMSE	7.688		7.197		4.665	
Aggregate distributional effect of the random parameters across the observations						
	Below zero	**Above Zero**	**Below zero**	**Above Zero**	**Below zero**	**Above Zero**
HVC and pedestrian sign indicator (1 if both are present, 0 otherwise)	53.40%	46.60%			-	-
HVC indicator (1 if HVC is present, 0 otherwise)	-	-	46.80%	53.20%	-	-
HVC type and position indicator (1 if HVC is ladder type and located at the end-of-block, 0 otherwise)	-	-	11.60%	88.40%	97.90%	2.10%
Lane position indicator (1 if vehicle is in the center lane of a multilane road, 0 otherwise)	-	-	88.60%	11.40%	-	-
Lead vehicle indicator (1 if lead vehicle is present, 0 otherwise)	-	-	74.40%	25.60%	-	-
Gender indicator (1 if driver is male, 0 otherwise)	47.80%	52.20%	-	-	55.10%	44.90%
Participant's age indicator (1 if greater than 50 years old, 0 otherwise)	40.10%	59.90%	-	-	-	-
Participant's age indicator (1 if greater than 65 years old, 0 otherwise)	-	-	-	-	75.60%	24.40%
Vehicle type indicator (1 if passenger car, 0 otherwise)	-	-	-	-	58.60%	41.40%

Diagonal and off-diagonal elements of the Γ matrix [t-stats in brackets], and correlation coefficients (in parentheses) for the correlated random parameters				
Speed at Benchmark location	HVC and pedestrian sign indicator (1 if both are present, 0 otherwise)	Gender indicator (1 if driver is male, 0 otherwise)	Driver's age indicator (1 if greater than 50 years old, 0 otherwise)	
HVC and pedestrian sign indicator (1 if both are present, 0 otherwise)	5.429 [38.780] (1.000)			
Gender indicator (1 if driver is male, 0 otherwise)	-6.173 [-23.220] (-0.623)	9.902 [30.071] (1.000)		
Driver's age indicator (1 if greater than 50 years old, 0 otherwise)	-5.792 [-21.760] (-0.734)	4.984 [28.020] (0.951)	7.893 [31.765] (1.000)	
Speed at HVC location	HVC indicator (1 if HVC is present, 0 otherwise)	HVC type and position indicator (1 if ladder type end-of-block located HVC, 0 otherwise)	Center lane indicator (1 if vehicle is in the center lane of a multilane road, 0 otherwise)	Leading vehicle indicator (1 if leading vehicle is present, 0 otherwise)
HVC indicator (1 if HVC is present, 0 otherwise)	5.980 [58.750] (1.000)			
HVC type and position indicator (1 if ladder type end-of-block located HVC, 0 otherwise)	-7.382 [-17.920] (-0.958)	2.199 [9.010] (1.000)		
Center lane indicator (1 if vehicle is in the center lane of a multilane road, 0 otherwise)	-5.870 [-36.430] (-0.768)	-1.981 [-17.030] (0.66193)	4.479 [41.590] (1.000)	
Leading vehicle indicator (1 if leading vehicle is present, 0 otherwise)	0.818 [6.630] (0.226)	0.983 [17.450] (-0.139)	-1.910 [-28.350] (-0.553)	2.794 [50.050] (1.000)
Speed Difference	HVC type and position indicator (1 if ladder type end-of-block, 0 otherwise)	Gender indicator (1 if driver is male, 0 otherwise)	Driver's age indicator (1 if greater than 65 years old, 0 otherwise)	Vehicle type indicator (1 if passenger car, 0 otherwise)
HVC type and position indicator (1 if ladder type end-of-block located HVC, 0 otherwise)	2.449 [2.770] (1.000)			

Gender indicator (1 if driver is male, 0 otherwise)	-0.216 [-2.000] (-0.429)	0.454 [5.040] (1.000)		
Driver's age indicator (1 if greater than 65 years old, 0 otherwise)	3.150 [10.480] (0.764)	1.842 [7.610] (0.076)	1.919 [7.870] (1.000)	
Vehicle type indicator (1 if passenger car, 0 otherwise)	0.850 [7.200] (0.408)	-1.375 [-11.770] (-0.771)	-1.016 [-8.910] (-0.210)	0.835 [8.240] (1.000)

Acceleration

Table 9 presents the descriptive statistics of the statistically significant variables (at 0.90 level of confidence) included in the acceleration models (at the benchmark and HVC locations, as well as for the acceleration difference between the benchmark and HVC locations). Table 10presents the model estimation results for the correlated grouped random parameters linear regression models for the acceleration at the benchmark and HVC locations, and for the acceleration difference between the benchmark and HVC locations.

Variables related to HVC were found to be statistically significant in all three models. The variable representing the simultaneous presence of HVC and pedestrian sign was found to have mixed effects on the acceleration at the benchmark and HVC locations. The acceleration at the benchmark location was found to decrease for 63% of the traversals, whereas the acceleration at the HVC location was found to decrease for 49% of the traversals. The difference in acceleration between the benchmark and HVC locations was found to decrease for 48% of the traversals, as shown in Table 10. Apart from the presence of HVC, the type (bar-pair) and location (end-of-block) of HVC were found to have a statistically significant effect in all three models for acceleration. Presence of bar-pair type end-of-block located HVC was found to increase acceleration at the HVC and benchmark locations and was also associated with an increase in the acceleration difference between the benchmark and HVC locations.

The presence of a lead vehicle ahead of the participant's vehicle was found to reduce acceleration at the benchmark location. On the other hand, the presence of both a lead vehicle and at least one vehicle obstructing the view of the HVC was found to increase the difference in acceleration between the benchmark and HVC locations. This could be attributed to the obstructed driver's vision towards the HVC that may subsequently lead the driver to apply a greater speed reduction. Similarly, poor windshield condition was also found to reduce acceleration at the HVC location, as well as the difference in acceleration between the benchmark and HVC locations.

The time of the day (dawn or dusk) during which the traversal occurred was found to increase the acceleration at the benchmark location. Despite the poor ambient lighting conditions, drivers may apply greater acceleration rates, possibly due to the traffic patterns observed in the roadway network during this time of the day. Traversals made between 6 AM and noon were found to reduce the acceleration at the HVC location. This could possibly be attributed to the peak traffic volume being typically observed during the morning commute.

Driver-specific characteristics, such as gender and age, were also found to be statistically significant factors for the acceleration surrogate safety measure. Older drivers (above 50 years of age) were associated with lower acceleration at the HVC location, while younger drivers (below 30 years of age) were associated with greater acceleration at the benchmark location. The driver's traversal frequency was also found to be statistically significant for the acceleration at the benchmark and HVC locations. Participants who undertook more than 60 traversals were correlated to lower acceleration at the benchmark locations. This can possibly be attributed to their familiarity with the location of the crosswalk on the specific route. Conversely, participants with more than 50 traversals were associated with an increase in acceleration at the HVC location. The experience of these drivers in crossing the HVCs may have resulted in greater driving self-efficacy, especially at the moment of the HVC crossing. Combining the last two findings, it can be inferred that the benchmark location is the most decisive point for possible changes in acceleration behavior of drivers with a high frequency of HVC traversals.

Table 9. Descriptive statistics for acceleration.

Variable	Mean	Standard Deviation	Minimum	Maximum
Acceleration at benchmark location (in g)	0.030	0.570	-6.016	5.491
Acceleration at HVC location (in g)	0.080	0.641	-3.351	21.439
Difference in Acceleration	0.050	0.757	-5.038	20.497
HVC and pedestrian sign indicator (1 if both are present, 0 otherwise) (Acceleration at benchmark)	0.541	0.498	0	1
HVC and pedestrian sign indicator (1 if both are present, 0 otherwise) (Acceleration at HVC)	0.541	0.498	0	1
HVC and Speed indicator (1 if HVC is present and average speed of trip greater than 5 mph over the speed limit, 0 ot0herwise)	0.542	0.498	0	1
HVC type and position indicator (1 if bar-pair type HVC located at the end-of-block, 0 otherwise) (Acceleration at benchmark)	0.157	0.363	0	1
HVC type and position indicator (1 if bar-pair type HVC located at the end-of-block, 0 otherwise) (Acceleration at HVC)	0.157	0.363	0	1
HVC type and position indicator (1 if bar-pair type HVC located at the end-of-block, 0 otherwise) (Acceleration difference)	0.157	0.363	0	1
Lead vehicle indicator (1 if leading vehicle is present, 0 otherwise)	0.527	0.499	0	1
Lead vehicle and Obstructing vehicle presence indicator (1 if lead vehicle is present and at least one obstructing vehicle is present near HVC, 0 otherwise)	0.500	0.500	0	1
Parked vehicle indicator (1 if more than 1 parked vehicle present near the crosswalk, 0 otherwise)	0.368	0.482	0	1
Gender indicator (1 if participant is female, 0 otherwise) (Acceleration at benchmark)	0.565	0.496	0	1
Gender indicator (1 if participant is female, 0 otherwise) (Acceleration at HVC)	0.565	0.496	0	1

Variable	Mean	Standard Deviation	Minimum	Maximum
Participant's age indicator (1 if less than 30 years old, 0 otherwise) (Acceleration at benchmark)	0.491	0.500	0	1
Participant's age indicator (1 if less than 30 years old, 0 otherwise) (Acceleration difference)	0.491	0.500	0	1
Participant's age indicator (1 if greater than 50 years old, 0 otherwise)	0.383	0.486	0	1
Time of day indicator (1 if trip occurs during dawn or dusk, 0 otherwise)	0.194	0.395	0	1
Time of trip indicator (1 if trip was undertaken between 6 AM to 12 Noon, 0 otherwise)	0.303	0.460	0	1
Trip frequency indicator (1 if participant undertook more than 60 traversals, 0 otherwise)	0.421	0.494	0	1
Trip frequency indicator (1 if participant undertook more than 50 traversals, 0 otherwise)	0.440	0.497	0	1
Windshield condition indicator (1 if the windshield condition was very poor, 0 otherwise) (Acceleration at benchmark)	0.051	0.219	0	1
Windshield condition indicator (1 if the windshield condition was very poor, 0 otherwise) (Acceleration difference)	0.051	0.219	0	1
Vehicle age (Acceleration at benchmark)	6.776	3.478	1	22
Vehicle age (Acceleration at HVC)	6.776	3.478	1	22
Vehicle age indicator (1 if vehicle is less than 6 years old, 0 otherwise)	0.423	0.494	0	1

Table 10. Correlated grouped random parameters linear regression models for acceleration.

	Acceleration at Benchmark		***Acceleration at HVC***		***Acceleration Difference***	
Variable	**Coefficient**	**t-stat**	**Coefficient**	**t-stat**	**Coefficient**	**t-stat**
Constant	0.093	2.920	-0.075	-1.960	0.057	1.86
Standard deviation of parameter distribution	-	-	*0.753*	*25.220*	-	-
HVC and pedestrian sign indicator (1 if both are present, 0 otherwise)	-0.055	-2.390	0.072	3.020	-	-
Standard deviation of parameter distribution	*0.165*	*11.530*	*0.398*	*11.790*	-	-
HVC and Speed indicator (1 if HVC is present and average speed of trip greater than 5 mph over the speed limit, 0 otherwise)	-	-	-	-	0.272	8.990
Standard deviation of parameter distribution			-	-	*1.565*	*21.440*
Lead vehicle indicator (1 if leading vehicle is present, 0 otherwise)	-0.108	-4.810	-	-	-	-
Lead vehicle and Obstructing vehicle presence indicator (1 if lead vehicle is present and at least one obstructing vehicle is present near HVC, 0 otherwise)	-	-	-	-	0.148	4.310
Gender indicator (1 if participant is female, 0 otherwise)	-0.119	-6.050	-0.071	-3.000	-	-
Participant age indicator (1 if greater than 50 years old, 0 otherwise)			-0.046	-1.860	-	-
Participant's age indicator (1 if less than 30 years old, 0 otherwise)	0.109	4.990	-	-	-0.179	-7.170
Time of day indicator (1 if trip occurs during dawn or dusk, 0 otherwise)	0.070	2.580	-	-		
Time of trip indicator (1 if trip was undertaken between 6 AM to 12 Noon, 0 otherwise)	-	-	-0.048	-4.550	-	-
Trip frequency indicator (1 if participant undertook more than 50 traversals, 0 otherwise)	-	-	0.069	2.810	-	-
Trip frequency indicator (1 if participant undertook more than 60 traversals, 0 otherwise)	-0.017	-0.760	-	-	-	-
Standard deviation of parameter distribution	*0.421*	*38.322*	-	-	-	-
HVC type and position indicator (1 if bar-pair type end-of-block located HVC, 0 otherwise)	0.226	6.680	0.353	9.690	0.197	5.040
Windshield condition indicator (1 if the windshield condition was very poor, 0 otherwise)	-	-	-0.132	-2.280	-0.220	-3.540
Parked vehicle indicator (1 if more than 1 parked vehicle present near the crosswalk, 0 otherwise)	-0.045	-1.840	-	-	-	-
Standard deviation of parameter distribution	*0.220*	*48.828*	-	-	-	-
Vehicle age	-0.005	-1.660	0.029	6.850	-	-
Standard deviation of parameter distribution	-	-	*0.131*	*22.405*	-	-
Vehicle age indicator (1 if vehicle is less than 6 years old, 0 otherwise)	-	-	-	-	-0.200	-6.190
Standard deviation of parameter distribution	-	-	-	-	*1.086*	*17.715*
Variance parameter, sigma	0.510	271.280	0.553	241.170	0.685	193.390

	Acceleration at Benchmark		*Acceleration at HVC*		*Acceleration Difference*	
Variable	**Coefficient**	**t-stat**	**Coefficient**	**t-stat**	**Coefficient**	**t-stat**
Number of drivers/Number of traversals	138/2645		138/2645		138/2645	
Number of estimated parameters	17		16		11	
Log-likelihood at convergence	-1850.784		-1835.161		-2556.395	
Log-likelihood at zero	-2260.613		-2574.598		-3014.674	
R^2	0.209		0.127		0.094	
Adjusted R^2	0.204		0.122		0.090	
MAD	0.324		0.319		0.380	
SSE	679.124		946.962		1371.362	
MSE	0.257		0.358		0.518	
RMSE	0.507		0.598		0.720	
Aggregate distributional effect of the random parameters across the observations						
	Below zero	**Above Zero**	**Below zero**	**Above Zero**	**Below zero**	**Above Zero**
HVC and pedestrian sign indicator (1 if both are present, 0 otherwise)	63.10%	36.90%	49%	51%	-	-
HVC and Speed indicator (1 if HVC is present and average speed of trip greater than 5 mph over the speed limit, 0 otherwise)	-	-	-	-	48.80%	51.20%
Trip frequency indicator (1 if participant undertook more than 60 traversals, 0 otherwise)	65.40%	34.60%	-	-	-	-
Parked vehicle indicator (1 if more than 1 parked vehicle present near the crosswalk, 0 otherwise)	60.60%	39.40%	-	-	-	-
Vehicle age	-	-	2.70%	97.30%	-	-
Vehicle age indicator (1 if vehicle is less than 6 years old, 0 otherwise)	-	-	-	-	88.90%	11.10%

Diagonal and off-diagonal elements of the Γ matrix [t-stats in brackets], and correlation coefficients (in parentheses) for the correlated random parameters			
Acceleration at Benchmark	HVC and pedestrian sign indicator (1 if both are present, 0 otherwise)	Trip frequency indicator (1 if participant undertook more than 60 traversals, 0 otherwise)	Parked vehicle indicator (1 if more than 1 parked vehicle present near the crosswalk, 0 otherwise)
HVC and pedestrian sign indicator (1 if both are present, 0 otherwise)	0.165 [11.530] (1.000)		
Trip frequency indicator (1 if participant undertook more than 60 traversals, 0 otherwise)	0.418 [11.420] (0.995)	0.043 [38.183] (1.000)	
Parked vehicle indicator (1 if more than 1 parked vehicle present near the crosswalk, 0 otherwise)	0.055 [2.30] (0.248)	-0.130 [-6.580] (0.186)	0.168 [48.651] (1.000)
Acceleration at HVC	Constant	HVC and pedestrian sign indicator (1 if both are present, 0 otherwise)	Vehicle age
Constant	0.175 [25.128] (1.000)		
HVC and pedestrian sign indicator (1 if both are present, 0 otherwise)	0.732 [14.200] (0.973)	0.398 [11.790] (1.000)	
Vehicle age	0.061 [12.710] (0.960)	0.114 [15.880] (0.875)	0.015 [22.324] (1.000)
Acceleration Difference	HVC and Speed indicator (1 if HVC is present and avg. speed of trip greater than 5 mph over speed limit, 0 otherwise)	Vehicle age indicator (1 if vehicle is less than 6 years old, 0 otherwise)	
HVC and Speed indicator (1 if HVC is present and average speed of trip greater than 5 mph over the speed limit, 0 otherwise)	1.565 [21.440] (1.000)		
Vehicle age indicator (1 if vehicle is less than 6 years old, 0 otherwise)	1.074 [3.130] (0.989)	0.164 [36.247] (1.000)	

Throttle Pedal Actuation

Table 11 provides the descriptive statistics of the variables that were found to be statistically significant in the model for the TPA safety surrogate measure. Table 12 provides the model estimation results of the correlated grouped random parameters linear regression models for TPA at the benchmark and HVC locations, as well as the correlated grouped random parameters linear regression model for the difference in TPA between the benchmark and HVC locations.

The presence of HVC with pedestrian signs was found to reduce TPA in almost 90% of the traversals, while it was observed to increase the difference in TPA between the benchmark and HVC locations. The end-of-block located HVC was observed to increase TPA at the benchmark location for almost all traversals. The bar-pair end-of-block located HVC was also found to increase TPA at the HVC location.

The presence of a lead vehicle and at least one vehicle obstructing HVC visibility was found to reduce TPA at the benchmark location; whereas, the same variable was found to increase the TPA difference between the benchmark and HVC benchmark locations. Vehicles traveling in the side lanes of a multi-lane road were found to affect the TPA in all model specifications. Specifically, when a vehicle traverses a side lane of a multi-lane road, the TPA at the benchmark location increases, the TPA at the HVC location decreases, whereas the difference in TPA between the benchmark and HVC locations also decreases.

With respect to the temporal characteristics of traversals, month and time-of-the-day for the traversals have been found to influence the TPA. Traversals made during the months that HVC was installed were found to reduce the difference in TPA between the benchmark and HVC locations. Approximately 49% of traversals that occurred between 6 and 9 AM were found to be associated with a lower difference in TPA between the benchmark and HVC locations. In addition, lower values of TPA at HVC were found in traversals made throughout the morning rush hour (between 6 and 9 AM).

The participant's age was found to have a statistically significant effect on TPA at the benchmark and HVC locations and on the TPA difference between the benchmark and HVC locations. The TPA at the benchmark location was found to decrease for about 53% of traversals undertaken by young drivers (less than 25 years old). A decrease in TPA at the HVC location was also found for older drivers (greater than 50 years old). The Difference in TPA between the benchmark and HVC locations was found to decrease for young drivers (less than 30 years old). Regarding the effect of environmental conditions, the presence of clear weather was found to increase the difference in TPA between the benchmark and HVC benchmark locations.

Table 11. Descriptive statistics for TPA.

Variable	Mean	Standard Deviation	Minimum	Maximum
TPA at benchmark	13.308	13.731	-11.552	100
TPA at HVC	13.327	12.092	-8.118	100
Difference in TPA	0.019	12.969	-100	83.859
HVC position indicator (1 if HVC is located at the end-of-block, 0 otherwise)	0.682	0.466	0	1
HVC and pedestrian sign indicator (1 if both are present, 0 otherwise) (TPA at benchmark)	0.546	0.498	0	1
HVC and pedestrian sign indicator (1 if both are present, 0 otherwise) (TPA difference)	0.546	0.498	0	1
HVC type and position indicator (1 if bar-pair type end-of-block located HVC, 0 otherwise)	0.112	0.316	0	1
Lead vehicle and Obstructing vehicle presence indicator (1 if lead vehicle is present and at least one obstructing vehicle is present near HVC, 0 otherwise) (TPA at benchmark)	0.472	0.499	0	1
Lead vehicle and Obstructing vehicle presence indicator (1 if lead vehicle is present and at least one obstructing vehicle is present near HVC, 0 otherwise) (TPA difference)	0.472	0.499	0	1
Lane position indicator (1 if vehicle is in the side lanes of a multilane road, 0 otherwise) (TPA at benchmark)	0.364	0.481	0	1
Lane position indicator (1 if vehicle is in the side lanes of a multilane road, 0 otherwise) (TPA difference)	0.363	0.481	0	1
Time of trip indicator (1 if trip was undertaken between 6 AM to 12 Noon, 0 otherwise)	0.307	0.461	0	1
Participant’s age indicator (1 if less than 25 years old, 0 otherwise)	0.334	0.472	0	1
Participant's age indicator (1 if greater than 50 years old, 0 otherwise)	0.410	0.492	0	1
Participant’s age indicator (1 if less than 30 years old, 0 otherwise)	0.457	0.498	0	1
Vehicle age	5.744	2.635	1	17
Vehicle Type indicator (1 if vehicle used is Passenger Car, 0 otherwise) (TPA at benchmark)	0.800	0.400	0	1
Vehicle Type indicator (1 if vehicle used is Car, 0 otherwise) (TPA difference)	0.800	0.400	0	1
Trip frequency indicator (1 if participant undertook more than 50 traversals, 0 otherwise)	0.420	0.494	0	1
Month of traversal indicator (If traversal occurred during June, July, August or October, 0 otherwise)	0.354	0.478	0	1
Time of trip indicator (1 if trip was undertaken between 6 to 9 AM, 0 otherwise)	0.215	0.411	0	1
Weather indicator (1 if clear weather, 0 otherwise)	0.491	0.500	0	1
Windshield condition indicator (1 if the windshield condition was very poor, 0 otherwise)	0.064	0.246	0	1
Lane position indicator (1 if vehicle is in the side lane of a multilane road, 0 otherwise) (TPA at HVC)	0.363	0.481	0	1

Table 12. Correlated grouped random parameters linear regression models for TPA.

	TPA at benchmark		*TPA at HVC*		*TPA difference*	
Variable	**Coefficient**	**t-stat**	**Coefficient**	**t-stat**	**Coefficient**	**t-stat**
Constant	8.197	14.350	13.668	31.060	1.734	2.430
Lead vehicle and Obstructing vehicle presence indicator (1 if lead vehicle is present and at least one obstructing vehicle is present near HVC, 0 otherwise)	-1.782	-2.960	-	-	2.448	6.510
Vehicle age	-	-	-0.622	-14.860	-	-
Standard deviation of parameter distribution	-	-	*1.055*	*15.707*	-	-
Vehicle Type indicator (1 if vehicle used is Car, 0 otherwise)	3.208	9.640	-	-	-1.198	-2.200
Standard deviation of parameter distribution			-	-	*8.778*	*141.350*
Lane position indicator (1 if vehicle is in the side lanes of a multilane road, 0 otherwise)	1.872	4.160	-0.739	-2.170	-2.117	-5.450
Participant's age indicator (1 if less than 25 years old, 0 otherwise)	-0.330	-5.030	-	-	-	-
Standard deviation of parameter distribution	*4.303*	*231.880*	-	-	-	-
HVC position indicator (1 if HVC is located at the end-of-block, 0 otherwise)	6.632	20.860	-	-	-	-
Standard deviation of parameter distribution	*5.779*	*22.585*	-	-	-	-
HVC type and position indicator (1 if bar-pair type end-of-block HVC, 0 otherwise)	-	-	0.902	1.740	-	-
HVC and pedestrian sign indicator (1 if both are present, 0 otherwise)	-	-	-0.792	-1.620	0.883	2.220
Standard deviation of parameter distribution	-	-	*0.609*	*2.820*	-	-
Trip frequency indicator (1 if participant undertook more than 50 traversals, 0 otherwise)	-	-	-2.352	-7.150	-	-
Participant's age indicator (1 if less than 30 years old, 0 otherwise)	-	-			-1.549	-4.110
Participant age indicator (1 if greater than 50 years old, 0 otherwise)	-	-	-3.935	-9.260		
Time of trip indicator (1 if trip was undertaken between 6 to 9 AM, 0 otherwise)	-	-	-2.240	-5.090	-3.117	-7.040
Standard deviation of parameter distribution	-	-	-	-	*6.781*	*193.749*
Windshield condition indicator (1 if the windshield condition was very poor, 0 otherwise)	-	-	1.594	2.170	-	-
Month of traversal indicator (If traversal occurred during June, July, August or October, 0 otherwise)	-	-	-	-	-1.096	-2.860
Weather indicator (1 if clear weather, 0 otherwise)	-	-	-	-	0.015	0.040

	TPA at benchmark		TPA at HVC		TPA difference	
Variable	**Coefficient**	**t-stat**	**Coefficient**	**t-stat**	**Coefficient**	**t-stat**
Standard deviation of parameter distribution	-	-	-	-	*3.239*	*9.780*
Variance parameter, sigma	11.039	294.780	10.208	286.730	8.220	101.120
Number of Participants/Number of traversals	111/2001		111/2001		2001	
Number of estimated parameters	10		13		16	
Log-likelihood at convergence	-7323.579		-7277.620		-7751.562	
Log-likelihood at zero	-8080.723		-7826.454		-7966.506	
R^2	0.278		0.283		0.667	
Adjusted R^2	0.275		0.279		0.665	
MAD	7.450		6.891		3.472	
SSE	272278.462		209574.542		111949.547	
MSE	136.071		104.683		55.919	
RMSE	11.665		10.231		7.478	
Aggregate distributional effect of the random parameters across the observations						
	Below zero	Above Zero	Below zero	Above Zero	Below zero	Above Zero
Vehicle age	-	-	80.30%	19.70%	-	-
Vehicle Type indicator (1 if vehicle used is Car, 0 otherwise)	-	-	-	-	58.40%	41.60%
Participant's age indicator (1 if less than 25 years old, 0 otherwise)	53.10%	46.90%	-	-	-	-
HVC position indicator (1 if HVC is located at the end-of-block, 0 otherwise)	0.01%	99.99%	-	-	-	-
HVC and pedestrian sign indicator (1 if both are present, 0 otherwise)	-	-	90.30%	10.70%	-	-
Time of trip indicator (1 if trip was undertaken between 6 to 9 AM, 0 otherwise)	-	-	-	-	69.50%	30.50%
Weather indicator (1 if clear weather, 0 otherwise)	-	-	-	-	49.80%	50.20%

Diagonal and off-diagonal elements of the Γ matrix [t-stats in brackets], and correlation coefficients (in parentheses) for the correlated random parameters

TPA at benchmark	Driver's age indicator (1 if less than 25 years old, 0 otherwise)	HVC position indicator (1 if HVC is located at the end-of-block, 0 otherwise)	
Driver's age indicator (1 if less than 25 years old, 0 otherwise)	4.303 [231.880] (1.000)		
HVC position indicator (1 if HVC is located at the end-of-block, 0 otherwise)	-5.773 [-59.790] (-0.999)	0.259 [22.483] (1.000)	
TPA at HVC	HVC and pedestrian sign indicator (1 if both are present, 0 otherwise)	Vehicle age	
HVC and pedestrian sign indicator (1 if both are present, 0 otherwise)	0.609 [2.820] (1.000)		
Vehicle age	0.762 [79.870] (0.722)	0.730 [15.636] (1.000)	
TPA difference	Weather indicator (1 if clear weather, 0 otherwise)	Time of trip indicator (1 if trip was undertaken between 6 to 9 AM, 0 otherwise)	Vehicle Type indicator (1 if vehicle used is Car, 0 otherwise)
Weather indicator (1 if clear weather, 0 otherwise)	3.239 [9.780] (1.000)		
Time of trip indicator (1 if trip was undertaken between 6 to 9 AM, 0 otherwise)	-2.935 [-7.270] (-0.433)	-3.117 [-7.040] (1.000)	
Vehicle Type indicator (1 if vehicle used is Car, 0 otherwise)	2.966 [10.570] (0.338)	-6.002 [-29.760] (-0.763)	5.677 [212.958] (1.000)

Binary outcome models: Speed, acceleration, and TPA decrease; Brake pedal state

To investigate the effect of the HVC on the driving behavior, in terms of the likelihood that a driver will reduce speed, acceleration, or TPA, between the benchmark and HVC locations, correlated grouped random parameters binary logit models were estimated. Similarly, to investigate the effect of HVC on the likelihood that a driver will brake near the benchmark or HVC locations, correlated grouped random parameters binary probit model was estimated. Descriptive statistics of selected variables (those that were found to be statistically significant in the models) are provided in Table 13, while the model estimation results are presented in Table 14.

Table 14 shows that the presence of HVC has a mixed effect on the speed decrease. Specifically, for a significant portion of the traversals (about 60% of the traversals), the presence of HVC was found to increase the likelihood of speed decrease. A similarly mixed effect of the HVC presence was also found in the TPA decrease model: for 55% of the traversals, the presence of HVC was found to decrease the likelihood of TPA decrease. On the contrary, the presence of HVC had a fixed effect on the acceleration decrease, with the likelihood of acceleration increasing by approximately 6% in the presence of HVC.

The simultaneous presence of HVC and pedestrian sign was found to increase the brake application likelihood – the likelihood of brake application increased by 19% in the presence of both HVC and pedestrian signs. Ladder end-of-block located HVCs also had mixed effects on the likelihood of speed decrease: an increase in the speed decrease likelihood was identified for approximately 53% of traversals. Bar-pair HVCs were observed to reduce the likelihood of acceleration decrease, while ladder HVCs were observed to decrease the likelihood of brake application. End-of-block located HVCs were found to increase the likelihood of acceleration decrease for 82% of the traversals, and increase the likelihood of TPA decrease for 66% of the traversals.

Pedestrian presence in the proximity of the crossings was found to reduce the likelihood of TPA decrease and to have mixed effects on the likelihood of brake application (the presence of pedestrians was found to increase the likelihood of brake application for 48% of the traversals). The presence of two or more vehicles obstructing the visibility of the HVC location increased the likelihood of speed decrease. On the other hand, the presence of three or more vehicles obstructing the visibility of the HVC location decreased the likelihood of acceleration decrease. If no vehicles were parked near the HVC, a speed decrease was found to be more likely to occur. When one or more parked vehicles were present in the proximity of the crosswalk, an acceleration decrease was less likely to occur. Similarly, the presence of a lead vehicle was found to reduce the likelihood of a TPA decrease.

Turning to driver-specific characteristics, younger participants (less than 30 years old) were observed to have a mixed effect on the likelihood of acceleration decrease. Specifically, more than 60% of the younger participants were found to be more likely to decrease their vehicles' acceleration. Older participants (over the age of 65) were found to be less likely to brake near the HVC. Table 14 shows that the majority (approximately 78%) of young drivers (less than 25 years old) were more likely to brake near HVC but were less likely to decrease their vehicles' speed. These findings can possibly shed some light on the behavioral patterns of younger drivers at HVCs. It is likely that such drivers would apply the brake momentarily as they approached closer to the HVC location, but would not generally prefer to reduce speed by a significant margin. The familiarity of drivers with HVCs was found to affect the likelihood of speed decrease and TPA decrease. Participants who made more than 50 traversals across the HVC sites during the study period, were more likely to decrease their vehicles' speed but less likely (by approximately 3%) to be associated with a TPA decrease between the benchmark and HVC locations. The increased likelihood of speed decrease may be capturing the possible influence of HVCs on driving behavior.

Table 13. Descriptive statistics for speed, acceleration and TPA decrease and brake pedal state.

Variable	Mean	Standard Deviation	Minimum	Maximum
Speed decrease	0.483	0.500	0	1
HVC indicator (1 if HVC is present, 0 otherwise)	0.563	0.496	0	1
Speed limit indicator (1 if the speed limit is below 30mph, 0 otherwise)	0.412	0.492	0	1
HVC type and position indicator (1 if ladder type end-of-block located HVC, 0 otherwise)	0.406	0.491	0	1
Obstructing vehicle indicator (1 if there are 2 or more vehicles obstructing the view to the crosswalk, 0 otherwise)	0.382	0.486	0	1
Parked vehicle indicator (1 if there is no parked vehicle near the crosswalk, 0 otherwise)	0.621	0.485	0	1
Participant Gender indicator (1 if driver is male, 0 otherwise)	0.422	0.494	0	1
Participant's age indicator (1 if less than 25 years old, 0 otherwise)	0.389	0.488	0	1
Trip frequency indicator (1 if participant undertook more than 50 traversals, 0 otherwise)	0.433	0.496	0	1
Vehicle Type indicator (1 if vehicle used is Passenger Car, 0 otherwise)	0.739	0.440	0	1
Acceleration decrease	0.467	0.499	0	1
HVC indicator (1 if HVC present, 0 otherwise)	0.598	0.490	0	1
Speed indicator (1 if vehicle speed is greater than 5 mph above the speed limit, 0 otherwise)	0.936	0.245	0	1
Parked vehicle indicator (1 if there is at least 1 parked vehicle near the crosswalk, 0 otherwise)	0.452	0.498	0	1
HVC position indicator (1 if HVC is located at the end-of-block, 0 otherwise)	0.670	0.470	0	1
Time of trip indicator (1 if trip was undertaken between 9 AM to 12 Noon, 0 otherwise)	0.085	0.278	0	1
Time of day indicator (1 if trip occurs during dawn or dusk, 0 otherwise)	0.194	0.395	0	1
HVC type indicator (1 if bar-pair type HVC, 0 otherwise)	0.310	0.463	0	1
Participant's age indicator (1 if less than 30 years old, 0 otherwise)	0.491	0.500	0	1
Obstructing vehicle indicator (1 if there are 3 or	0.181	0.385	0	1

Variable	Mean	Standard Deviation	Minimum	Maximum
more vehicles obstructing the view of the crosswalk, 0 otherwise)				
Vehicle type indicator (1 if vehicle is SUV or minivan, 0 otherwise)	0.203	0.402	0	1
TPA decrease	0.432	0.495	0	1
HVC indicator (1 if HVC is present, 0 otherwise)	0.590	0.492	0	1
Pedestrian presence indicator (1 if pedestrian is present near the HVC, 0 otherwise)	0.105	0.307	0	1
HVC position indicator (1 if HVC is located at the end-of-block, 0 otherwise)	0.632	0.482	0	1
Lane position indicator (1 if vehicle is in the side lanes of a multilane road, 0 otherwise)	0.344	0.475	0	1
Lead vehicle indicator (1 if lead vehicle is present, 0 otherwise)	0.486	0.500	0	1
Vehicle make indicator (1 if vehicle is manufactured by Honda, 0 otherwise)	0.266	0.442	0	1
Trip frequency indicator (1 if participant undertook more than 50 traversals, 0 otherwise)	0.467	0.499	0	1
Brake pedal state	0.102	0.302	0	1
HVC and pedestrian sign indicator (1 if both are present, 0 otherwise)	0.505	0.500	0	1
Pedestrian presence indicator (1 if pedestrian is present near the HVC, 0 otherwise)	0.103	0.304	0	1
Speed indicator (1 if vehicle speed is greater than 5 mph above the speed limit, 0 otherwise)	0.936	0.246	0	1
HVC position indicator (1 if HVC is located at the end-of-block, 0 otherwise)	0.699	0.459	0	1
HVC type indicator (1 if ladder type HVC, 0 otherwise)	0.732	0.443	0	1
Participant’s age indicator (1 if less than 25 years old, 0 otherwise)	0.267	0.443	0	1
Participant’s age indicator (1 if greater than 65 years old, 0 otherwise)	0.152	0.359	0	1

Table 14. Correlated grouped random parameters binary logit models for speed, acceleration and TPA decrease and correlated grouped random parameters binary probit model for brake pedal state.

	Speed decrease		*Acceleration decrease*		*TPA decrease*		*Brake pedal state*	
Variable	**Coeff. (t-stat)**	**Elasticity**	**Coeff. (t-stat)**	**Elasticity**	**Coeff. (t-stat)**	**Elasticity**	**Coeff. (t-stat)**	**Elasticity**
Constant	-0.715 (-6.410)	-	-0.574 (-6.710)	-	-0.191 (-2.310)	-	-0.764 (-3.630)	-
HVC indicator (1 if HVC is present, 0 otherwise)	0.163 (2.750)	4.654	0.193 (3.690)	6.008	-0.067 (-1.080)	-2.144	-	-
Standard deviation of parameter distribution	*0.649 (8.510)*	-	-	-	*0.476 (5.840)*	-	-	-
HVC and pedestrian sign indicator (1 if both are present, 0 otherwise)	-	-	-	-	-	-	0.205 (2.500)	19.136
HVC type and position indicator (1 if ladder type end-of-block located HVC, 0 otherwise)	0.071 (1.070)	1.457	-	-	-	-	-	-
Standard deviation of parameter distribution	*0.798 (49.230)*	-	-	-	-	-	-	-
HVC type indicator (1 if bar-pair type HVC, 0 otherwise)	-	-	-0.540 (-8.670)	-8.750	-	-	-	-
HVC type indicator (1 if ladder type HVC, 0 otherwise)	-	-	-	-	-	-	-0.425 (-3.320)	-57.391
HVC position indicator (1 if end-of-block located HVC, 0 otherwise)	-	-	0.361 (4.770)	12.620	0.200 (3.120)	6.862	0.287 (2.140)	36.992
Standard deviation of parameter distribution	-	-	*0.390 (70.553)*	-	*0.483 (52.170)*	-	-	-
Speed limit indicator (1 if the speed limit is above 30mph, 0 otherwise)	0.148 (1.900)	3.097	-	-	-	-	-	-
Speed indicator (1 if vehicle speed is greater than 5 mph above the speed limit, 0 otherwise)	-	-	0.294 (3.250)	14.385	-	-	-0.656 (-3.370)	-113.33
Standard deviation of parameter distribution	-	-	-	-	-	-	*0.127 (52.033)*	-
Pedestrian presence indicator (1 if pedestrian is present near the HVC, 0 otherwise)	-	-	-	-	-0.306 (-3.450)	-1.741	-0.036 (-0.170)	-0.683
Standard deviation of parameter distribution	-	-	-	-	-	-	*0.617 (3.700)*	-

Obstructing vehicle indicator (1 if there are 2 or more vehicles obstructing the view to the crosswalk, 0 otherwise)	0.201 (4.510)	3.919	-	-	-	-	-	-
Obstructing vehicle indicator (1 if there are 3 or more vehicles obstructing the view of the crosswalk, 0 otherwise)	-	-	-0.136 (-1.990)	-1.288	-	-	-	-
Parked vehicle indicator (1 if there is no parked vehicle near the crosswalk, 0 otherwise)	0.404 (5.410)	12.746	-	-	-	-	-	-
Parked vehicle indicator (1 if there is at least 1 parked vehicle near the crosswalk, 0 otherwise)	-	-	-0.151 (-2.630)	-3.551	-	-	-	-
Lead vehicle indicator (1 if lead vehicle is present, 0 otherwise)	-	-	-	-	-0.176 (-2.300)	-4.632	-	-
Participant's age indicator (1 if less than 25 years old, 0 otherwise)	-0.163 (-2.340)	-3.214	-	-	-	-	0.188 (1.480)	9.264
Standard deviation of parameter distribution	-	-	-	-	-	-	*0.238 (49.957)*	-
Participant's age indicator (1 if less than 30 years old, 0 otherwise)	-	-	0.093 (1.500)	2.393	-	-	-	-
Standard deviation of parameter distribution	-	-	*0.349 (3.900)*	-	-	-	-	-
Participant's age indicator (1 if greater than 65 years old, 0 otherwise)	-	-	-	-	-	-	-0.356 (-2.380)	-9.97
Trip frequency indicator (1 if participant undertook more than 50 traversals, 0 otherwise)	0.127 (1.830)	2.803	-	-	-0.113 (-1.750)	-2.857	-	-
Lane position indicator (1 if vehicle is in the side lanes of a multilane road, 0 otherwise)	-	-	-	-	0.086 (1.180)	1.604	-	-
Standard deviation of parameter distribution	-	-	-	-	*0.919 (47.190)*	-	-	-
Vehicle type indicator (1 if passenger car, 0 otherwise)	0.167 (2.070)	6.270	-	-	-	-	-	-
Vehicle type indicator (1 if vehicle is	-	-	0.247	2.621	-	-	-	-

SUV or minivan, 0 otherwise)			(4.180)					
Vehicle make indicator (1 if vehicle is manufactured by Honda, 0 otherwise)	-	-	-	-	0.296 (4.120)	4.256	-	-
Gender indicator (1 if driver is male, 0 otherwise)	0.133 (1.940)	2.862	-	-	-	-	-	-
Standard deviation of parameter distribution	*0.538* *(58.030)*	-	-	-	-	-	-	-
Time of trip indicator (1 if trip was undertaken between 9 AM to 12 Noon, 0 otherwise)	-	-	-0.230 (-2.200)	-1.019	-	-	-	-
Time of day indicator (1 if trip occurs during dawn or dusk, 0 otherwise)	-	-	0.192 (2.330)	1.942	-	-	-	-
Number of drivers/Number of traversals	149/2696		138/2645		143/2524		83/1397	
Number of estimated parameters	16		14		14		14	
Log-likelihood at convergence	-1758.200		-1737.360		-1646.100		-417.101	
Log-likelihood at zero	-1810.600		-1827.713		-1689.900		-459.174	
McFadden ρ^2	0.029		0.049		0.026		0.092	
Corrected McFadden ρ^2	0.020		0.042		0.018		0.061	
MAD	0.446		0.463		-0.458		0.156	
SSE	584.454		599.893		-0.502		109.727	
MSE	0.217		0.227		0.542		0.079	
RMSE	0.466		0.476		-0.426		0.280	

Aggregate distributional effect of the random parameters across the observations

	Speed decrease		***Acceleration decrease***		***TPA decrease***		***Brake pedal state***	
	Below zero	**Above Zero**	**Below zero**	**Above Zero**	**Below zero**	**Above Zero**	**Below zero**	**Above Zero**
HVC indicator (1 if HVC is present, 0 otherwise)	40.10%	59.90%	-	-	55.60%	44.40%	-	-
HVC type and position indicator (1 if ladder type end-of-block located HVC,0 otherwise)	46.50%	53.50%	-	-	-	-	-	-
HVC position indicator (1 if end-of-block located HVC, 0 otherwise)	-	-	17.70%	82.30%	33.90%	66.10%	-	-
Speed indicator (1 if vehicle speed is	-	-	-	-	-	-	99.99%	0.01%

greater than 5 mph above the speed limit, 0 otherwise)								
Pedestrian presence indicator (1 if pedestrian is present near the HVC, 0 otherwise)	-	-	-	-	-	-	52.30%	47.70%
Participant's age indicator (1 if less than 25 years old, 0 otherwise)	-	-	-	-	-	-	21.50%	78.50%
Participant's age indicator (1 if less than 30 years old, 0 otherwise)	-	-	39.50%	60.50%	-	-	-	-
Lane position indicator (1 if vehicle is in the side lanes of a multilane road, 0 otherwise)	-	-	-	-	46.30%	53.70%	-	-
Gender indicator (1 if driver is male, 0 otherwise)	40.20%	59.80%	-	-	-	-	-	-

Diagonal and off-diagonal elements of the Γ matrix [t-stats in brackets], and correlation coefficients (in parentheses) for the correlated random parameters			
Speed Decrease	HVC indicator (1 if HVC is present, 0 otherwise)	HVC type and position indicator **(**1 if ladder type end-of-block located HVC, 0 otherwise)	Gender indicator (1 if driver is male, 0 otherwise)
HVC indicator (1 if HVC is present, 0 otherwise)	0.649 [8.510] (1.000)		
HVC type and position indicator (1 if ladder type end-of-block located HVC, 0 otherwise)	-0.616 [-7.270] (-0.772)	0.798 [49.230] (1.000)	
Gender indicator (1 if driver is male, 0 otherwise)	0.277 [3.110] (0.515)	-0.442 [-5.960] (-0.920)	0.538 [58.030] (1.000)
Acceleration Decrease	Driver's age indicator (1 if less than 30 years old, 0 otherwise)	HVC position indicator (1 if end-of-block located HVC, 0 otherwise)	
Driver's age indicator (1 if less than 30 years old, 0 otherwise)	0.349 [3.900] (1.000)		
HVC position indicator (1 if end-of-block located HVC, 0 otherwise)	-0.321 [-4.200] (-0.635)	0.390 [70.553] (1.000)	
TPA Decrease	HVC indicator (1 if HVC is present, 0 otherwise)	HVC position indicator (1 if end-of-block located HVC, 0 otherwise)	Lane position indicator (1 if vehicle is in either left or right lane of a multilane road, 0 otherwise)
HVC indicator (1 if HVC is present, 0 otherwise)	0.476 [5.840] (1.000)		
HVC position indicator (1 if end-of-block located HVC, 0 otherwise)	-0.253 [-3.200] (-0.525)	0.483 [52.170] (1.000)	
Lane position indicator (1 if vehicle is in either left or right lane of a multilane road, 0 otherwise)	-0.622 [-7.740] (-0.676)	0.607 [6.510] (0.917)	0.919 [47.190] (1.000)

Diagonal and off-diagonal elements of the Γ matrix [t-stats in brackets], and correlation coefficients (in parentheses) for the correlated random parameters			
Brake Pedal State	Pedestrian presence indicator (1 if pedestrian is present near the HVC, 0 otherwise)	Speed indicator (1 if vehicle speed is greater than 5 mph above the speed limit, 0 otherwise)	Driver's age indicator (1 if less than 25 years old, 0 otherwise)
Pedestrian presence indicator (1 if pedestrian is present near the HVC, 0 otherwise)	0.617 [3.700] (1.000)		
Speed indicator (1 if vehicle speed is greater than 5 mph above the speed limit, 0 otherwise)	-0.300 [-3.810] (-0.921)	0.127 [52.033] (1.000)	
Driver's age indicator (1 if less than 25 years old, 0 otherwise)	-0.338 [-2.640] (-0.575)	-0.418 [-3.790] (0.252)	0.238 [49.957] (1.000)

5. ANALYSIS OF EYE GLANCE DATA

The in-vehicle instrument suite in the SHRP2 NDS program included cameras that focused on the driver. Specifically, one camera was dedicated to observing the driver's face. This data was post-processed to provide data on where the driver was looking at any point in their trip. This data was identified as eye glance data. In this program, eye glance and vehicle kinematic data from a subset of traversals was acquired and analyzed.

The potential benefit of this data is to provide insight as to changes in driver behavior on the approach to, and traversal through, the HVC location. This data can be used to examine a driver's change in attentiveness to the HVC environment caused by HVC signage and markings. The analysis performed on the eye glance data in this program provides additional data to evaluate HVCs and their impact on driver behavior. The number of HVC traversals analyzed in this program are insufficient to develop statistically significant results but do provide unique data on the effectiveness of HVCs not available through other methods. The sections that follow describe the process of acquisition, processing, and results of the analysis of eye glance data during HVC traversals.

PROCESS OF ACQUISITION OF EYE GLANCE DATA

During this program 3,480 video and time-history files on traversals through 18 HVC locations were acquired. These traversals occurred prior to and after the installation of the HVC. The analysis of eye glance data from all the traversals was impractical in this program due to financial constraints. A subset of traversals was selected from specific configurations/locations to analyze driver Eye Glance scanning behavior at HVCs.
The resulting set of traversals had the following characteristics:

Traversals with:

- Pedestrians present
- No lead vehicle influencing NDS vehicle speed/gap

Traversals with:

- No Pedestrians
- No lead vehicle influencing NDS vehicle speed/gap

Traversals were selected from 15 of the 18 HVC locations identified for analysis. Three locations were not included due to issues with an insufficient number of traversals or traversal not available due to PII issues. Traversals were selected with no lead vehicle so that the NDS vehicle driver behavior observed during the traversals was not influenced in either speed or vehicle-to-vehicle gap. Also, traversals were selected with pedestrians either present or not present. This resulted in a total of 327 traversals being selected; 75 with pedestrians and 252 without pedestrians. This list of traversals was provided to VTTI. The data files generally encompassed 10 seconds before the HVC crossing and two seconds after crossing. The time interval selected for HVC locations 1 and 2 was shorter (approximately 6-8 seconds) due to the physical layout of the roadways on the approach to the HVC.

Trained researchers at VTTI reviewed the traversal video files and produced a list of eye glance data files for the selected traversals. The researchers examined each frame of the traversal and determined an eye glance location. The potential entries for the eye glance location were as follows:

- Cell Phone
- Center Stack
- Cup-Holder/Console
- Forward
- Instrument Cluster
- Left Window/Mirror
- Left Windshield
- No Eyes Visible
- Other
- Over the shoulder (left or right)
- Passenger
- Rearview Mirror
- Right Window/Mirror
- Right Windshield

The resulting data files were provided for analysis.

ANALYSIS PROCESS (METHODOLOGY) OF EYE GLANCE DATA

The eye glance data files received from VTTI required further processing before analysis. The video data in the NDS vehicles was recorded at a rate of 15 Hz while the vehicle data (speed, throttle position, brake pedal state, acceleration, etc.) was recorded at a rate of 10Hz. The analysis methodology required that the eye glance and vehicle data be merged. To merge the data, the eye glance was converted from a 15Hz to a 10Hz rate. This was accomplished by matching the timestamps for the two data sources (eye glance time-series and vehicle time-series) and deleting the data points from the eye glance data that did not match the vehicle time-series timestamps. This process resulted in a merged file including vehicle data and eye glance data.

With the merging of the eye glance and vehicle files accomplished the following parameters were estimated or calculated in each file:

- Event Time: Timeline of the HVC traversal initiated at first data point in time-series file.
- Time of HVC crossing: The time of HVC crossing is necessary to establish vehicle distance and time to the HVC. This value was determined through observation of the NDS forward video. The point at which the vehicle crossed the HVC was recorded.
- Vehicle Speed: Vehicle speed had two potential sources; the NDS vehicle onboard network or the onboard GPS within the NDS equipment suite. The preferred source was the on-board vehicle network, as in the vehicles categorized as "Prime" vehicles the speed data was recorded at a 10 Hz rate. Other vehicles designated as "Sub-Prime", "Legacy", or "Basic" had no onboard vehicle bus, or earlier versions that sampled the vehicle speed at lower rates.

The other source of vehicle speed data was the NDS onboard GPS. However, the GPS acquired and recorded vehicle speed at a 1 Hz rate. In the cases where speed data was not acquired and recorded at a 10 Hz rate, the speed data was interpolated between data points to develop a speed profile at a 10 Hz rate.

- Time to HVC: The time to HVC crossing is calculated using the HVC crossing time and event time for the traversal.
- Distance to HVC: Distance to the HVC is calculated based on vehicle speed. Distances prior to HVC crossing are presented as negative values while distances after HVC crossing are presented as positive values.
- Duration of eye glance location during HVC traversal: The duration and location of driver eye glance was acquired by developing a pivot table for each traversal. This table produces data including glance direction and time duration for each glance during the traversal.

FINAL SAMPLE SIZE

The sample of traversals used in the analysis described in the following sections was divided among the HVC configurations, locations and the presence or absence of pedestrians at the HVC. The eye glance data supplied by VTTI contained 327 total traversals. During processing, it was found that three traversals lacked vehicle speed data from either the vehicle data bus or the onboard GPS. This precluded the association of eye glance with distance to HVC traversal. These traversals were omitted from the received files. The final listing of 724 eye glance traversal data, broken down by configuration/location, and the presence of pedestrians is provided in Table 15 below. Note that this sample included very few (7) traversals with pedestrians at mid-block locations. This lack of data results in the inability to provide conclusions on the effectiveness of mid-block locations with pedestrians.

Table 15. Eye glance by configuration, location, and presence of pedestrians.

Pedestrians Present	Configuration	Location	Traversals
No	Ladder	End-of-Block	97
No	Ladder	Mid-Block	10
No	Continental	End-of-Block	46
No	Continental	Mid-Block	10
No	Bar-Pair	End-of-Block	39
No	Bar-Pair	Mid-Block	48
Yes	Ladder	End-of-Block	36
Yes	Ladder	Mid-Block	0
Yes	Continental	End-of-Block	21
Yes	Continental	Mid-Block	2
Yes	Bar-Pair	End-of-Block	10
Yes	Bar-Pair	Mid-Block	5
		Total	**324**

EYE GLANCE ANALYSIS RESULTS

For this study, an evaluation of the change in driver eye scanning behavior on the approach to the HVC prior to and after the HVC was installed. Figure 40 illustrates typical driver eye glance behavior during the traversal of an intersection that was subsequently enhanced with a HVC. The traversal shown below was prior to the installation of the HVC. The height of the shapes provides information on the duration of the driver's glance. The color of the shape indicates the direction glance. In this case, as the driver approaches the intersection, they scan the travel lane (forward) and then to the right side of the road and back in reaction to vehicles or pedestrians at the intersection. The duration of these glances shows that the driver is concentrating on observing the conditions in the forward aspect of the roadway. Glances to the side are short (typically less than 1 second) before returning to the forward travel direction. The figure is annotated with features from a review of the traversal video. Figure 41 illustrates this same traversal plotted with the glance duration and direction with respect to the distance to the intersection. This data can provide information as to how the driver observes signage before the intersection. Prior to the installation of the HVC at this location, there was no signage in proximity to the intersection.

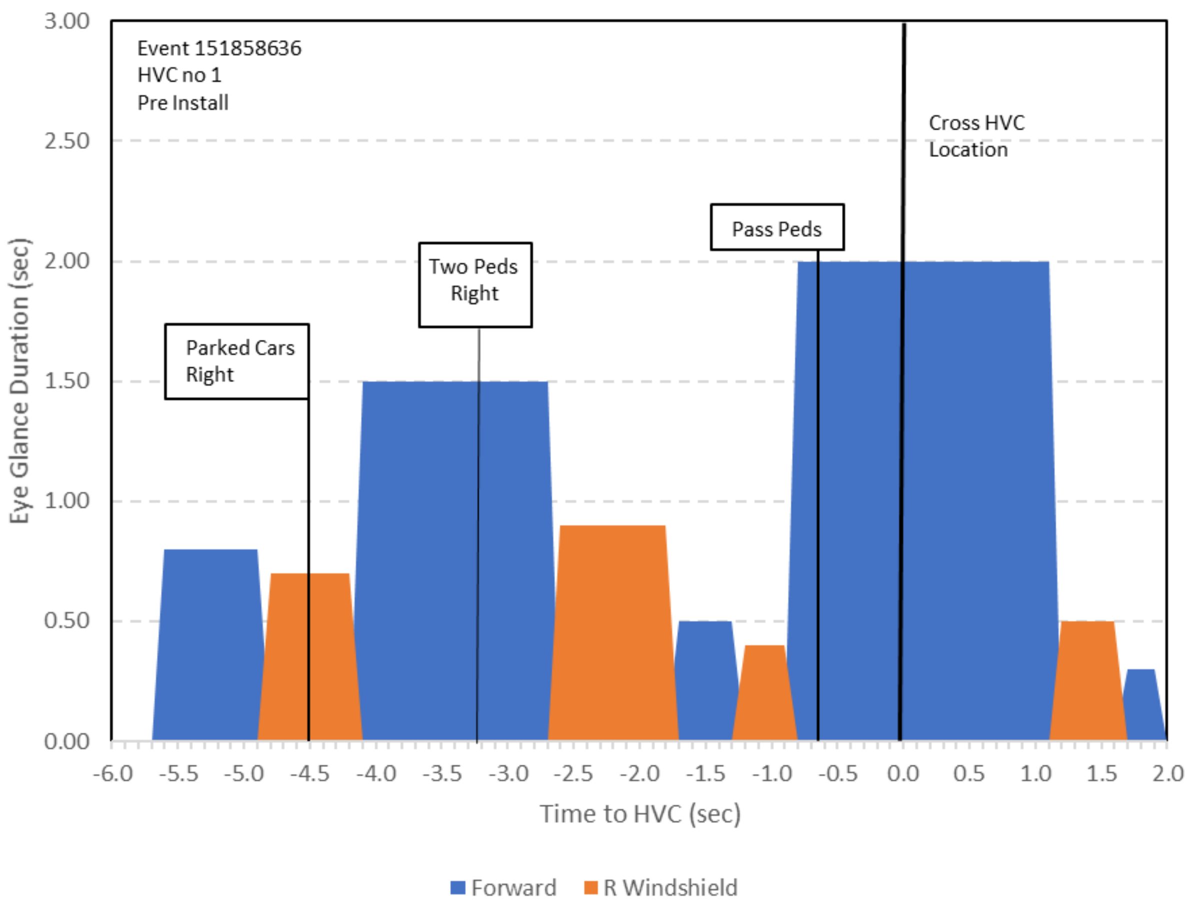

Figure 37. Example of eye glance direction and duration versus time to HVC.

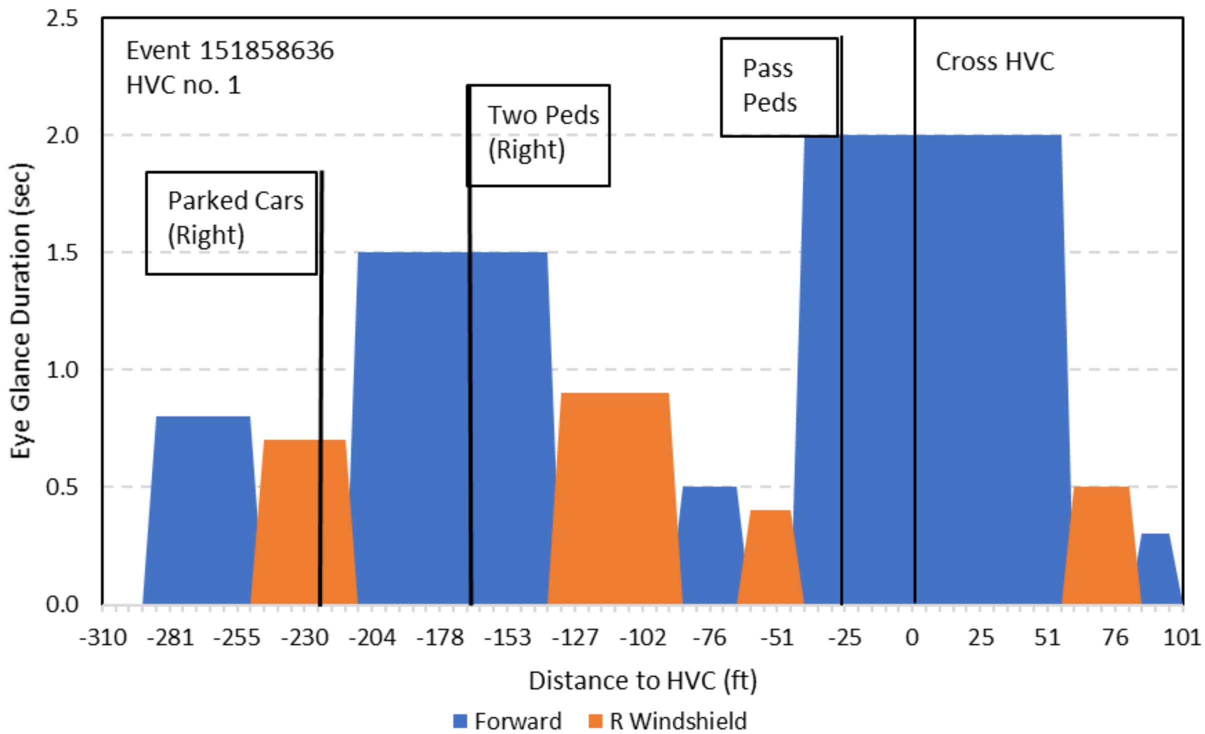

Figure 38. Example of eye glance direction and duration versus distance to HVC.

Comparison of Before/After Driver Behavior

A measure of the effectiveness of HVCs is their ability to divert a driver's attention from the travel lane to the roadside to scan for pedestrians. To examine this hypothesis an examination of driver behavior prior to and after HVC installation at a single location was performed. A sample of six drivers was selected. These drivers had traversed the HVC location multiple times prior to and after the HVC installation. The eye glance direction values listed above were aggregated in this analysis, with the "forward" data compared to "side" glances consisting of the right and left windshield and right and left window/mirror categories. The result of this analysis is presented in Figure 42. As may be observed there is a decrease in forward eye glances in five of the six drivers. Eye glance behavior to the side of the vehicle increases in three of the six drivers. These results confirm that the installation of HVCs can modify drivers' eye glance behavior in a proportion of the drivers traversing the HVC.

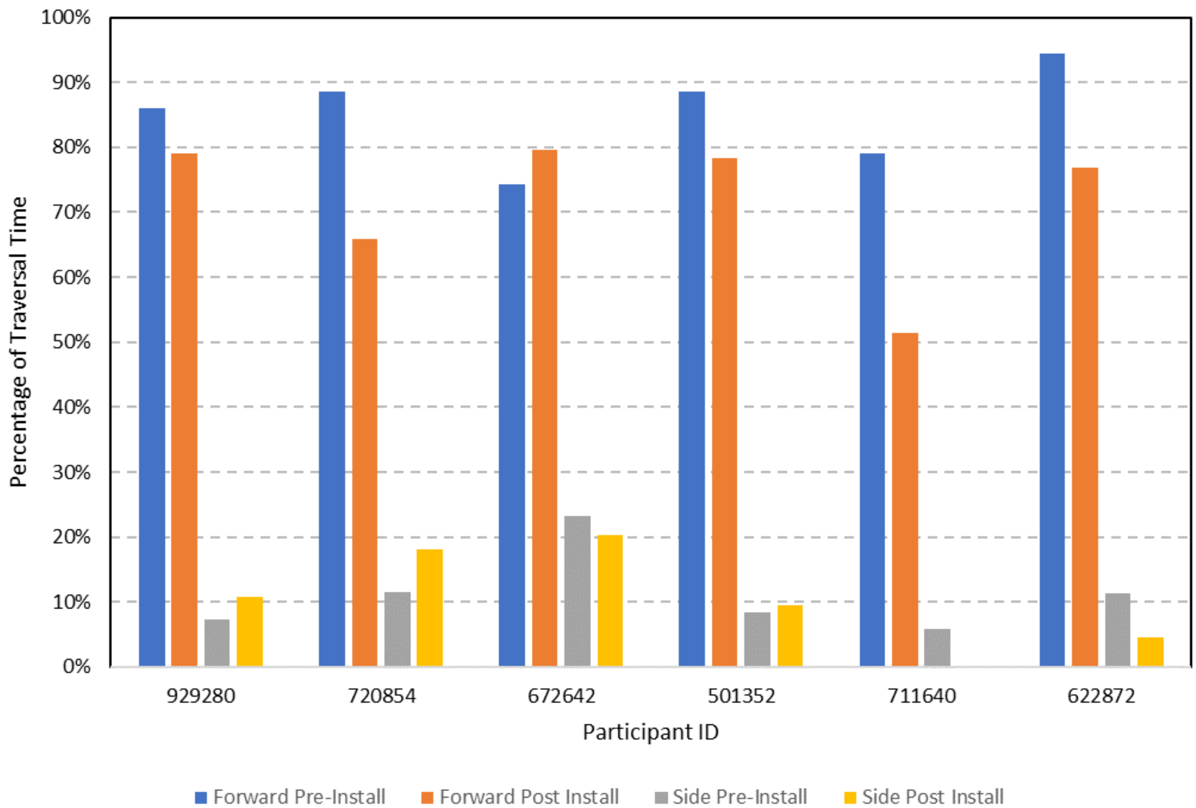

Figure 39. Before and after behavior of selected drivers.

Table 16 provides the values of the change in eye glance direction as shown in Figure 42.

Table 16. Change in driver eye glance behavior after HVC install.

Participant ID	Pre HVC-Install		Post HVC Install		Change	
	Forward	Side	Forward	Side	Forward	Side
929280	81.6%	7.4%	79.0%	10.8%	-7.1%	3.4%
720854	88.6%	11.4%	65.8%	18.2%	-22.7%	6.7%
672642	74.3%	23.2%	79.6%	20.3%	5.3%	-2.8%
501352	88.7%	8.4%	78.3%	9.4%	-10.4%	1.1%
711640	79.1%	5.8%	51.5%	0.0%	-27.6%	-5.8%
622872	94.3%	11.3%	76.8%	4.5%	-17.5%	-6.8%

Driver Eye Glance Results for HVC Configurations/Locations

The examination of driver eye glance behavior presented above illustrates that the installation of HVCs can change the eye scan behavior of drivers traversing HVCs. An expansion of this line of inquiry can be performed to determine if there are different ranges of change for the various configurations of HVC. To examine this hypothesis the driver eye glance behavior at each configuration was examined. An analysis of eye glance direction prior to and after HVC installation at each configuration/location combination was again performed. The change in eye glance direction for all participants at each available HVC configuration/location combination was calculated. An example of this process is shown in Table 17 for locations 1, 2, and 3 (ladder configuration, end-of-block location). Data for individual participants were aggregated into values for each combination to develop the average amount of change in external (forward), interior, exterior (side) and other glance directions for the HVC combinations. These results are summarized in Table 18. The values in Table 18 reflect the change in eye glance direction when compared to the baseline (pre-install).

Table 17. Example of eye glance change from pre-install baseline.

HVC	Participant ID	Heading (Deg)	Exterior (Forward)	Interior	Exterior (Left & Right)	Other
1	720854	0	-15.8%	9.0%	6.8%	0.0%
1	733168	0	-16.9%	16.8%	0.1%	0.0%
1	672642	0	0.9%	-2.5%	1.6%	0.0%
1	501352	0	-10.4%	2.5%	-4.4%	12.3%
1	711640	0	-27.6%	-1.7%	-5.9%	35.2%
1	929280	0	-7.1%	3.6%	3.4%	0.0%
1	622872	0	-17.5%	2.4%	-1.1%	16.3%
2	185431	180	9.2%	-2.9%	10.3%	-16.6%
2	219296	180	-9.9%	-7.5%	17.4%	0.0%
2	501352	180	-16.0%	6.4%	9.6%	0.0%
2	672642	180	3.8%	-1.6%	-2.3%	0.0%
2	720854	180	4.2%	3.9%	-8.2%	0.0%
3	911965	0	-9.1%	8.0%	1.2%	0.0%

Table 18. Percent change in driver eye glance by HVC configuration and location.

Configuration	Location	Exterior (Forward)	Interior	Exterior (Left & Right)	Other
Ladder	End-of-Block	-8.6%	2.8%	2.2%	3.6%
Continental	End-of-Block	3.2%	1.1%	-5.1%	0.8%
Bar-Pair	End-of-Block	-0.9%	-2.9%	-1.0%	4.9%
Ladder	Mid-Block	-32.0%	-2.1%	9.8%	24.3%
Continental	Mid-Block	-	-	-	-
Bar-Pair	Mid-Block	5.3%	-4.6%	-1.1%	1.3%

Examining the percentage of drivers from the sample showed an increase in external (side) scanning can provide insight into the effectiveness of the HVC configuration. Figure 40 presents the data for end-of block HVC locations and shows the ladder configuration was found to change the behavior of the most drivers, with over 61% of drivers. Continental and bar-pair configurations changed the behavior for a smaller percentage of drivers. As stated previously mid-block locations lacked sufficient data to provide a similar ranking of HVCs.

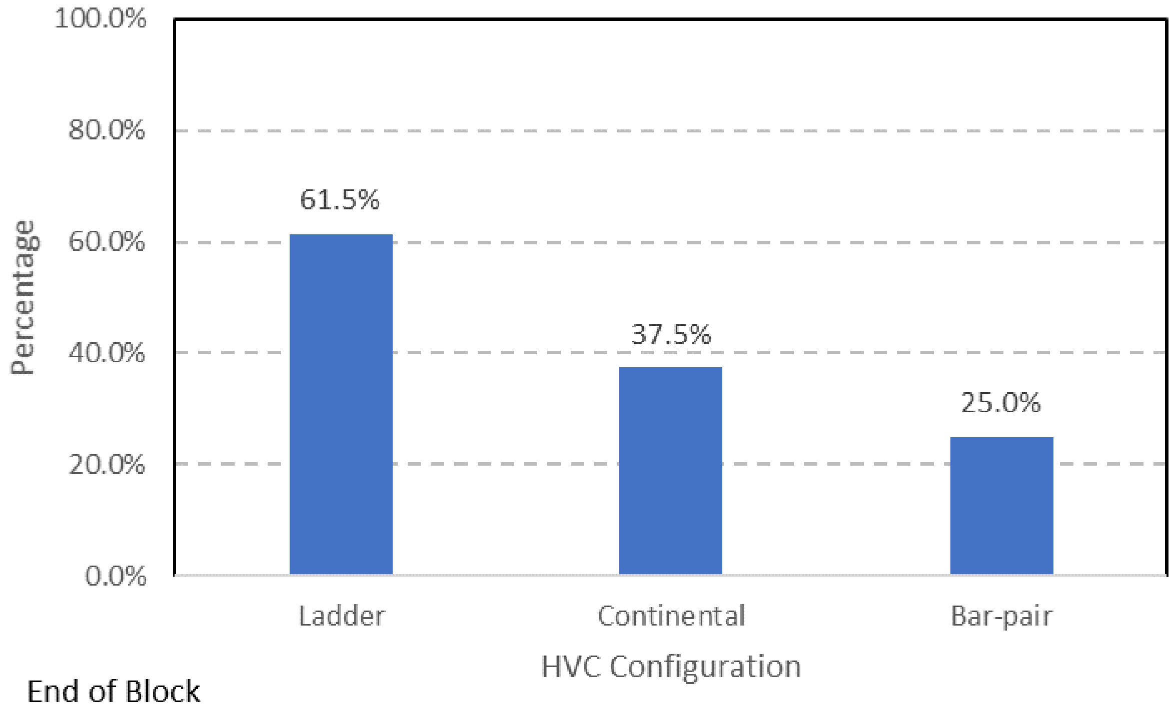

Figure 40. Percentage of Drivers with increased external scanning: end-of-block.

HVC Traversals with Pedestrians

The above analysis was carried out on those traversals where no pedestrians were present at the HVC. This analysis was repeated on those traversals where pedestrians were present. The sample size for this analysis was 74 traversals. The breakdown of these traversals by HVC configuration and location is provided in Table 19.

Table 19. Breakdown of traversals with pedestrians by HVC configuration and location.

Pedestrians Present	Configuration	Location	Traversals
Yes	Ladder	End-of-Block	36
Yes	Ladder	Mid-Block	0
Yes	Continental	End-of-Block	21
Yes	Continental	Mid-Block	2
Yes	Bar-Pair	End-of-Block	10
Yes	Bar-Pair	Mid-Block	5
		Total	74

As described earlier, the number of available traversals with pedestrians at mid-block locations was small, therefore the analysis was limited to the end-of-block traversals. The process used to develop this data is the same as described above, with the change from the pre-install baseline condition calculated for the available traversals. Table 20 illustrates the results; when pedestrians are present the change in driver eye glance scanning is less than with no pedestrians present.

Table 20. Average percent change in eye glance direction by configuration.

Configuration	Location	Exterior (Forward)	Interior	Exterior (L&R Side)	Other
Ladder	End-of-Block	-0.9%	-0.5%	3.0%	-1.3%
Continental	End-of-Block	-7.6%	0.5%	0.5%	6.4%
Bar-Pair	End-of-Block	8.3%	-1.1%	-7.3%	0.0%

The percentage of drivers who show an increase in external scanning is approximately the same for the ladder configuration; with 61.5% when pedestrians are not present vs. 57.1% when pedestrians are present. The continental configuration shows an increase in the number of drivers increasing their external scanning behavior. The small number of participants for the bar-pair configuration may have resulted in the 0.0% value shown in Figure 41.

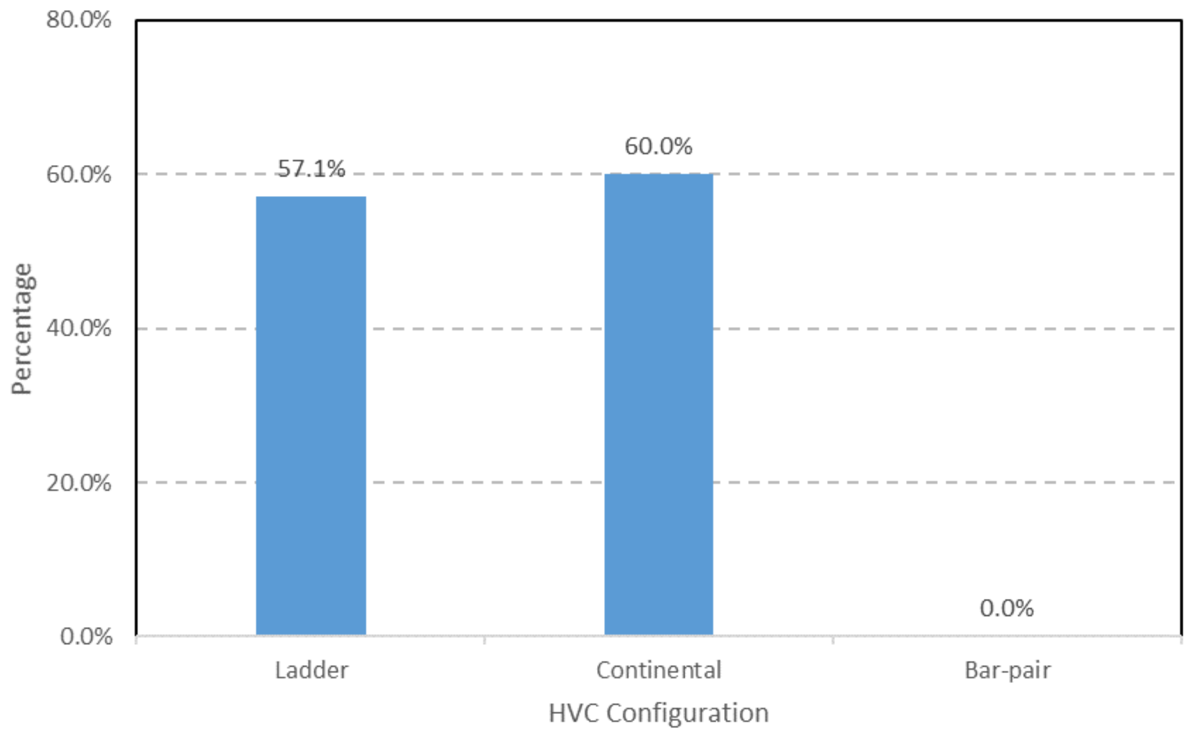

Figure 41. Percentage of driver's showing increase in external (side) scanning.

Merging "No Pedestrians" and "With Pedestrians" Data

Combining the results from the analysis of the "No Pedestrians" and the "With Pedestrians" scenarios can provide information regarding how these various HVC Configurations can affect drivers' behavior. The combining of these two data sets can provide a more complete estimate of the effect of the installation of HVCs on driver behavior. The results of this process are shown in Figure 42. The data indicates that the ladder configuration has the greatest effect on driver eye scanning behavior, followed by the continental and then bar-pair configurations.

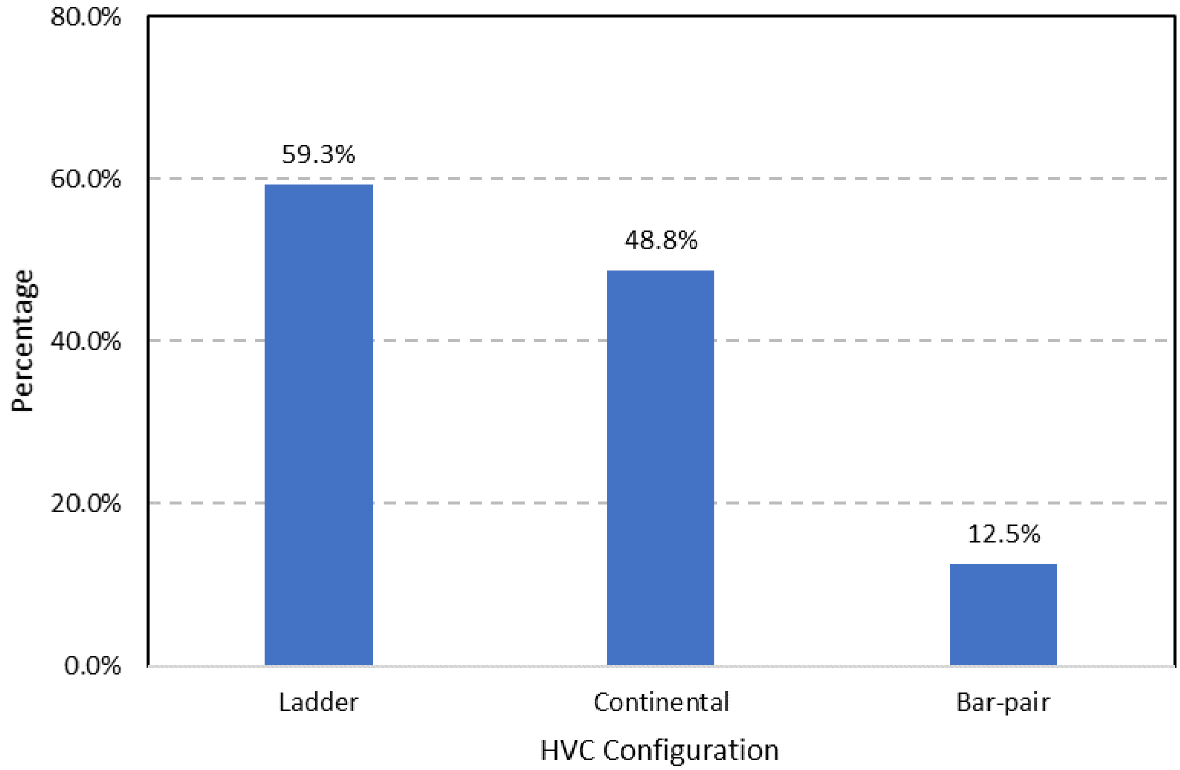

Figure 42. Drivers showing increase in external scanning with and without pedestrians.

6. CONCLUSION

This study provides an evaluation of the effectiveness of HVCs in terms of improving pedestrian safety at uncontrolled locations using SHRP2 NDS data. The NDS data offer a unique opportunity to analyze observed driving behavior over a period of time. Eighteen uncontrolled crosswalk locations from the NDS test sites were selected for analysis. The locations had HVCs installed during the NDS data collection period, allowing for a before and after analysis. A representative random sample of 3,480 trips by 183 participants was selected for the study. For each trip, forward-facing video, time-series data, and basic driver and vehicle information was processed and compiled into a single dataset for the analysis.

The results of this study are especially timely for New York State. NYSDOT, in conjunction with safety partners from the Governor's Traffic Safety Committee, NYSDOH, FHWA, Metropolitan Planning Organizations, and local transportation agencies, have recently implemented a Pedestrian Safety Action Plan (PSAP). The Strategies in the plan include enforcement, education and engineering actions with the goal to significantly reduce pedestrian crashes in New York. The package of engineering measures outlined in the PSAP includes systemic treatments at locations that contain risk factors associated with pedestrian crashes. Over a five-year period (2016-2020), NYSDOT plans to study and install HVC markings at a number of existing uncontrolled crosswalks and at signalized intersections for state-maintained facilities. This research is intended to justify the use of HVC, as well as help NYSDOT utilize the most effective design for these crossings for both the markings as well as other elements such as warning sign placement. Furthermore, many of the pedestrian crashes in NYS occur off-system, on roadways maintained by local jurisdictions. The results of this research will assist NYSDOT in demonstrating to local agencies the benefits of using HVC markings.

The statistical analysis employed in this study aimed to identify the in-depth effects of HVCs on modifying driving behavior in terms of improving pedestrian safety. To comprehensively evaluate the effectiveness of HVCs, different HVC positions (mid-block vs. end-of-block) and different HVC marking designs (continental, bar-pair, and ladder.) were considered in the analysis. As no pedestrian-vehicle crashes or conflicts were identified from the forward-facing videos and time-series information of the SHRP2 NDS data, crash surrogate measures were employed to identify and analyze modifications in driving behavior at or near the HVCs.

Due to the high-dimensional nature of the NDS data, the presence of panel effects arising from multiple traversals undertaken by each participant, the effect of unobserved characteristics, as well as their unobserved correlations, constituted possible misspecification issues. To account for these issues the correlated grouped random parameters estimation framework was employed. In this context, several correlated grouped random parameters linear regression models were estimated for speed, acceleration, and TPA at the benchmark and HVC locations, as well as for the difference between the benchmark and HVC locations. To investigate the likelihood of speed, acceleration, TPA, and brake application decrease between the benchmark and HVC, a correlated grouped random parameters discrete outcome modeling framework was employed, which also accounts for the aforementioned misspecification issues.

SUMMARY

Overall, the results of the analysis suggest that the presence of HVCs reduce speed, acceleration, and TPA at the benchmark and HVC locations. HVC presence is also found to reduce the speed, acceleration, and TPA difference between the benchmark and HVC locations. The simultaneous presence of HVC and pedestrian sign is found to have a mixed effect in acceleration at the benchmark and HVC locations and to decrease the difference in acceleration between the benchmark and HVC locations. Apart from the presence of HVC, the HVC type (e.g., ladder, bar-pair) and in-block location (mid-block, end-of-block) were also found to affect the vehicles' speed, acceleration, TPA, and brake application.

Ladder type end-of-block located HVCs were found to have a mixed effect on the speed at the benchmark and HVC location although a reduction at either point was found to occur in 97 percent of all traversals. End-of-block located HVCs indicated mixed effects on TPA at the benchmark location, while bar-pair type end-of-block located HVCs increased the TPA at the HVC location, the acceleration at the benchmark and the HVC locations, and the acceleration difference between the benchmark and HVC locations. Bar-pair type HVCs were found to have a decreasing effect on the likelihood of acceleration decrease, whereas ladder type HVCs were found to decrease the likelihood of brake application. End-of-block located HVCs were found to increase the overall likelihood of both acceleration decrease and TPA decrease.

Apart from the HVC-related characteristics, trip and traffic characteristics, such as the speed limit in the area where a traversal was undertaken, and the presence of a lead or obstructing vehicle, were found to be statistically significant in most of the estimated models. The presence of a lead vehicle and the absence of parked vehicles near the HVC location were also found to decrease the speed difference between the benchmark and HVC location.

Finally, various driver-specific characteristics were also found to be statistically significant in modifying driving behavior at HVC locations. Younger drivers were found to be more likely to increase acceleration at the benchmark location, while older drivers were found to show mixed effects on traversal speed at the benchmark location. Participants' traversal frequency was also found to play a significant role in most of the estimated models. A summary of the notable factors having a statistically significant impact on the safety surrogates can be found below.

Vehicle speed

Several variables were found to have statistically significant effects on the speed observed at HVC locations, notably:

- Presence of HVC and pedestrian signs led to a reduced speed in 53% of the traversals
- Presence of HVC without signs was found to have a speed reduction in 46% of the traversals
- Ladder configuration of end-of-block located HVCs were found to have a speed reduction in 97% of the traversals
- Drivers over the age of 65 years had a lower speed *difference* between the benchmark and HVC locations for 75% of traversals
- Presence of pedestrians understandably were found to reduce the difference in vehicle speed between the benchmark and HVC locations

Acceleration
Several variables were found to have statistically significant effects on acceleration observed at HVC locations, notably:

- The simultaneous presence of a HVC and pedestrian signs were found to have a reduction of acceleration in 63% of traversals at the benchmark and in 49% of the traversals at the HVC
- Bar-pair End-of-Block HVCs were found to have increased instances of acceleration
- Presence of a lead vehicle was found to reduce acceleration at the benchmark location
- Presence of a lead vehicle and an obstructed view of the HVC increased acceleration
- Drivers above 50 years of age were associated with lower acceleration at the HVC location
- Drivers younger than 30 were associated with greater acceleration at the benchmark location
- Drivers who traversed a HVC more than 60 times were associated with lower acceleration at the benchmark location and increased acceleration at the HVC location

Throttle Pedal Actuation
Several variables were found to have statistically significant effects on TPA at HVC locations, notably:

- Presence of HVC with pedestrian signs was found to reduce TPA in 90% of the traversals
- End-of-Block located HVCs were observed to increase TPA at the benchmark location for almost all traversals
- Bar-pair End-of-Block located HVC was also found to increase TPA at the HVC location
- The presence of a lead vehicle and at least one vehicle obstructing HVC visibility was found to reduce TPA at the benchmark location
- Traversals made during the month that HVC was installed were found to reduce the difference in TPA between the benchmark and HVC locations
- TPA at benchmarks decreased in 53% of traversals by drivers less than 25 years old
- A decrease in TPA at the HVC location was also found for drivers older than 50 years old

Brake application
Several variables were found to have statistically significant effects on brake application at HVC locations, notably:

- The simultaneous presence of HVC and pedestrian sign was found to increase the brake application likelihood by 19%
- Ladder HVCs were observed to decrease the likelihood of brake application
- Pedestrian presence increased the likelihood of brake application for 48% of the traversals
- Older drivers were found to be less likely to brake near the HVC in 78% of the traversals
- Younger drivers (less than 25 years old) were more likely to brake near HVC locations

Eye glance behavior
A casual examination of eye glance direction and scanning patterns of drivers found the following to be of significance:

- Side scanning increased at the same location for the same drivers after HVCs were installed
- The presence of pedestrians at HVCs decreases side-scanning behavior
- Ladder configurations, more than other types, were found to increase external scanning patterns in 61% of drivers at end-of-block locations

RECOMMENDATIONS FOR IMPLEMENTATION

This research provides information about driver behavior and characteristics that can be used to improve and optimize HVC implementations. The use of the SHRP2 NDS data provided the opportunity to examine driver behavior in response to HVCs in ways that have not been possible in the past. The evaluation of HVC implementation in the past primarily depended upon the identification of the number of crashes before and after the installation of the HVC, or the comparison of observed crash rates at comparable sites at where HVC were not installed; roadside observational studies of driver compliance; number of citations issued before and after the implementation; and surveys to identify any self-reported changes in driver behaviors. These strategies provide a measure of the effectiveness of the HVC to change aggregate driver behavior but fall short in evaluating the effects of the HVC on different groups of drivers. SHRP2 NDS data provided a unique opportunity to have access to detailed driver demographics over a period of time. The use of the SHRP2 NDS data allowed for the examination of other driving behaviors including throttle and brake pedal actuation from the time-series data and eye glance and scanning patterns that were only observable through the interior video data in the SHRP2 NDS equipped vehicles.

The information provided in this study can help aid in the more efficient use and design of HVCs. This systematic use of HVCs has the potential to reduce speed and acceleration, and increase scanning near and at crosswalks. The real-world benefits of this will be the reduction of vehicle-pedestrian conflicts, vehicle-pedestrian crashes, fatalities, injuries and the economic costs associated with them. This study provides a unique perspective, based on SHRP2 NDS data, on which driver behaviors are most affected by HVC implementation as well as the demographics and characteristics of those associated drivers. Four main recommendations can be drawn from this study. First, the placement of pedestrian crossing signs in advance of the HVC was found to significantly improve the safety surrogates associated with the traversals through that location. Second, ladder type configurations of pavement markings were shown to be most effective in improving the safety surrogates associated with the traversals through those HVCs as well as increasing external scanning patterns. Third, directing specific education and awareness programs towards *young* drivers (less than 25) and *older* drivers (greater than 65) through public service announcements, social media outlets, and other means could prove to be successful in enhancing the effectiveness of HVC implementations.

A final recommendation for the transportation safety community, in general, is to design the evaluation of HVC implementations into future naturalistic driving data collection programs. A limitation of this study was finding HVC locations that were installed in the SHRP2 NDS test sites during the data collection period. This proved to be a tedious and time-consuming process that ended up limiting the sites available for analysis and in-turn the total number of traversals. Utilizing complete information collected by traditional roadside equipment, in-vehicle sensors, associated driver demographics and characteristics, and crash and citation records could potentially provide more complete analysis of the overall effectiveness of all types and implementations of HVCs. Additionally, the methodological framework of this study can serve as a basis for other before and after studies involving SHRP2 NDS data (e.g., investigating the effectiveness of HVC at controlled or more complex intersections, the resulting changes to accessibility, mobility, or walking patterns).

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