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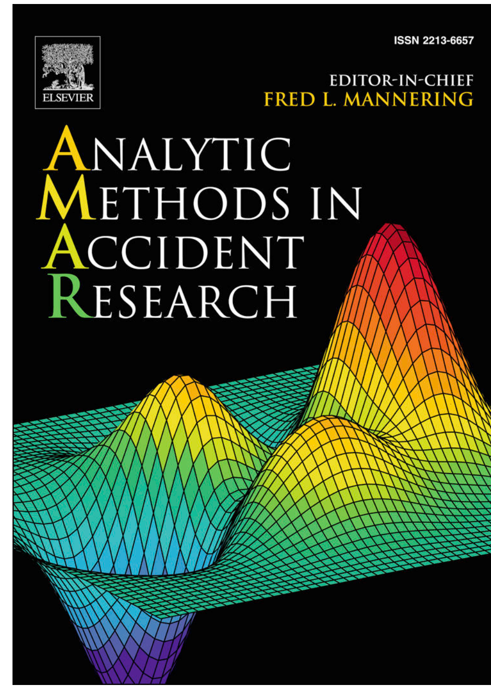

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ABSTRACT

In this study, the effectiveness of High-Visibility Crosswalks (HVCs) in improving pedestrian safety at urban settings is assessed using SHRP2 (Second Strategic Highway Research Program) Naturalistic Driving Study (NDS) data. Various HVCs located at different positions on the roadway segment (mid-block *vs* end-of-block) and featuring different HVC marking designs (continental, bar-pair, and ladder) were selected for the assessment. As no pedestrian-vehicle crashes or conflicts were identified from the forward-facing videos and time series information of the SHRP2 Naturalistic Driving Study data, crash surrogate measures (i.e., speed; acceleration; throttle pedal actuation; and brake application) were employed to identify and analyze modifications in driving behavior at or near the HVCs.

The surrogate measures were statistically modeled using a correlated grouped random parameters estimation framework. This can account for panel effects arising from multiple traversals undertaken by each participant, for the effect of unobserved characteristics, as well as for their unobserved correlations, which constitute possible misspecification issues of statistical modeling. The results of the analysis showed that the presence of HVC modifies driving behavior, thus reducing the risk of motor vehicle – pedestrian conflicts. Apart from the presence of HVC, the HVC type (ladder, continental or bar-pair), the HVC location (mid-block or end-of-block) and various driver, roadway and trip characteristics were found to affect the vehicle speed, acceleration, throttle pedal actuation, and brake application.

Keywords: Pedestrian crosswalks; Driving behavior; Pedestrian safety; Correlated grouped random parameters; Naturalistic Driving Study.

INTRODUCTION

Pedestrians have been long identified as one of the most vulnerable groups of roadway users. Due to their significant physical exposure to roadway hazards, pedestrian-involved accidents are more likely to result in serious or fatal injuries compared to any other motorist-involved accidents. Interestingly, in 2016, a pedestrian casualty was observed approximately every 1.5 hours in road accidents in the United States (NHTSA, 2016). Previous studies of pedestrian-involved crashes and conflicts (Zeeger et.al, 2005; Papadimitriou et.al., 2009; Mitman et.al., 2010; Paleti et al., 2010; Aziz et.al., 2013; Haleem et.al., 2015; Behnood and Mannering, 2016; Alhajyaseen et.al., 2017; Xin et al, 2017; Stapleton et al., 2017; Wang et al, 2019) have shown that drivers' failure to yield to pedestrians constitutes a major contributing factor of pedestrian-vehicle crashes. Overall, the level of pedestrian safety has been found to be determined by vehicles' speed and driver's reaction time, especially in urban settings (Tefft, 2013; Jurecki and Stańczyk, 2014; Yasmin et al., 2014).

High Visibility Crosswalks (HVC) constitute one of the pedestrian safety countermeasures aiming to increase the upstream visibility of the crosswalks to the drivers as well as drivers' consciousness about the possible presence of pedestrians. HVCs consist of pavement marking patterns (e.g., transverse lines, solid markings, ladder or continental markings, and so on) that can be easily detected from longer distances. Despite their low cost and ease of installation, the pedestrian hazards that are tackled by this type of crosswalk pavement markings have not been fully outlined to date. Previous studies were mostly devoted to the effectiveness of various types of HVCs in eliminating motor vehicles – pedestrian conflicts using either observed field data or data from driving simulation experiments (Gómez et.al, 2013; Samuel et.al., 2013). However, these studies did not capture drivers' behavioral responses to the presence of crosswalks, or they did not control for the interaction of such responses with the prevailing weather, roadway, vehicle or traffic conditions. To account for the effect of the aforementioned conditions in the context of a comprehensive safety appraisal of HVCs, the naturalistic driving study (NDS) data from the second Strategic Highway Research Program (SHRP2) are used. The latter can provide a wide spectrum of drivers' behavioral nuances, along with high-dimensional vehicle and road environment information (Campbell, 2012; Hamzeie et al., 2017). For the assessment of HVCs, safety surrogates (i.e., speed, acceleration, throttle pedal actuation, and brake pedal state) are employed (Hadi and Thakkar, 2003; Guo et.al, 2010; Tarko et.al, 2011; Mohammed and Saunier, 2013; Wang and Stamatiadis, 2014; Vedagiri and Killi, 2015; Dougald, 2016; Sarwar et al., 2017b; Pantangi et al., 2020) as no pedestrian-vehicle crashes or conflict incidents were identified in the vicinity of crosswalks during the study period.

This study builds upon a previous, preliminary analysis of the effectiveness of HVCs at uncontrolled locations carried out by Sarwar et.al. (2017a); in that study, three ladder-style high visibility crosswalks at uncontrolled locations in the Erie County, NY were investigated in terms of their effectiveness to decrease the occurrence and intensity of crash surrogates. In this work, we provide a more comprehensive assessment of the HVC effectiveness by focusing on various HVCs across multiple States, on different in-block locations, and on different crosswalk configuration types. For this purpose, SHRP2 NDS data corresponding to an extensive set of HVC traversals were obtained and statistically analyzed to understand whether and how the presence of HVCs amends drivers' behavioral patterns.

METHODOLOGICAL APPROACH

To identify variations in the effect of different HVC configurations on driving behavior, three types of HVCs are investigated: Ladder, Continental, and Bar-Pair. As the location of the crosswalks may affect drivers' visibility and perceptions (Broek, 2011; Avinash et.al, 2019), crosswalks installed either in the middle of block, or at the end of the block were identified and included in the analysis. These uncontrolled HVC sites were chosen based on availability of at least 350 traversals through the site, with approximately half of them occurring prior to HVC installation and the remaining half occurring after the HVC installation. Table 1 provides the HVC sites that were used in this study along with their type and location characteristics.

Due to the absence of observable crash data, the effectiveness of HVCs on pedestrian safety was measured using surrogate measures, namely: vehicle acceleration and speed, brake pedal state, and throttle pedal actuation (TPA) during trips including traversals across the HVCs. The variations of the selected surrogate measures throughout the HVC traversals were captured through the SHRP2 NDS data. For the purposes of this study, we analyzed two major components of the SHRP2 NDS data: (i) the forward-facing video of each individual trip; and (ii) the time series data corresponding to each individual trip.

Table 1. High visibility crosswalk (HVC) sites and their characteristics

HVC number	Naturalistic driving study (NDS) site	Location	HVC type	Within-block location	Speed limit (mph)
1	New York (NY)	Elm / Eagle	Ladder	End-of-Block	30
2	New York (NY)	Oak / Eagle	Ladder	End-of-Block	30
3	New York (NY)	Union Rd	Ladder	End-of-Block	40
4	Florida (FL)	S. Village Dr.	Ladder	Mid-Block	40
5	Florida (FL)	North 50th St	Ladder	Mid-Block	35
6	Indiana (IN)	N. Rogers St	Continental	End-of-Block	30
7	North Caroline (NC)	Pullen Rd.	Continental	End-of-Block	30
8	Pennsylvania (PA)	Waupelani Drive	Continental	End-of-Block	25
9	Pennsylvania (PA)	E. Pollack Rd.	Continental	Mid-Block	25
10	Indiana (IN)	Hillsborough St	Continental	Mid-Block	25
11	Washington (WA)	N. 50th St	Bar-Pair	End of Block	25
12	Washington (WA)	S. McClellan St	Bar-Pair	End-of-Block	25
13	Washington (WA)	University Way NE	Bar-Pair	End-of-Block	30
14	Washington (WA)	SW 320th St	Bar-Pair	Mid-Block	30
15	Washington (WA)	SW 348th St	Bar-Pair	Mid-Block	25
16	Washington (WA)	SW 336 St	Bar-Pair	Mid-Block	40
17	New York (NY)	Hamburg	Ladder	Mid-Block	35

Video processing was conducted for recordings of trips undertaken by the SHRP2 participants in the HVC sites that were identified throughout the period considered for the study. Before the analysis of the video data, an upstream benchmark point was identified for each HVC location and direction of traversal. The basic criterion in determining the benchmark was the identification of an appropriate distance from the HVC, where the drivers were expected to detect the HVC and adjust their driving behavior. To that end, the benchmark location was set ro be 50 meters upstream the crosswalk for all sites. To spatially determine the benchmark points, the optimal visibility of the HVCs (as identified from the videos) and the distance of easily identifiable landmarks (e.g., traffic lights, signposts and so on) from the HVCs were also considered. Upon a systematic review of the videos, the time points when the vehicle crossed the benchmark and HVC locations were identified. Additional information was also extracted from the videos, such as upstream pedestrian sign presence, pedestrian presence, presence of preceding and parked vehicles, the level of obstructed visibility of the HVC, windshield condition and wipers' usage, weather conditions, pavement surface conditions, and ambient lighting conditions. Using the time stamps on the videos, the time series data were linked to the trip-specific information extracted from the videos. The on-board vehicle equipment recorded information at 60 Hz intervals; however, a few values of the time-varying surrogates corresponding to the benchmark and crosswalk locations were missing from the time series data. Thus, using the time stamps from the videos and appropriate values from the time series data, the missing values were estimated through linear interpolation. Overall, the data processing was conducted in a fashion similar to that described in Sarwar et.al. (2017a).

Upon reviewing the forward-facing videos and time series data, 3,480 traversals were eventually 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 in 269 traversals; the remaining 1,192 traversals were condcucted before the installation of the HVCs. While pedestrian presence was identified for 333 traversals, pedestrians were also observed crossing the roads adjacent to the HVC location in 77 traversals.

The time series and video processing data were eventually coupled with driver- and vehicle-specific data, which constitute an integral part of the SHRP2 NDS framework. These data were derived from several questionnaires that were filled out by the participants of the SHRP2 NDS program. These include demographic characteristics of the participants (age, gender, etc.) and vehicle-specific information (vehicle type, vehicle age, etc.).

To statistically identify the effect of the HVC presence on the vehicle speed and acceleration, and on the throttle pedal actuation, correlated grouped random parameters linear regression models were estimated, at benchmark and HVC locations. Using the same approach, a set of models was also developed to analyze the differences in vehicle speed, acceleration, and throttle pedal actuation, between the benchmark and HVC locations. The standard linear regression model is defined as (Greene, 2012; Sarwar et.al., 2017a; Pantangi et.al., 2019; Washington et al., 2020):

$$\mathrm{y_i} = \alpha + \boldsymbol{\beta}_\mathrm{i}\mathbf{X}_\mathrm{i} + \varepsilon_\mathrm{i} \tag{1}$$

where, y is the crash surrogate serving as the dependent variable, α denotes the constant term, **X** is a vector of independent variables (e.g., HVC, roadway/roadside and weather conditions, and driver/vehicle/trip characteristics) for driver i (i = 1, 2, …, n), **β** denotes a vector of estimable parameters relating to **X**, and ε is a disturbance term.

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 statistically investigated through the estimation of discrete binary outcome models. The linear function A_{ki} that determines the occurrence of speed, acceleration, and TPA decrease, or brake application during the traversal k of the driver i, is defined as (Washington et.al., 2020):

$$A_{ki} = \boldsymbol{\beta}_k \mathbf{X}_{ki} + \varepsilon_{ki} \qquad (2)$$

where, $\mathbf{X}$ is a vector of explanatory variables, $\boldsymbol{\beta}$ denotes a vector of estimable parameters corresponding to $\mathbf{X}$, and ε is a disturbance term. It should be noted that the binary dependent variables were defined as follows: 1 for the occurrence of the crash surrogate, 0 otherwise.

The binary logit framework was leveraged to statistically analyze the likelihood of occurrence of speed, acceleration, and TPA decrease between the benchmark and HVC locations. For the occurrence of brake pedal application, the binary probit framework was adopted. The binary outcome probability in the logit and probit frameworks are defined respectively as (Washington et.al., 2020):

$$P_k(i) = \frac{e^{(\boldsymbol{\beta}_k \mathbf{X}_{ki})}}{1 + e^{(\boldsymbol{\beta}_k \mathbf{X}_{ki})}} \qquad (3)$$

$$P_k(i) = P(\boldsymbol{\beta}_1 \mathbf{X}_{1k} - \boldsymbol{\beta}_2 X_{2k} \geq \boldsymbol{\varepsilon}_{2k} - \boldsymbol{\varepsilon}_{1k}) \qquad (4)$$

To account for the effect of unobserved factors (i.e., unobserved heterogeneity) on the crash surrogate measures, random parameters were incorporated in model estimation (Anastasopoulos and Mannering, 2009, 2016; Behnood and Mannering, 2017; Fountas et.al., 2018a, 2018b; Eker et al., 2019, 2020a, 2020b; Ahmed et al., 2020, 2021). Since the majority of SHRP2 drivers carried out multiple trips across the HVC locations, the set of HVC traversals corresponding to each specific participant may share systematic unobserved variations stemming from driver-specific traits that are not captured by the SHRP2 dataset. These unobserved variations typically result in unbalanced panel effects, which may be evident among the driver-specific subsets of the traversal population. To control for panel effects, grouped random parameters are estimated. Specifically, a separate coefficient (**β**) is estimated for each specific driver, with this coefficient representing all the traversals made by the specific driver. Hence, the model parameters vary across the drivers, as (Wu et.al., 2013; Fountas et.al., 2019):

$$\boldsymbol{\beta}_i = \beta + \boldsymbol{\Gamma}\,\mu_i \tag{5}$$

where, $\boldsymbol{\beta}_\mathbf{i}$ is the vector of random parameters corresponding to driver i, **β** denotes the vector with the means of the random parameters, μ_i is a randomly distributed error term (with mean equal to 0 and variance equal to σ^2), and Γ is a triangular Cholesky matrix that accounts for cross-parameter correlations in the distribution of $\boldsymbol{\beta}_i$. To identify possible correlations among the random parameters, the below diagonal elements of the Γ matrix are allowed to be non-zero. The identification of correlated random parameters constitutes an important feature of the employed approach, as it can unveil possible interdependencies between the sources of unobserved factors (e.g., human behavior, environmental conditions), which cannot be captured by the traditional random parameters approach (Coruh et al., 2015; Fountas et.al., 2018a; Fountas et al., 2018b). To incorporate random parameters in the estimation process, the probability functions are adjusted accordingly. For example, the binary logit probability takes the following form (Washington et al., 2020):

$$P_k(i) = \int \frac{e^{(\boldsymbol{\beta}_k \mathbf{X}_{ki})}}{1+e^{(\boldsymbol{\beta}_k \mathbf{X}_{ki})}} f\left(\boldsymbol{\beta}\middle|\boldsymbol{\varphi}\right) d\boldsymbol{\beta} \tag{6}$$

Several distributional forms for the random parameters were tested during the model estimation process (e.g., normal, log-normal, triangular, uniform, Weibull). Herein, the normal distribution was found to provide the best statistical fit for all the models, and was used for the final model specifications.

To estimate the statistical models, a simulated maximum likelihood estimation (SMLE) technique was used. To draw the sample values of the $\boldsymbol{\beta}$ for the random parameters from their predefined distribution, and to increase the simulation efficiency, Halton draws were used at the individual driver level (Halton, 1960). Upon extensive testing, the models were estimated using 1,200 Halton draws, which were found to yield stable parameter estimates.

For the discrete outcome models, we also computed the elasticities of the explanatory variables in order to identify how one-unit change in the value of a continuous variable impacts upon the likelihood related to the dependent variable (Fountas and Anastasopoulos, 2017). In cases where the explanatory factors are indicator variables, we calculated pseudo-elasticities, which show how much the dependent variable changes when the value of the indicator variable shifts from zero to one.

MODEL ESTIMATION RESULTS

Tables 2 and 3 present the descriptive statistics and estimation results, respectively, of the correlated grouped random parameters linear regression models for vehicle speed (at benchmark and HVC locations) and for speed difference (between the benchmark and HVC locations). Table 4 provides the diagonal and off-diagonal elements of the Γ matrix as well as the correlation matrices for the random parameters included in the linear regression models. Note that the correlation refers to the possible association among the unobserved factors captured by the pair of random parameters, and not to the linear association between the two parameters. Various HVC-

, driver- and trip-specific characteristics were found to influence vehicle speed at benchmark and HVC locations, as well as the difference in speed between the two locations.

A number of HVC-related variables were found to affect the speed observed at benchmark and HVC locations, and the speed difference between these 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; specifically, the speed reduces for 53% of the traversals and increases for the rest 47% of 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 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) across end-of-block HVCs of ladder type.

Among trip-specific characteristics, lane position of the vehicle (if the vehicle was traveling in the centerlane of a multilane road) was found to have a statistically significant effect on speed of the vehicle both at benchmark and HVC. In fact, for about 88% of traversals, speed at HVC was observed to decrease for vehicles travelling in the centerlane of a multilane road. Speed at benchmark was observed to reduce for vehicles travelling in the centerlane.

Among the driver-specific characteristics, age and gender were found to have a statistically significant effect on the speed measures. Table 3 shows that drivers older than 65 years were associated with lower speed difference between the benchmark and HVC locations, for 75.60% of the traversals. Among the vehicle-specific characteristics, vehicle type (passenger car) was found to have statistically significant, yet mixed effect on the speed measures. For 58.60% of the traversals, passenger cars were found to reduce the speed difference between the benchmark and HVC. The presence of a lead vehicle and the presence of pedestrians near the HVC location were also identified as determinants of vehicle speed. The pedestrian presence was found to reduce the difference in vehicle speed between the benchmark and HVC locations. Presence of one or more vehicles obstructing the view of the croasswalk during a traversal was found to reduce speed at HVC. Traversals that occurred in snowy or rainy weather conditions were found to decrease the speed at the HVC location. This is an interesting finding, as it may capture nuances of risk-compensating behavior of drivers under inclement weather conditions (Fountas et al., 2019; Fountas at al., 2020). Furthermore, speed difference between the benchmark and HVC was observed to increase if the speed limit of the road was below 30 mi/h.

Focusing on the unobserved effects captured by the correlated random parameters, Table 4 shows that, among others, the random parameters produced by the gender indicator and the driver's age indicator have consistent implications on the models of vehicle speed (at benchmark) and speed difference. Specifically, the correlation coefficient is positive in both cases showing that the unobserved characteristics captured by the indicators of male drivers and older drivers have homogeneous effects on the dependent variables of the models (i.e., vehicle speed at benchmark and speed difference). This finding possible picks up the impact of non-observable socio-demographic attributes on driving behavior (Fountas et al., 2019).

Table 2. Descriptive statistics for vehicle speed (linear regression models)

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	1
HVC indicator (1 if HVC is present, 0 otherwise) [Speed at HVC]	0.578	–	0	1
HVC indicator (1 if HVC is present, 0 otherwise) [Speed Difference]	0.563	–	0	1
HVC position indicator (1 if end-of-block located HVC, 0 otherwise)	0.643	–	0	1
HVC type and position indicator (1 if ladder type end-of-block located HVC, 0 otherwise) [Speed at HVC]	0.336	–	0	1
HVC type and position indicator (1 if ladder type end-of-block located HVC, 0 otherwise) [Speed Difference]	0.406	–	0	1
Pedestrian presence indicator (1 if pedestrian is present near the HVC, 0 otherwise)	0.096	–	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	1
Lane position indicator (1 if vehicle is in the center lane of a multilane road, 0 otherwise) [Speed at HVC]	0.425	–	0	1
Lead vehicle indicator (1 if lead vehicle is present, 0 otherwise) [Speed at Benchmark]	0.499	–	0	1
Lead vehicle indicator (1 if lead vehicle is present, 0 otherwise) [Speed at HVC]	0.499	–	0	1
Lead vehicle indicator (1 if lead vehicle is present, 0 otherwise) [Speed difference]	0.523	–	0	1
Parked vehicle indicator (1 if there is no parked vehicle near the crosswalk, 0 otherwise)	0.619	–	0	1
Parked vehicle indicator (1 if there is no parked vehicle near the crosswalk, 0 otherwise) [Speed difference]	0.621	–	0	1
Obstructing vehicle indicator (1 if there is 1 or more vehicles obstructing the view to the crosswalk, 0 otherwise)	0.664	–	0	1
Vehicle type indicator (1 if passenger car, 0 otherwise)	0.739	–	0	1
Speed limit indicator (1 if the speed limit is below 30mph, 0 otherwise)	0.588	–	0	1
Participant Gender indicator (1 if driver is male, 0 otherwise) [Speed at HVC]	0.487	–	0	1
Participant Gender indicator (1 if driver is male, 0 otherwise) [Speed difference]	0.422	–	0	1

Variable	Mean	Standard deviation	Minimum	Maximum
Participant's age indicator (1 if greater than 50 years old, 0 otherwise)	0.374	−	0	1
Participant's age indicator (1 if greater than 60 years old, 0 otherwise)	0.177	−	0	1
Participant's age indicator (1 if greater than 65 years old, 0 otherwise)	0.141	−	0	1
Weather indicator (1 if weather is rainy or snowy, 0 otherwise)	0.119	−	0	1

Table 3. Correlated grouped random parameters linear regression models for vehicle speeds (at benchmark and at HVC locations), and for speed difference

	Speed at benchmark		Speed at HVC		Speed difference	
Variable	**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 density function	*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 density function	–	–	*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 density function	–	–	*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 density function	–	–	*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 density function	–	–	*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 density function	*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 density function	*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 density function	–	–	–	–	*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 density function	–	–	–	–	*2.084*	*40.340*
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

	Speed at benchmark		Speed at HVC		Speed difference	
Variable	**Coefficient**	**t-stat**	**Coefficient**	**t-stat**	**Coefficient**	**t-stat**
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	
Mean Absolute Deviation (MAD)	5.694		5.359		3.023	
SSE (Sum of Squared Errors)	192896.651		169146.323		58642.375	
MSE (Mean Squared Errors)	59.098		51.790		21.760	
RMSE (Root Mean Squared Errors)	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%

Table 4. Diagonal and off-diagonal elements of the Γ matrix [t-stats in brackets], and correlation coefficients (in parentheses) for the correlated random parameters in the models for vehicle speeds

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 located HVC, 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)

Tables 5 and 6 present the descriptive statistics and estimation results, respectively, corresponding to 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. The elements of the Γ matrix along with the correlation coefficients for the random parameters of the acceleration models are provided in Table 7.

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 48.80% of the traversals, as shown in Table 6. Apart from the presence of HVC, the type (bar-pair) and location (end-of-block) of HVC were found to have statistically significant effect in all three models for acceleration. Presence of bar-pair HVC at the end of the block was found to increase acceleration at the HVC and benchmark locations and to expand the acceleration difference between the benchmark and HVC locations. Presence of HVC when considered in conjunction with average speed of the traversal was observed to have a mixed effect on the difference in acceleration between benchmark and HVC (increase in about 51% of the traversals).

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.

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 (Fountas et al., 2020). 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 that is typically observed during the morning commute.

Regarding the effect of driver-specific characteristics, 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. Participants who undertook more than 60 traversals were associated with lower acceleration at the benchmark location. This can possibly be attributed to their expectation for pedestrian crossing near the location, due to their familiarity with 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.

Presence of more than one parked vehiccles near the crosswalk had a mixed effect on the acceleration of the participant's vehicle at benchamrk, as it reduces acceleration for about 61% of the traversals. Vehicle age (older vehicles) was also associated with a reduction in acceleration at benchmark as well as in the difference between acceleration at benchmark and HVC. For about 97% of traversals, acceleration of older vehicles was observed to increase at HVC.

Focusing on the correlated random parameters included in the acceleration models, Table 7 demonstrates the interelationship of the unobserved effects captured by the HVC and pedestrian sign indicator and the trip frequency indicator in the model for acceleration at benchmark. Both variables result in random parameters that are positively correlated; the latter implies the homogeneous effect of the unobserved characteristics associated with these two variables. This result is intuitive, as high trip frequency in conjunction with observable elements of traffic calming (e.g., HVC and signage) may interact with the behavioral implications of familiarity and memory in terms of speed-related choices (Colonna et al., 2016). The random parameters generated by the HVC and pedestrian sign indicator and the vehicle age are also positively correlated in the model for acceleration at HVC. In this case, the unobserved, yet interrelated effects that are raised through the correlated random parameters may stem from the risk-averting behavior induced by these two variables.

Table 5. Descriptive statistics for acceleration (linear regression models)

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 (in g)	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	1
HVC and pedestrian sign indicator (1 if both are present, 0 otherwise) [Acceleration at HVC]	0.541	−	0	1
HVC and Speed indicator (1 if HVC is present and average speed of trip greater than 5 mph over speed limit, 0 otherwise)	0.542	−	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	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	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	1
Lead vehicle indicator (1 if leading vehicle is present, 0 otherwise)	0.527	−	0	1
Lead vehicle and Obstructing vehicle presence indicator (1 if lead vehicle is present and at-least one obstructing vehicles is present near HVC, 0 otherwise)	0.500	−	0	1
Parked vehicle indicator (1 if more than 1 parked vehicle present near the crosswalk, 0 otherwise)	0.368	−	0	1
Gender indicator (1 if participant is female, 0 otherwise) [Acceleration at benchmark]	0.565	−	0	1
Gender indicator (1 if participant is female, 0 otherwise) [Acceleration at HVC]	0.565	−	0	1
Participant's age indicator (1 if less than 30 years old, 0 otherwise) [Acceleration at benchmark]	0.491	−	0	1
Participant's age indicator (1 if less than 30 years old, 0 otherwise) [Acceleration difference]	0.491	−	0	1
Participant's age indicator (1 if greater than 50 years old, 0 otherwise)	0.383	−	0	1
Time of day indicator (1 if trip occurs during dawn or dusk, 0 otherwise)	0.194	−	0	1
Time of trip indicator (1 if trip was undertaken between 6 AM to 12 Noon, 0 otherwise)	0.303	−	0	1
Trip frequency indicator (1 if participant undertook more than 60 traversals, 0 otherwise)	0.421	−	0	1
Trip frequency indicator (1 if participant undertook more than 50 traversals, 0 otherwise)	0.440	−	0	1

Variable	Mean	Standard deviation	Minimum	Maximum
Windshield condition indicator (1 if the windshield condition was very poor, 0 otherwise) [Acceleration at benchmark]	0.051	–	0	1
Windshield condition indicator (1 if the windshield condition was very poor, 0 otherwise) [Acceleration difference]	0.051	–	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	1

Table 6. Correlated grouped random parameters linear regression models for acceleration (at benchmark and at HVC locations), and for acceleration difference

	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 density function	–	–	*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 density function	*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 speed limit, 0 otherwise)	–	–	–	–	0.272	8.990
Standard deviation of parameter density function			–	–	*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 vehicles 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 density function	*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 density function	*0.220*	*48.828*	–	–	–	–
Vehicle age	-0.005	-1.660	0.029	6.850	–	–
Standard deviation of parameter density function	–	–	*0.131*	*22.405*	–	–

	Acceleration at benchmark		Acceleration at HVC		Acceleration difference	
Variable	**Coefficient**	**t-stat**	**Coefficient**	**t-stat**	**Coefficient**	**t-stat**
Vehicle age indicator (1 if vehicle is less than 6 years old, 0 otherwise)	–	–	–	–	-0.200	-6.190
Standard deviation of parameter density function	–	–	–	–	*1.086*	*17.715*
Variance parameter, sigma	0.510	271.280	0.553	241.170	0.685	193.390
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	
Mean Absolute Deviation (MAD)	0.324		0.319		0.380	
Sum of Squared Errors (SSE)	679.124		946.962		1371.362	
Mean Squared Errors (MSE)	0.257		0.358		0.518	
Root Mean Squared Errors (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 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%

Table 7. Diagonal and off-diagonal elements of the Γ matrix [t-stats in brackets], and correlation coefficients (in parentheses) for the correlated random parameters in the models for acceleration

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 average 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 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)

Tables 8 and 9 provide the descriptive statistics and estimation results, respectively, of the correlated grouped random parameters linear regression models for throttle pedal actuation (TPA) at the benchmark and HVC locations, as well as for the difference in throttle pedal actuation between the benchmark and HVC locations. Table 10 provides the diagonal and off-diagonal elemennts of the Γ matrix and the correlation matrices of the random parameters for the same models.

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. End-of-block HVCs were observed to increase TPA at the benchmark location for almost all traversals. In particular, the bar-pair end-of-block 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 locations. Vehicles traveling in 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 impact of temporal characteristics, traversals made during the months that HVC were installed (June, July, August or October) are associated with lower 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 in the morning, between 6 and 9 AM.

The TPA at the benchmark location was found to decrease for about 53% of traversals undertaken by drivers younger than 25 years of age. A decrease in TPA at the HVC location was also found for drivers older than 50 years of age. The difference in TPA between the benchmark and HVC locations was found to decrease for drivers younger than 30 years. With regard to the effect of environmental conditions, clear weather conditions were found to increase the difference in TPA between the benchmark and HVC benchmark locations.

Table 10 shows that end-of-block HVCs and young drivers (younger than 25 years old) resulted in random parameters that are negatively correlated in the model of throttle pedal actuation at benchmark. This implies that the interactions of the unobserved factors captured by these two variables have mixed effects on the throttle pedal actuation. Such finding might be attributed to the highly heterogeneous behavior of young drivers, especially in locations where pedestrian traffic is expected, as in the end of blocks. In the model for the difference of throttle pedal actuation, negative correlation of the unobserved characteristics was identified for the variables representing early morning trips and clear weather as well as for the variables representing early morning trips and passenger cars.

Table 8. Descriptive statistics for throttle pedal actuation (linear regression models)

Variable	Mean	Standard deviation	Minimum	Maximum
Throttle pedal actuation at benchmark	13.308	13.731	-11.552	100
Throttle pedal actuation at HVC	13.327	12.092	-8.118	100
Difference in Throttle pedal actuation	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	1
HVC and pedestrian sign indicator (1 if both are present, 0 otherwise) [Throttle pedal actuation at benchmark]	0.546	−	0	1
HVC and pedestrian sign indicator (1 if both are present, 0 otherwise) [Throttle pedal actuation difference]	0.546	−	0	1
HVC type and position indicator (1 if bar-pair type end-of-block located HVC, 0 otherwise)	0.112	−	0	1
Lead vehicle and Obstructing vehicle presence indicator (1 if lead vehicle is present and at least one obstructing vehicles is present near HVC, 0 otherwise) [Throttle pedal actuation at benchmark]	0.472	−	0	1
Lead vehicle and Obstructing vehicle presence indicator (1 if lead vehicle is present and at least one obstructing vehicles is present near HVC, 0 otherwise) [Throttle pedal actuation difference]	0.472	−	0	1
Lane position indicator (1 if vehicle is in the side lanes of a multilane road, 0 otherwise) [Throttle pedal actuation at benchmark]	0.364	−	0	1
Lane position indicator (1 if vehicle is in the side lanes of a multilane road, 0 otherwise) [Throttle pedal actuation difference]	0.363	−	0	1
Time of trip indicator (1 if trip was undertaken between 6 AM to 12 Noon, 0 otherwise)	0.307	−	0	1
Participant's age indicator (1 if less than 25 years old, 0 otherwise)	0.334	−	0	1
Participant's age indicator (1 if greater than 50 years old, 0 otherwise)	0.410	−	0	1
Participant's age indicator (1 if less than 30 years old, 0 otherwise)	0.457	−	0	1
Vehicle age (in years)	5.744	−	1	17
Vehicle type indicator (1 if passenger car, 0 otherwise) [Throttle pedal actuation at benchmark]	0.800	−	0	1
Vehicle type indicator (1 if passenger car, 0 otherwise) [Throttle pedal actuation difference]	0.800	−	0	1
Trip frequency indicator (1 if participant undertook more than 50 traversals, 0 otherwise)	0.420	−	0	1
Month of traversal indicator (If traversal occurred during June, July, August or October, 0 otherwise)	0.354	−	0	1

Variable	Mean	Standard deviation	Minimum	Maximum
Time of trip indicator (1 if trip was undertaken between 6 to 9 AM, 0 otherwise)	0.215	−	0	1
Weather indicator (1 if clear weather, 0 otherwise)	0.491	−	0	1
Windshield condition indicator (1 if the windshield condition was very poor, 0 otherwise)	0.064	−	0	1
Lane position indicator (1 if vehicle is in the side lanes of a multilane road, 0 otherwise) [Throttle pedal actuation at HVC]	0.363	−	0	1

Table 9. Correlated grouped random parameters linear regression models for throttle pedal actuation (at benchmark and at HVC locations), and for throttle pedal actuation difference

	Throttle pedal actuation at benchmark		Throttle pedal actuation at HVC		Throttle pedal actuation 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 vehicles is present near HVC, 0 otherwise)	-1.782	-2.960	–	–	2.448	6.510
Vehicle age	–	–	-0.622	-14.860	–	–
Standard deviation of parameter density function	–	–	*1.055*	*15.707*	–	–
Vehicle type indicator (1 if passenger car, 0 otherwise)	3.208	9.640	–	–	-1.198	-2.200
Standard deviation of parameter density function			–	–	*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 density function	*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 density function	*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 density function	–	–	*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 density function	–	–	–	–	*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
Standard deviation of parameter density function	–	–	–	–	*3.239*	*9.780*

	Throttle pedal actuation at benchmark		Throttle pedal actuation at HVC		Throttle pedal actuation difference	
Variable	**Coefficient**	**t-stat**	**Coefficient**	**t-stat**	**Coefficient**	**t-stat**
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	
Mean Absolute Deviation (MAD)	7.450		6.891		3.472	
Sum of Squared Errors (SSE)	272278.462		209574.542		111949.547	
Mean Squared Errors (MSE)	136.071		104.683		55.919	
Root Mean Squared Errors (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 passenger 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%

Table 10. Diagonal and off-diagonal elements of the Γ matrix [t-stats in brackets], and correlation coefficients (in parentheses) for the correlated random parameters in the models for throttle pedal actuation

Throttle pedal actuation 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)

Throttle pedal actuation 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)

Throttle pedal actuation 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 passenger 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 passenger car, 0 otherwise)	2.966 [10.570] (0.338)	-6.002 [-29.760] (-0.763)	5.677 [212.958] (1.000)

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 11, while the model estimation results and the elements of the Γ matrix (along with the correlation coefficients of the random parameters) are presented in Table 12 and Table 13, respectively.

Table 12 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 12 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.

With regard to the correlation of the random parameters, Table 13 shows that the interaction of unobserved characteristics related to end-of-block HVCs and young drivers (younger than 30 years old) has heterogeneous effects on acceleration decrease, as the corresponding correlation coefficient is negative. Similar effects are also observed for the variables representing speeding vehicles (more than 5 miles/hour above the speed limit) and presence of pedestrian in the brake application model. The inverse correlation of the random parameters for these two variables reflects the likely contradictory effects of the unobserved factors they capture. Specifially, speeding vehicles may indicate more aggressive driving patterns, whereas presence of pedestrians may activate calming nuances of driving behavior.

The use of correlated grouped random parameters in the linear regression models resulted in significant improvement in model fit compared to the fixed parameter linear regression model counterparts. The improvements in model fit are presented in Table 14. As seen in Table 14, the R^2 and adjusted R^2 values for the correlated grouped random parameter models are substantially higher than those of the fixed parameters models, demonstrating the statistical superiority of the model. Similarly, the improvement in model fit for the correlated grouped random parameters binary outcome models in comparison to their fixed parameters model counterparts is presented in Table 15.

Table 11. Descriptive statistics for speed, acceleration, and throttle pedal actuation (TPA) decrease, and for brake application (binary outcome models)

Variable	Mean	Standard deviation	Minimum	Maximum
Speed decrease	**0.483**	**–**	**0**	**1**
HVC indicator (1 if HVC is present, 0 otherwise)	0.563	–	0	1
Speed limit indicator (1 if the speed limit is below 30mph, 0 otherwise)	0.412	–	0	1
HVC type and position indicator (1 if ladder type end-of-block located HVC, 0 otherwise)	0.406	–	0	1
Obstructing vehicle indicator (1 if there are 2 or more vehicles obstructing the view to the crosswalk, 0 otherwise)	0.382	–	0	1
Parked vehicle indicator (1 if there is no parked vehicle near the crosswalk, 0 otherwise)	0.621	–	0	1
Participant gender indicator (1 if driver is male, 0 otherwise)	0.422	–	0	1
Participant's age indicator (1 if less than 25 years old, 0 otherwise)	0.389	–	0	1
Trip frequency indicator (1 if participant undertook more than 50 traversals, 0 otherwise)	0.433	–	0	1
Vehicle type indicator (1 if passenger car, 0 otherwise)	0.739	–	0	1
Acceleration decrease	**0.467**	**–**	**0**	**1**
HVC indicator (1 if HVC present, 0 otherwise)	0.598	–	0	1
Speed indicator (1 if vehicle speed is greater than 5 mph above speed limit, 0 otherwise)	0.936	–	0	1
Parked vehicle indicator (1 if there is at least 1 parked vehicle near the crosswalk, 0 otherwise)	0.452	–	0	1
HVC position indicator (1 if HVC is located at the end of block, 0 otherwise)	0.670	–	0	1
Time of trip indicator (1 if trip was undertaken between 9 AM to 12 Noon, 0 otherwise)	0.085	–	0	1
Time of day indicator (1 if trip occurs during dawn or dusk, 0 otherwise)	0.194	–	0	1
HVC type indicator (1 if bar-pair type HVC, 0 otherwise)	0.310	–	0	1
Participant's age indicator (1 if less than 30 years old, 0 otherwise)	0.491	–	0	1
Obstructing vehicle indicator (1 if there are 3 or more vehicles obstructing the view of the crosswalk, 0 otherwise)	0.181	–	0	1
Vehicle type indicator (1 if SUV or minivan, 0 otherwise)	0.203	–	0	1
TPA decrease	**0.432**	**–**	**0**	**1**
HVC indicator (1 if HVC is present, 0 otherwise)	0.590	–	0	1
Pedestrian presence indicator (1 if pedestrian is present near the HVC, 0 otherwise)	0.105	–	0	1
HVC position indicator (1 if HVC is located at the end of block, 0 otherwise)	0.632	–	0	1

Variable	Mean	Standard deviation	Minimum	Maximum
Lane position indicator (1 if vehicle is in the side lanes of a multilane road, 0 otherwise)	0.344	–	0	1
Lead vehicle indicator (1 if lead vehicle is present, 0 otherwise)	0.486	–	0	1
Vehicle make indicator (1 if vehicle is manufactured by Honda, 0 otherwise)	0.266	–	0	1
Trip frequency indicator (1 if participant undertook more than 50 traversals, 0 otherwise)	0.467	–	0	1
Brake application	**0.102**	**–**	**0**	**1**
HVC and pedestrian sign indicator (1 if both are present, 0 otherwise)	0.505	–	0	1
Pedestrian presence indicator (1 if pedestrian is present near the HVC, 0 otherwise)	0.103	–	0	1
Speed indicator (1 if vehicle speed is greater than 5 mph above speed limit, 0 otherwise)	0.936	–	0	1
HVC position indicator (1 if HVC is located at the end of block, 0 otherwise)	0.699	–	0	1
HVC type indicator (1 if ladder type HVC, 0 otherwise)	0.732	–	0	1
Participant’s age indicator (1 if less than 25 years old, 0 otherwise)	0.267	–	0	1
Participant’s age indicator (1 if greater than 65 years old, 0 otherwise)	0.152	–	0	1

Table 12. Correlated grouped random parameters binary outcome (logit and probit) models and (pseudo-)elastisticities (in perecentage) for speed, acceleration, and throttle pedal actuation (TPA) decrease, and for brake application

	Speed decrease (logit)		**Acceleration decrease (logit)**		**TPA decrease (logit)**		**Brake application (probit)**	
Variable	**Coeff. (t-stat)**	**(Pseudo-) Elasticity**	**Coeff. (t-stat)**	**(Pseudo-) Elasticity**	**Coeff. (t-stat)**	**(Pseudo-) Elasticity**	**Coeff. (t-stat)**	**(Pseudo-) 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 density function	*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 density function	*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 density function	–	–	*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 speed limit, 0 otherwise)	–	–	0.294 (3.250)	14.385	–	–	-0.656 (-3.370)	-113.33
Standard deviation of parameter density function	–	–	–	–	–	–	*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 density function	–	–	–	–	–	–	*0.617 (3.700)*	–

Variable	Speed decrease (logit) Coeff. (t-stat)	Speed decrease (logit) (Pseudo-) Elasticity	Acceleration decrease (logit) Coeff. (t-stat)	Acceleration decrease (logit) (Pseudo-) Elasticity	TPA decrease (logit) Coeff. (t-stat)	TPA decrease (logit) (Pseudo-) Elasticity	Brake application (probit) Coeff. (t-stat)	Brake application (probit) (Pseudo-) Elasticity
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 density function	–	–	–	–	–	–	*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 density function	–	–	*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 density function	–	–	–	–	*0.919 (47.190)*	–	–	–
Vehicle type indicator (1 if passenger car, 0 otherwise)	0.167 (2.070)	6.270	–	–	–	–	–	–
Vehicle type indicator (1 if SUV or minivan, 0 otherwise)	–	–	0.247 (4.180)	2.621	–	–	–	–

	Speed decrease (logit)		Acceleration decrease (logit)		TPA decrease (logit)		Brake application (probit)	
Variable	**Coeff. (t-stat)**	**(Pseudo-) Elasticity**	**Coeff. (t-stat)**	**(Pseudo-) Elasticity**	**Coeff. (t-stat)**	**(Pseudo-) Elasticity**	**Coeff. (t-stat)**	**(Pseudo-) Elasticity**
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 density function	*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	

Aggregate distributional effect of the random parameters across the observations

	Speed decrease		Acceleration decrease		TPA decrease		Brake application	
	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 greater than 5 mph above speed limit, 0 otherwise)	–	–	–	–	–	–	99.99%	0.01%
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%	–	–	–	–	–	–

Table 13. Diagonal and off-diagonal elements of the Γ matrix [t-stats in brackets], and correlation coefficients (in parentheses) for the correlated random parameters in the models for speed, acceleration, and throttle pedal actuation (TPA) decrease, and for brake application

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)

Throttle Pedal Actuation 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)

Brake Application			
	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 speed limit, 0 otherwise)	Driver's age indicator (1 if less than 25 years old, 0 otherwise)
Pedestrian presence indicator (1 if pedestrian	0.617 [3.700] (1.000)	–	–

is present near the HVC, 0 otherwise)			
Speed indicator (1 if vehicle speed is greater than 5 mph above 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)

Table 14. Goodness-of-fit measure for the competing linear regression models

	Fixed parameters model	Correlated grouped random parameters model	Fixed parameters model	Correlated grouped random parameters model	Fixed parameters model	Correlated grouped random parameters model
	Speed at benchmark		*Speed at HVC*		*Speed difference*	
Log-likelihood at convergence	-12282.972	-11191.200	-12234.317	-11077.900	-8216.572	-7861.900
Log-likelihood at zero	-12816.400	-12816.400	-12845.001	-12845.001	-8286.260	-8286.260
R^2	0.279	0.608	0.312	0.661	0.050	0.207
Adjusted R^2	0.277	0.606	0.31	0.659	0.047	0.201
	Acceleration at Benchmark		*Acceleration at HVC*		*Acceleration difference*	
Log-likelihood at convergence	-2171.010	-1850.784	-2536.918	-1835.161	-2981.294	-2556.395
Log-likelihood at zero	-2260.613	-2260.613	-2574.598	-2574.598	-3014.674	-3014.674
R^2	0.068	0.209	0.028	0.127	0.025	0.094
Adjusted R^2	0.065	0.204	0.025	0.122	0.023	0.090
	Throttle pedal actuation at benchmark		*Throttle pedal actuation at HVC*		*Throttle pedal actuation difference*	
Log-likelihood at convergence	-8007.856	-7323.579	-7754.716	-7277.620	-7933.049	-7751.562
Log-likelihood at zero	-8080.723	-8080.723	-7826.454	-7826.454	-7966.506	-7966.506
R^2	0.080	0.278	0.069	0.283	0.033	0.667
Adjusted R^2	0.068	0.275	0.065	0.279	0.029	0.665

Table 15. Goodness-of-fit measure for the competing binary outcome (probit and logit) models

	Speed decrease (logit)		**Acceleration decrease (logit)**		**TPA decrease (logit)**		**Brake application (probit)**	
	Fixed parameters model	Correlated grouped random parameters model	Fixed parameters model	Correlated grouped random parameters model	Fixed parameters model	Correlated grouped random parameters model	Fixed parameters model	Correlated grouped random parameters model
Log-likelihood at convergence	-1810.572	-1758.200	-1752.719	-1737.360	-1689.906	-1646.100	-442.670	-417.101
Log-likelihood at zero	-1867.086	-1867.086	-1827.713	-1827.713	-1726.262	-1726.262	-459.174	-459.174
Mcfadden ρ^2	0.030	0.058	0.041	0.049	0.021	0.046	0.036	0.092
Corrected Mcfadden ρ^2	0.025	0.050	0.035	0.042	0.016	0.038	0.019	0.061

SUMMARY AND CONCLUSIONS

In this study, various types of High Visibility Crosswalks were evaluated in terms of their potential to modify driving behavior and increase pedestrian safety. The use of SHRP2 NDS data enabled a comprehensive evaluation of driving reactions in presence of HVCs using multiple time-varying indicators while controlling for the impact of traditional determinants of driving behavior. To evaluate the effectiveness of HVCs in relation to their location and marking characteristics, different HVC positions (mid-block vs. end-of-block) and different HVC marking designs (Continental, Bar-Pair, and Ladder) were considered in the analysis. For this purpose, NDS data including trips at seventeen crosswalk locations from 6 different States across the US were obtained and processed. As no pedestrian-vehicle crashes or conflicts were identified from the SHRP2 NDS data, crash surrogate measures were employed to identify and analyze modifications in driving behavior at or near the HVCs.

The statistical analysis of the crash surrogates seeked to identify the in-depth effects of HVCs on multiple layers of driving behavior that are typically associated with high risk of motor vehicle-pedestrian accidents or conflicts. The high-dimensional nature of the NDS data, the presence of panel effects arising from multiple traversals undertaken by each participant as well as the existence of influential, yet unobserved characteristics, along with their unobserved correlations, may induce significant misspecification issues in the statistical modeling process. To account for these issues, the correlated grouped random parameters framework was employed for the estimation of linear regression and discrete outcome models for various crash surrogates.

Overall, the results of the analysis suggested that the presence of HVC reduces speed, acceleration, and TPA at both, the benchmark and HVC locations. HVC presence was also found to reduce the speed, acceleration, and TPA difference between the benchmark and HVC locations.

The simultaneous presence of HVC and pedestrian sign was found to have a mixed effect on acceleration at the benchmark and HVC locations and to decrease the difference in acceleration between the benchmark and HVC locations. Ladder styled end-of-block HVCs had a mixed effect on the speed at HVC location, whereas end-of-block HVCs were found to decrease the speed at benchmark locations. End-of-block HVCs were associated with mixed effects on TPA at the benchmark location, while end-of-block HVCs of bar-pair style increased the TPA at the HVC, the acceleration at benchmark and HVC, and the acceleration difference between the benchmark and HVC. Bar-pair HVCs were less likely to decrease the acceleration between the benchmark and HVC, whereas ladder HVCs reduced the likelihood of brake application between the same points. End-of-block HVCs increased the likelihood of both acceleration decrease and TPA decrease between the benchmark and HVC.

Presence of lead vehicle and absence of parked vehicles near the HVC location were also found to decrease the speed difference between the benchmark and HVC locations. Finally, various driver-, roadway-, weather-, vehicle-, and trip-specific characteristics were also found to be associated with shifts in driving behavior near or at the HVC locations.

From an application perspective, this study provides new insights into driver behavior and HVC design characteristics that can be used to improve the criteria for installing HVCs, and, as such, optimize the pedestrian safety benefits that they can bear. Another contribution of this study arises from the re-validation of the SHRP2 NDS data as a robust evaluation tool offering the opportunity to examine drivers' behavioral aspects at a disaggregate extent that could not be easily accomplished in the past through conventional data collection techniques.

Future research could focus on the investigation of spatial or temporal unobserved variations that can potentially be present in the analysis of the SHRP2 NDS data. In this context, spatial effects models (Aguero-Valverde et al., 2016; Tischer et al., 2019) or scaled logit/generalized logit models (Swait and Louviere, 1993; Marcoux et al. 2018) could be leveraged. Such models may have the potential to identify specific temporal or spatial effects, which are likely to be captured as pure unobserved heterogeneity, even with the use of advanced random parameter models.

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HIGHLIGHTS

- Effectiveness of various High Visibility Crosswalk (HVC) types was evaluated.
- Naturalistic Driving Study data were used to identify driving behavioral change.
- Various safety surrogate measures were statistically modeled.
- Correlated grouped random parameters models with panel effects were estimated.
- The HVC presence was found to modify driving behavior and improve pedestrian safety.