

**SHRP 2 Implementation Assistance Program
Concept to Countermeasure – Research to
Deployment Using the SHRP2 Safety Data (NDS)
Influence of Roadway Design Features on Episodic
Speeding in Washington State**

Phase 2 REPORT

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**SHRP 2 Implementation Assistance Program
Concept to Countermeasure –
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Influence of Roadway Design Features on Episodic Speeding in Washington
State**

FINAL REPORT

September 2015

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REPORTING OF PHASE 2 RESULTS

EXECUTIVE SUMMARY

This Phase 2 Implementation Assistance program (IAP) research project conducted analyses of the SHRP 2 NDS data to examine the effects of **specific roadway locations** and **infrastructure features** on **episodic speeding** by NDS participants in and around Seattle, WA.

The specific objective was to identify roadway characteristics that are associated with a greater frequency of speeding episodes and/or higher maximum driving speeds.

The Phase 2 work was fully successful in meeting the objective, specifically:

- Analyses confirmed existing relationships found in previous literature and policy
- Analyses found new relationship between speed and factors that can potentially be used to develop new countermeasures for speed control
- The research developed an approach for measuring natural influences of roadway characteristics on speed that are less affected by individual driver differences

Based on the team's discussions with WSDOT, the outcome of this research can be used to develop countermeasures that fill important gaps in the toolset that engineers have for addressing speed control in their designs. The Phase 3 plan proposes a countermeasure approach developed with feedback from WSDOT, which includes:

- A reference guide and Diagnostic Assessment tool to assist engineers in addressing speed at individual locations
- A one-day training course to help engineers apply the guide and tool to design problems they encounter, or are currently dealing with
- An optional implementation study to provide further validation of the Phase 2 results using spot-speed studies that capture data from a broader range of drivers

Based on the outcome of the Phase 2 work, the project team is confident that the Phase 3 plan provides an approach that will result in a low-risk, highly-useful set of countermeasures that will meet the immediate needs that engineers have for more detail Human Factors and design information related to speed control.

INTRODUCTION

It is clear from both everyday observation and research data that most drivers do not comply with posted speed limits (Harkey, Robertson, and Davis, 1990; Richard et al., 2013; Schroeder et al., 2013). Though generally low compliance rates with posted speeds may be clear from the research, what is less clear is our ability to predict drivers' speed choices associated with relevant geometric, environmental, and traffic factors. Limited research has been published in this area and is summarized in Appendix A. Some relationships between speeding and infrastructure features are well-established (such as the effects of higher design speeds and lane width), but others are unclear (i.e., mixed) or lack sufficient data to draw conclusions.

The goal of the current study was to examine these relationships. The research objective aligns with the Context Sensitive Solutions approach, which recognizes that speed control is linked to design. More importantly, the focus is on resolving many uncertainties about the relationship between roadway elements and speed behavior, which has practical implications for roadway design. Specifically, a challenge faced by roadway engineers is that they lack clear guidance regarding how to identify when driver speeding is potentially linked to the roadway characteristics, and how they can implement measures to curtail this speeding behavior.

Of particular interest in the current study was visual characteristics of the roadway environment. For example, the few studies that have examined this issue tend to show that heavily treed roads have lower operating speeds than roads surrounded by wide flat fields (Fitzpatrick et al. 2001, Fildes et al. 1987, & Ewing & Dumbaugh 2009). While greater perceived risk with roadside objects may play a role, another possible explanation is that nearby objects provide stronger visual cues that lead drivers to overestimate their speed. Although this possibility has long been implicated in speed behavior, there is a lack of on-road empirical studies of this potential cause of speeding. The current study specifically examined “visual confinement” of the roadway environment, which has the potential to lead to new speeding countermeasures.

Summary of Project Goal and Objective Attainment to Date

The goal of this project is to identify characteristics of roadway segments that facilitate episodic speeding or that generally leads to faster driving because of intentional or unintentional speed-maintenance behavior. More broadly, the focus is on obtaining a deeper understanding of how specific roadway features individually, and in combination with other features, affect driver speed behavior. Additionally, a practical goal of this project is to apply this understanding to develop countermeasures that give engineers better tools and solutions for speed control and addressing fast driving in general. The specific objective of the Phase 2 work was to:

- 1) Identify roadway characteristics that are associated with a greater frequency of episodic speeding and/or higher maximum driving speeds

The analyses provided clear support for the research objective. Specifically, the analyses identified multiple factors that influence both speeding episodes and maximum speed exceedance (highest speed above the posted speed limit). Most of the roadway factors yielded results that were in expected directions based on previous research and general design principles¹. Furthermore, A key outcome that cuts across individual findings is that the approach taken in this project was successful in isolating the effects of roadway characteristics on speed behavior.

The project findings show clear promise for developing practical countermeasures. The information provided in the analyses can help fill important gaps in our understanding of how roadway characteristics influence driver speed behavior. Specifically, this project’s WSDOT sponsors expressed that their engineers currently lack the tools and Human Factors information to help them address speeding at problem locations. The findings from this project, in addition to other information from previous research and other sources, can be used to develop more detailed training and tools that engineers can use to make informed decisions about design

¹ Note that results are still based on preliminary analyses, and specific findings are likely to change as we incorporate data from locations that were not ready in time for this report. These delays were caused by data quality issues that had to be fixed by the data provider.

tradeoffs when addressing speed control. The Phase 3 plan describes how we can build on the Phase 2 work to develop resources that help engineers better understand the Human Factors of speeding, roadway factors that affect speed control, and strategies for managing speed. These countermeasures would include a reference guide, a Diagnostic Assessment tool, and a one-day training course on the application of these resources to problem locations.

In summary, the Phase 2 analyses indicated that the data were of sufficient quality to obtain meaningful findings about the influence of roadway characteristics on speed behavior. Moreover, these findings can form the foundation for developing countermeasures around improved tools and training for engineers in their efforts to more effectively control speeds on roadways.

DATA AND METHODS USED FOR DATA ANALYSIS

The following sections describe the data used in the project and the methodological approach used to investigate the effects of roadway characteristics on speed. For clarity, the following terms are used throughout this report:

- **Location:** A one-half mile (approximately) section of road with characteristics of interest. A location includes through lanes in both directions.
- **Traveled way:** Lanes associated with travel in one direction at a location. For example, all RID variables associated with the north-bound lanes of a location are considered variables associated with the north-bound traveled way.

DATA USED

Two primary data sources were used to conduct the analysis: the NDS time series data and the RID roadway data. These sources were supported by supplementary data from the RID mobile-van videos and Google Earth. Following are details describing these sources.

NDS Variables: Time series data from the NDS dataset were used to identify driving behavior. Specifically, these data provided continuous measures—such as instantaneous speed and acceleration—that indicated drivers’ speed, lane position, proximity to lead vehicles, etc. at each GPS position. Travel speed measures, combined with speed limit data from the RID, were used to identify opportunity to speed, occurrence of speeding, and maximum delta speed (i.e., the maximum difference between travel speed and the speed limit). Speeding was used as a single, binary variable per traversal, and maximum delta speed was used as a continuous variable in the analyses. Table 8 in Appendix C lists the NDS time series variables obtained.

RID Variables: A wide variety of roadway variables are available in the RID dataset. Variables such as number of through lanes, lane width, shoulder width, and so forth, were used both for site selection and for the analyses of speeding. In site selection, the RID variables were used to identify: (a) locations that included RID data captured in the S04 mobile van data collection effort and (b) availability of roadway characteristics of interest. For the analyses, the roadway variables were aggregated over traveled way and used primarily as the independent measures representing roadway features. See *Calculation of Dependent Measures* for more information. Table 9 in Appendix C lists the RID variables used in the analyses.

Supplementary Data Sources: The iVision utility and Google Earth were used to assist in site selection and to derive a subjective measure called “Visual Confinement” (VC). This variable was developed to bridge the gap between the quantitative descriptions of roadway characteristics

in the RID and the qualitative, perceptual experience of driving on those roads. A VC score was assigned to each traveled way at the location. The VC score indicated the level of visual complexity and overall feeling of restrictiveness a driver might experience through the traveled way. The visual confinement scores considered the height of the roadside environment, proximity of the roadside environment, medians, barriers, shoulders, overhead environment, and the number of lanes to create a holistic score based on how these factors may influence speed. The VC scores were used as an independent measure in the analyses. More information on how visual confinement was assessed is provided in Appendix B.

METHODOLOGICAL APPROACH

This section describes the approach used to investigate the effects of roadway characteristics on speeding in this research. Figure 1 outlines the steps performed in the conduct of the study.

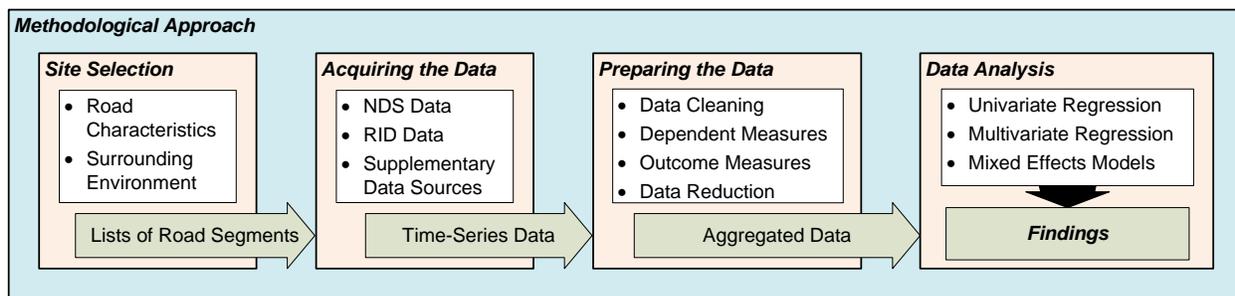


Figure 1. Methodology for conducting the research.

Overview

Time series data from the SHRP2 NDS were combined with roadway characteristics from the RID to identify characteristics associated with elevated speeds relative to the posted speed limit. In this approach, 99 locations with varying characteristics were selected, and all available time series data for vehicles that traversed each location in either direction were extracted from the NDS data. Each location was approximately one-half mile in length. Figure 2 illustrates a typical traversal site, with examples of some of the variables included in the study.

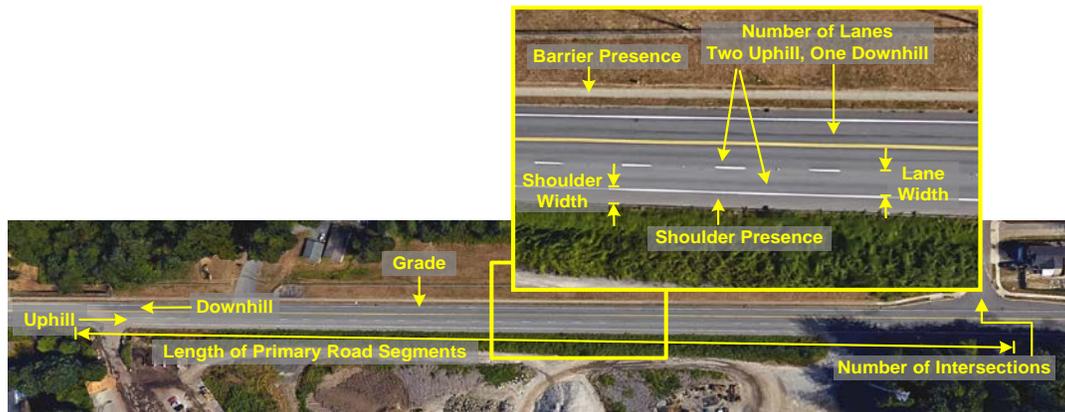


Figure 2. Examples of variables examined at a typical site².

² This figure is intended for illustrative purposes only and includes some elements not found at this site. Also, for clarity, the figure does not show the actual length of the primary road segment zone.

A traversal began when the vehicle entered the primary, contiguous road segments (links) upon which the location was defined. Only those traversals in which the driver crossed straight through the entire location were extracted. Drivers' speeding behaviors were analyzed in conjunction with variables that describe the characteristics of the roads at each site. The time series data were cleaned, and locations with problematic characteristics (e.g., speed limit transition within the traveled way) were discarded. The two traveled ways at each remaining location were treated independently in the analysis, yielding analyses of 128 traveled ways³. Traversals were analyzed using univariate and multivariate regressions with mixed effects models to identify road characteristics with significant effects on speeding behavior.

Site Selection

The goal of the site selection process was to identify locations with differing roadway and environmental characteristics in order to obtain sufficient variability in terms of key predictors of speeding. To select appropriate sites for the project, several considerations regarding availability of data and sample size had to be balanced. These considerations included: (a) availability of RID roadway data at the location, (b) availability of a sufficient number of traversals driven by a sufficient number of participants at the location, and (c) balance of environmental and roadway variables. State routes were chosen for the majority of locations because they were generally included in the RID mobile van data, driving on state routes was well represented in the SHRP2 NDS data, and these roads included a confined range of speed limits. Nevertheless, some roads that were not state routes were chosen to achieve the required balance of desired characteristics.

Potential locations were identified using the RID iVision utility and Google Street View based on the following criteria: few or (preferably) no intersections, no traffic control devices, absence of sharp curves, and roadways with a consistent roadside environment (e.g., did not transition abruptly from tall, confining buildings to open fields). Next, the counts of traversals and participants who drove at the location were determined using the Travel Density dataset on the SHRP2 InSight Portal. For this project, a minimum of 40 participants and at least 250 traversals overall were required for a location to qualify for inclusion. Finally, the location was examined to determine whether the roadway data were available in the RID.

Once a location was selected, its roadway features were catalogued. The roadside environment was also coded; this consisted of three components: (1) whether the site had an urban or rural appearance, (2) the visual density of foliage and greenery along the road, and (3) a general categorization of the land use along the site (industrial, commercial, farmland, etc.). Visual confinement scores were computed based on iVision and Google Earth images.

Acquiring and Preparing the Data

The time series data associated with 99 locations (198 traveled ways) were requested and delivered to Battelle in accordance with the terms of a SHRP2 Data Use License. RID variables and supplemental data sources were also identified and gathered from their respective sources.

Data Cleaning

Data quality checking and cleaning were performed to ensure the data had sufficient quality to reliably conduct the analyses. Data cleaning activities included removal of erroneous or poor quality data, computing travel speed based on the two travel-speed variables provided, and

³ Some traveled ways are excluded because some data were not provided in time to include in this first-look analysis

removal of traversals that did not conform to target behavior (e.g., interrupted traversals and traffic-bound driving). Due to data quality issues on the data-providers end, Battelle was not able to validate the data for 38 traveled ways in time to include them in the analyses; however, data from these sites will be included in the final version of this report.

Computing Travel Speed

The SHRP2 dataset contains two measures that provide travel speed. The GPS speed variable contains travel speed reported by the GPS unit, while the network speed variable contains travel speed from the vehicle’s onboard computer. Network speed was chosen as the principal speed measure because it is most likely to correspond with the speed reported on the speedometer. GPS speed was used whenever the network speed was not available (e.g., if the vehicle’s onboard computer did not provide it at the OBD2 port).

Removal of Traversals That Do Not Have the Opportunity to Speed

One objective in the data cleaning process was to remove traversals in which drivers clearly had no opportunity to speed. Because we could not validate the quality of the radar data, we used a proxy for opportunity to speed known as “free-flow” driving, which simply represents travel above a minimum speed threshold (see Richard et al., 2013). A traversal was considered in free-flow if the vehicle speed across the traveled way was greater than 5 mph below the posted speed limit for at least 90% of the traversal. Speeding was defined as traveling at least 10 mph above the speed limit for at least 10% of the length of the traveled way. Figure 3 illustrates how free-flow driving and speeding were defined based on travel speed relative to posted speed limit.

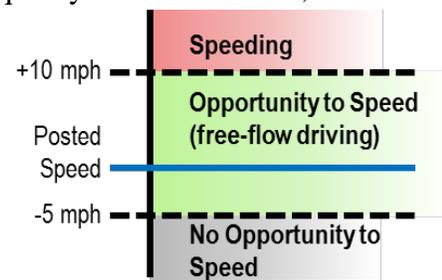


Figure 3. Thresholds for classifying speed records as speeding, and Free-Flow driving (opportunity to speed)

Calculation of Dependent Measures

A total of 15 dependent measures were selected and generated from the RID data: (a) mean lane width, (b) proportion of center lane presence, (c) mean number of through lanes, (d) proportion of bike lane presence, (e) mean of left shoulder width, (f) mean of right shoulder width, (g) mode of median type, (h) percentage of left barrier length, (i) percentage of right barrier length, (j) visual confinement (low/high), (k) number of speed signs, (l) posted speed limit, (m) number of access points, (n) development density (low/high), and (o) traveled way division (divided/undivided).

Calculation of Outcome Measures

Two outcome measures were calculated to represent speeding behavior: (a) speeding (binary variable indicating whether the event includes speeding for at least 10% of the duration of travel across the traveled way), and (b) maximum delta speed (continuous variable).

Data Reduction

After cleaning, the data included a total of 147,421 traversal events from 670 drivers across 160⁴ traveled ways. RID data and manually coded visual confinement scores, development density,

⁴ Due to ongoing data quality issues, 38 traveled ways were not included in the early findings analysis; however, we expect that these data will be included in the final version of this report.

and classification for divided/undivided roadways were synchronized with the GPS data. Multiple rounds of data filtering were conducted: (a) percentage of free flow periods over trip duration was calculated and trips with low free flow percentage were removed (< 90%), (b) short trips (trip duration < 20 seconds) were excluded to avoid incomplete/partial trips, (c) traveled ways where multiple posted limits existed (e.g., 40 mph and 50 mph signs within the same traveled way) were excluded, (d) four traveled ways without RID data were excluded, and (e) 30 events where Driver IDs were not available were excluded. After this filtering, a total number of events was 70,782 (*n* of drivers = 647 and *n* of traveled ways = 128).

Data Analysis

See *Findings to Date and a Description of the Significance of Those Findings* section below for a discussion of the methods used to analyze the data.

DATA ANALYSIS METHODS

The main objective of this preliminary analysis was to identify relationships between roadway characteristics and speeding outcomes. We conducted regression analyses to examine multiple aspects of these relationships. Figure 4 shows the overall flow and objective of each approach. First, we investigated roadway features individually for two types of speeding outcomes (binary speeding measure and maximum delta speed) using univariate models. We expected that univariate models could explain a main effect of each roadway feature on speed outcomes without potential interactions with other roadway features. A univariate approach was similar to many previous studies that examined certain roadway features in isolation (see Appendix A). Second, we applied multivariate models, which integrated 15 roadway features, to test emergent effects of these features on the two speed outcomes. A multivariate approach was preferable because many roadway features vary jointly across functional classes or other design aspects, which introduces confounding relationships. Third, based on the multivariate model, we ran a variable selection algorithm to build the most efficient model, which consisted of the best subset of the predictors to avoid potential multicollinearity. Lastly, we tested Random Forest models to see if the outputs from the regression analyses had consistency with other analytical methods, and to identify relative importance of the predictors.

Analytical Approach

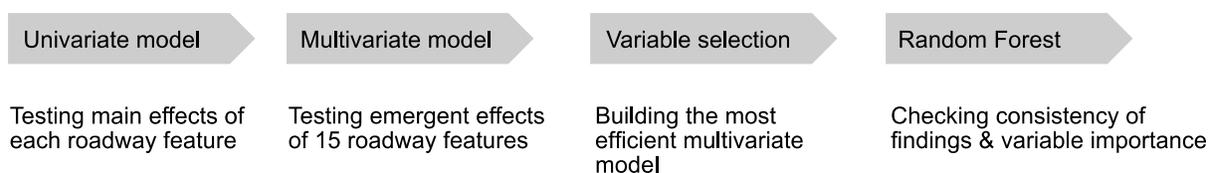


Figure 4. Overall flow of analytical approach and roles of each stage.

A unique aspect of the SHRP 2 NDS is that it provides an opportunity to observe the same drivers making multiple traversals of the same locations. To take advantage of these repeated observations, we used mixed effects models with *Driver ID* as a random effect. An additional random effect included in half the analyses was *Traveled Way*. As Figure 5 illustrates, there is substantial variation in both dependent measures across traveled ways. Although some of these

variations likely arise from the independent measures, it is also likely that there are unique aspects associated with individual traveled ways that cannot be captured by the independent measures available in the current analysis. Including *Traveled Way* as a random factor allowed the regression models to account for these intrinsic differences. As shown in Figure 5, the *Traveled Way* variable itself explained speeding to some degree, so we assumed models without *Traveled Way* as a random effect tested simple effects and trends of the roadway features, whereas models with *Traveled Way* as a random effect tested the effects of roadway characteristics by controlling potential differences among the traveled ways.

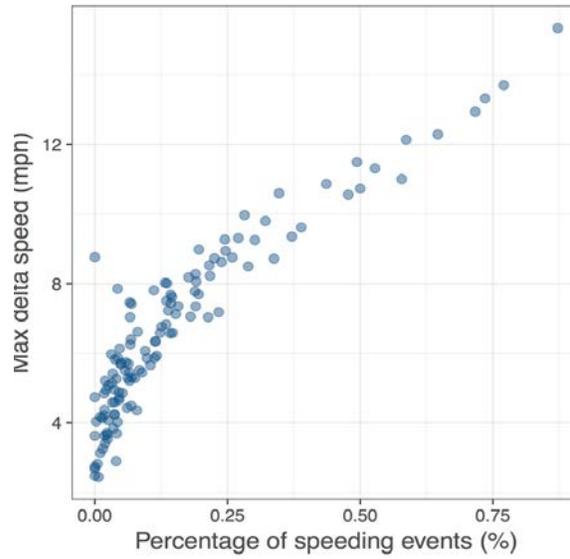


Figure 5 Distributions of two outcome measures across all traveled ways.

The initial regression models were run without *Traveled Way* as a random effect to provide an indication of the general trends associated with each roadway variable. Follow-up models included the *Traveled Way* as a random factor to better account for between-site differences (see Figure 6).

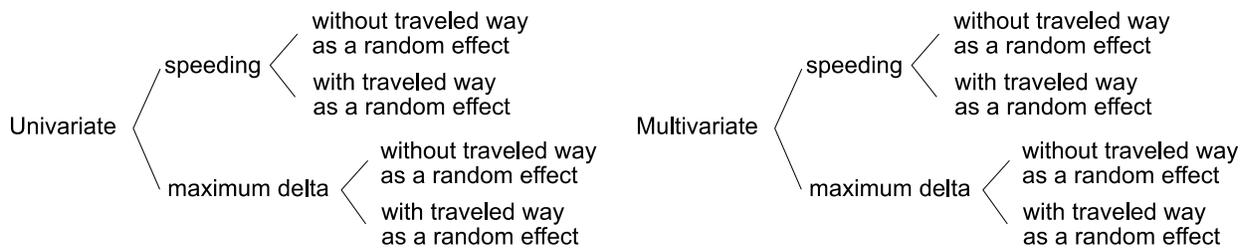


Figure 6: Structure of the regression analysis.

FINDINGS TO DATE AND A DESCRIPTION OF THE SIGNIFICANCE OF THOSE FINDINGS

Findings from each analytical approach are described in the subsequent section.

Univariate Regression Analysis

Table 1 shows the coefficients from the Univariate Modeling to test for simple effects. Model Odds Ratios are provided in Appendix D. Models with and without *Traveled Way* are shown for the two speed-related dependent measures. For both speeding and maximum delta speed, all models without the *Traveled Way* random effect were statistically significant (highlighted in bold font), except the lane width model for maximum delta speed. Directions of the significant coefficients across two sets (binary vs. continuous outcome) were the same, indicating that results across two sets were consistent in terms of the direction of relationships between predictors and speeding measures (this consistency was maintained in the multivariate models).

With the *Traveled Way* random effect, the number of significant predictors decreased (compared to the previous results). For episodic speeding: number of through lanes, median types, percent coverage by a left-side barrier, visual confinement, posted speed, and number of access point models were significant. For maximum delta speed: number of through lanes, median type, posted speed, number of access points, and development density models were significant. Number of through lanes showed positive relationships with speeding and maximum delta speed, indicating that more through lanes was likely associated with more speeding/higher delta speed. Median type was tested compared to a “concrete” median type. Results showed that compared to concrete median, flush/painted median, no median, and raised median were less likely to be associated with speeding. Similarly, for maximum delta speed, flush/painted median and no median were less likely to be associated with delta speed compared to the concrete median type. Visual confinement was only significant in predicting episodic speeding, with low visual

Table 1: Coefficients from the univariate regression analysis (note that each row represents individual model).

	Episodic Speeding		Maximum delta speed	
	With Traveled Way	Without Traveled Way	With Traveled Way	Without Traveled Way
Models	Coeff.	Coeff.	Coeff.	Coeff.
Lane width	0.00	0.02 **	-0.01	0.01
Center lane proportion	0.06	-0.79 ***	0.63	-0.99 ***
Number of through lanes	0.97 ***	0.30 ***	1.33 ***	0.62 ***
Bike lane proportion	-0.54	-1.25 ***	-0.17	-1.54 ***
Shoulder width (Left)	0.03	-0.12 ***	-0.08	-0.27 ***
Shoulder width (Right)	-0.02	-0.04 ***	-0.10	-0.11 ***
Median type (Depressed/raised-barrier)	-1.13	-1.35 ***	-2.18	-2.27 ***
Median type (Flush-painted)	-1.49 ***	-0.63 ***	-1.97 ***	-0.86 ***
Median type (No median)	-1.20 ***	-0.95 ***	-1.55 *	-1.34 ***
Median type (Raised)	-1.24 **	-0.45 ***	-1.20	-0.63 ***
Barrier proportion (Left)	1.00 **	0.58 ***	1.21	0.87 ***
Barrier proportion (Right)	0.43	-1.17 ***	0.28	-2.02 ***
Visual confinement (Low)	0.99 ***	0.69 ***	0.99	0.73 ***
Number of speed signs	-0.06	-0.25 ***	0.10	-0.34 ***
Posted speed	-0.04 **	-0.05 ***	-0.11 ***	-0.13 ***
Number of access points	-0.23 ***	-0.14 ***	-0.25 ***	-0.16 ***
Development density (Low)	-0.51	-0.69 ***	-0.99 *	-0.80 ***
Traveled way division (Undivided)	-0.42	0.43 ***	0.03	1.38 ***

* $p < .05$, ** $p < .01$, *** $p < .001$

confinement associated with more speeding. Posted speed and number of access points were consistently significant across types of models. Number of access point was likely related to traffic flow. Consequently, road segments with more access points were associated with less speeding and lower maximum delta speeds.

One pattern that should be noted is the negative relationship between posted speed limit and both speed-related dependent measures. This was the strongest relationship observed in the data. Although this pattern seems somewhat counterintuitive, it is consistent with some previous studies--specifically, on non-freeway roads in a previous naturalistic driving study examining speeding in Seattle and rural Texas (Richard et al., 2014). Also, a spot-speed study examining comparable roadways in Phoenix, AZ found a similar relationship (Semmens & Skszek, 2006).

Most, but not all of the trends for individual dependent measures were in the expected direction based on existing trends and design guidance. For example, exceptions included higher speeding/speeds being negatively associated with shoulder width, and positively associated with undivided roadways. These exceptions are not surprising given that the effects of multiple dependent measures were not controlled for in the univariate models.

Multivariate Regression Analysis

Table 2 shows the coefficients from the Multivariate Modeling to test emergent effects of multiple roadway features. Models with and without the *Traveled Way* are shown for the two

Table 2: Coefficients from the multivariate regression analysis (each column is a model).

	Episodic Speeding		Maximum delta speed	
	With Traveled Way	Without Traveled Way	With Traveled Way	Without Traveled Way
Models	Coeff.	Coeff.	Coeff.	Coeff.
(Intercept)	2.97 **	3.81 ***	16.20 ***	18.53 ***
Lane width	0.04	0.06 ***	0.08	0.12 ***
Center lane proportion	0.34	0.29 *	-0.10	0.59 ***
Number of through lanes	0.57 *	0.31 ***	0.66	0.21 ***
Bike lane proportion	-0.45	-1.04 ***	-0.47	-1.35 ***
Shoulder width (Left)	-0.05	-0.04 ***	-0.16	-0.07 ***
Shoulder width (Right)	0.00	-0.02 ***	0.01	-0.04 ***
Median type (Depressed/raised-barrier)	-0.35	-0.23 *	-0.80	-0.26 **
Median type (Flush-painted)	-0.44	-0.13 *	-0.57	-0.07
Median type (No median)	-0.14	-0.42 ***	-0.03	-0.65 ***
Median type (Raised)	-0.68	-0.22 **	-0.58	-0.16
Barrier proportion (Left)	1.40 **	1.31 ***	3.26 ***	3.50 ***
Barrier proportion (Right)	0.48	-0.22 ***	0.72	-0.13
Visual confinement (Low)	0.69 *	0.97 ***	1.16	1.83 ***
Number of speed signs	-0.42 ***	-0.38 ***	-0.60 **	-0.66 ***
Posted speed	-0.15 ***	-0.16 ***	-0.28 ***	-0.32 ***
Number of access points	-0.26 ***	-0.26 ***	-0.38 ***	-0.42 ***
Development density (Low)	0.39	0.20 ***	0.81	0.83 ***
Traveled way division (Undivided)	0.95 *	0.86 ***	2.03	2.14 ***

* $p < .05$, ** $p < .01$, *** $p < .001$

speed-related dependent measures. Similar to the univariate model outputs, for both speeding and maximum delta speed, most of the predictors without the *Traveled Way* random effect were

statistically significant, except the barrier proportion (right) for maximum delta speed. Also, directions of the significant coefficients across two sets were the same, indicating that directions of the relationship between each predictor and outcome measures were consistent across the models. With the *Traveled Way* random effect, number of through lanes, percent coverage by a left-side barrier, visual confinement, number of speed signs, posted speed, number of access points, and traveled way division were statistically significant for the speeding outcome. For maximum delta speed, percent coverage by a left-side barrier, number of speed signs, posted speed, and number of access points were statistically significant.

Most of the significant relationships are interpretable, and factors such as number of speed limit signs and visual confinement readily lend themselves to countermeasure development. One consideration, however, is that there is probably an interaction involving left barriers and divided roadways in the dataset that is not fully unaccounted for in the model. Left barriers are highly correlated with divided roadways ($r = 0.6$), but additional analyses and recoding of the dataset are likely required to better resolve this relationship.

Final Model after Variable Selection

Table 3 shows coefficients from two final models after selecting important predictors and excluding unnecessary predictors from the previous multivariate models.

For the two multivariate models (speeding and max delta speed) with the *Traveled Way* random effect, a variable selection algorithm was applied. The Backfitting algorithm, which tests the model with the full set of predictors and then removes an unnecessary variable step by step, was used. Table 3 shows final models selected after the backfitting process. Across two final models, number of speed signs, posted speed, and number of access points were consistently significant.

Table 3. Coefficients from the final models after variable selection.

Speeding (binary) With traveled way random effect		Maximum delta speed (continuous) With traveled way random effect	
Predictors	Coeff.	Predictors	Coeff.
(Intercept)	4.35 ***	(Intercept)	17.36 ***
Number of through lanes	0.71 **	Barrier proportion (Left)	3.65 ***
Median type (Depress/raised barrier)	-0.90	Visual confinement (Low)	1.57 ***
Median type (Flush-painted)	-1.21 ***	Number of speed signs	-0.50 **
Median type (No median)	-0.79 *	Posted speed	-0.29 ***
Median type (Raised)	-1.80 ***	Number of access points	-0.45 ***
Number of speed signs	-0.42 ***	Development density (Low)	1.10 *
Posted speed	-0.13 ***	Traveled way division (Undivided)	2.53 **
Number of access points	-0.26 ***		

* $p < .05$, ** $p < .01$, *** $p < .001$

Random Forest Model

As a complementary analysis, Random Forest models were tested with the same variable set with multivariate models with the *Traveled Way* random effect. One benefit of this approach is that Random Forest models can handle random effect variables and estimate the importance of specific variables along with other fixed effect variables.

Random Forests train many classification or regression trees on different random subsets of the data. In each tree, only a random subset of the covariates is considered at each split. These sources of randomness induce trees, which are uncorrelated and when averaged together, improve the predictive capability of the model. Variable importance for a covariate is measured by randomly permuting the values of the covariate. This is measured by percent increase in mean squared error for continuous responses or the mean decrease in accuracy for categorical responses. Variable importance was calculated using subsampling and the permutation method, without standardizing the importance measures (Strobl et al. 2007).

Across both Random Forest models, posted speed, median type, barrier proportion (left), number of through lanes, and number of access points were classified as important variables, and general consistency with the outputs from the regression models was maintained (see Figure 7). The results also showed that between the two random effects (*Driver ID* vs. *Traveled Way*), the *Traveled Way* variable was a substantially more important variable for predicting episodic speeding and maximum delta speed compared to the *Driver ID* variable (i.e., individual differences or driver characteristics). The relatively low importance of the *Driver ID* compared to many other roadway variables is notable. In most behavior studies, individual differences are the primary source of variance; however, the low importance in this analysis suggested that roadway characteristics were a dominant factor in controlling and overriding individual speed behavior. This is generally consistent with the notion of “self-enforcing” roads.

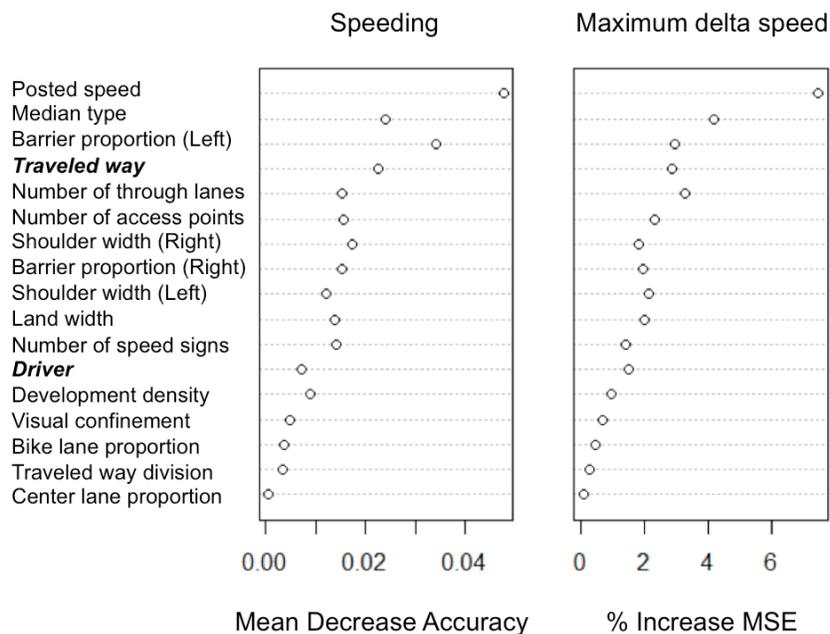


Figure 7: Variable importance for both speeding (left) and maximum delta speed (right) models (note that random effect variables are in bold and italic).

One global aspect that we have not examined in detail is inherent complexity in the dataset that likely arises from relationships among roadway features from design practices. For example, in the current analyses, roadways were treated monolithically, and the resultant predictive factors were ones that were globally relevant across all road types examined. A more detailed analysis would likely identify clearer situational patterns based on subsets of roadways (e.g., divided vs.

undivided; 2 vs. 3 through lanes, etc.). The first-look analysis described in this report did not specifically account for these patterns, but further investigation is included in the Phase 3 plan.

COMPARISON WITH LITERATURE, POLICIES AND PROCEDURES

The findings from Phase 2 provide information that can be directly applied to speed control on specific roadway segments. Our findings are consistent with findings from previous research on the effects of roadway geometry on operating speed (see Appendix A for details) and key policy guidance. Moreover, the findings from the current analyses help explain some of the mixed results of previous studies, which are typically limited to examining one or two roadway characteristics at a time (see Appendix A). In particular, the current analysis was able take a more holistic view when evaluating the impacts and interactions that multiple roadway features have on speed. This approach aligns with the goal of WSDOT’s context sensitive design policy to create an inclusive understanding of the effects of the roadways on users and the environment.

The WSDOT Contextual Classification of Roads document, the AASHTO Green book, and the Highway Safety Manual contain limited guidance about the effects of geometric roadway features on driver speed and behavior. All the primary variables under investigation are documented, but not all include guidance that could support engineering solutions to speeding. Table 4 summarized the existing guidance and how they compare to our findings.

Our findings are generally consistent with the guidance found in key reference works. However, our findings can substantially expand upon the cursory explanations they provide. There appear to be effects of infrastructure detected by this study that could provide additional information to designers and engineers. These findings could be incorporated into these reference manuals and other documents to improve the understanding of the nuanced effects infrastructure has on speed.

Table 4. Relationship of findings to current policy documents.

Feature	Page #	What is existing guidance? How specific is it?	How do our findings relate?
Lane Width/Number of Lanes	CC ⁵ : V-3.7, 3.13 GB ⁶ : 4-7, 4-8 HSM ⁷ : 13-3	Narrow lanes force vehicles to operate closer together causing them to reduce their speeds. Width to speed reduction numbers are not given.	Higher speeds on wider roads with more lanes
Shoulder Width	CC: V-3.10, 3.13 GB:4-9, 4-10, 4-11 HSM: 13-3	Wider shoulders are associated with high speed roads where the shoulder may be used for accident recovery. Larger shoulders may incidentally widen the road, indirectly increasing speed.	Findings are inconsistent: Wide shoulders appear associated with less speeding.
Urban/Rural Roads	CC: V-3.2, 3.13 HSM: 13-3	Urban and Suburban roads may have greater speed variance. Overall speed differences are not commented on.	Higher speeds on “rural” roads
Median	CC: V-3.9, 3.14 GB: 4-31, 4-32, 4-34, 4-35 HSM: 13-3	Effects of median on speed depend on median type. Medians that divide roadways are used on high speed roads to prevent collisions and curbed medians with landscaping are recommended for traffic calming.	Certain median types, painted and curbed, appear to be associated with lower speeds compared to concrete.

⁵ WSDOT Contextual Classification of Roads reference

⁶ AASHTO Green Book reference

⁷ Highway Safety Manual Reference

Barriers	CC: V-3.11, 4.5 GB: 4-29, 4-30	There is little guidance about how barriers impact speeds.	Results are inconclusive
Access Points	CC: V-6.6 GB: 2-73, 2-74 HSM: 13-50	Increased access is associated with a reduction in speed. -2-3 mph per access point per mile.	More access points appear associated with lower speeds.

PLANS FOR PHASE 3:

IMPLICATIONS OF PHASE 2 FINDINGS FOR COUNTERMEASURE IMPLEMENTATION DURING PHASE 3

Potential countermeasures, policies and/or procedure changes

The countermeasures from this work align with the Task Force’s focus areas of 1) driver speed, and 2) roadway features and driver performance. The first part of this countermeasure will consist of a guide and tool that will assist engineers in conducting Diagnostic Analysis of locations with suspected speed-related safety problems. A companion guide will be developed to help engineers better understand the interaction between drivers, location characteristics, and speed behavior, in addition to providing practical guidance on how engineers can address those issues. Finally, we will develop a 1-day training course that provides background on the interplay between drivers, roadways, and speeding. The training course will also cover how to apply the speed control guide and tool to improve speed control in roadway design.

Implementation Plan

The Phase 3 work will involve four primary tasks and one optional evaluation task (see Figure 8). The first technical task involves conducting additional data analyses to obtain a more detailed understanding of “micro-level” driver speeding behaviors. This information will be combined with information from existing research and interviews with WSDOT engineers to develop a tool and guide to assist them in diagnosing speed-related design issues and to identify effective solutions. This information will be supplemented by a training course that will be developed based on the guide. We are also proposing an optional evaluation task that would involve conducting a natural experiment to confirm the key relationships identified in Phase 2 using spot-speed measurements at locations with different roadway characteristics.

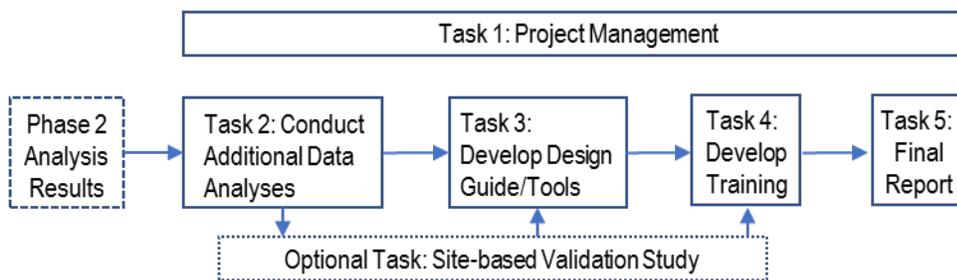


Figure 8. Overview of Phase 3 Tasks.

Task 1: Project Management

This task would involve conducting regular coordination meetings with WSDOT to coordinate activities involving WSDOT personnel. This task will include preparing and submitting quarterly reports to FHWA and presenting a kickoff and a final briefing for FHWA.

Task 2: Conduct Additional Data Analyses

The objective of this task is to extend the Phase 2 findings by examining time-series data within sites to identify localized roadway elements that exert global influences on driver speed behavior. These patterns are apparent in the speed time-series at certain locations but not others, which indicates the presence of systematic influences roadway elements on speed behavior. Two common forms observed in Phase 2 include 1) differences in variability in speeds across locations, and 2) undulations in speed within locations that are synchronized across drivers.

Task 2 would involve reanalyzing Phase 2 data at the level of individual traversals (see Figure 9). Each speed record within a trip would be matched with continuously coded roadway characteristics from the RID dataset, which would permit analyses of variations in features *within* traveled ways. For example, lane width was typically non-uniform within a travelled way; however, it was coded as a single median value in the Phase 2 regression modeling. The time-series analyses would provide a more systematic approach for examining these types of variations. In addition, WSDOT will provide new information about the locations (e.g., instantaneous sight distance) that may explain some of the observed patterns, and which can be incorporated into our understanding of speed behavior. We will also work with WSDOT to divide traveled ways into logical subsets representing different design cases. This will permit us to examine the relation between speed behaviors and roadway characteristics in more situationally relevant contexts.

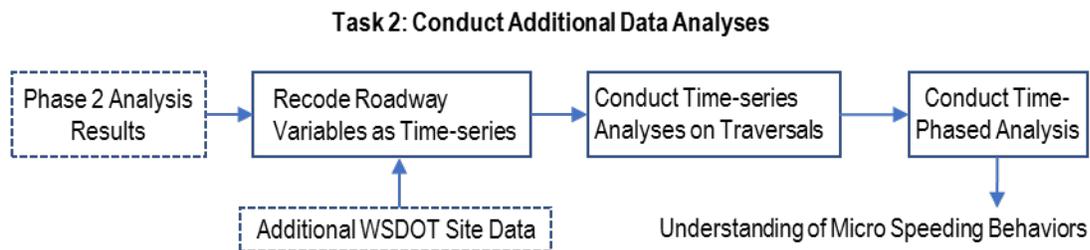


Figure 9. Overview of Task 2 data processing and analysis activities.

One aspect that this analysis will address is the time lag between roadway characteristics and changes in vehicle speed. This lag occurs because of vehicle inertia, and possibly cognitive/perceptual factors that delay driver responses. We will include a time-phased element in the analyses that would link speed changes to nearby upstream features.

The outcomes of this task will include a better understanding of how roadway characteristics effect micro-level speeding behavior, which will provide valuable information for the Phase 3 guide and tool, in addition to possibly providing information that can be applied to the design of roadway transition zones. The time-series information would also inform the optional validation task; specifically, the selection of where to position spot-speed measurement zones.

Task 3: Develop Speed Control Tools and Guide

The Phase 2 results suggest that roadway characteristics influence driver speed behaviors. One challenge that roadway engineers face is that they have limited tools for understanding, assessing, and addressing driver speed behaviors. A key objective in this task will be to develop resources to assist engineers in dealing with speeding at individual locations. These resources will include a guide that provides background information about the influence of specific roadway characteristics on speed behavior. This guide will include diagnostic tools for identifying potential causes of speeding, and applicable design solutions.

The development of the resources will be geared towards existing references, policies, and processes in currently in place at WSDOT. Future work could adapt these materials to a broader audience. The Battelle team will coordinate with WSDOT to identify relevant individuals and conduct interviews with WSDOT engineers and supervisors to understand the current processes and resources, information needs, specific design challenges that they typically encounter, and approaches they use for developing solutions. We will obtain approval from Battelle's IRB prior to conducting any interview or outreach activities.

The guide will integrate the findings from Phase 2 and Task 2 (see Figure 10) with more recent research related to infrastructure and speed, particularly information related to speed control and Context Sensitive Solutions (ITE 2007). The focus will be on design problems and solutions that roadway engineers regularly encounter. Part of this will include Diagnostic Assessment materials that can be used in Road Safety Audits. Battelle has developed this type of tool for the Human Factors Guidelines for Road Systems (HFG; Campbell et al., 2012). The guide and tool will be developed so that they can be used in conjunction with the Highway Safety Manual (HSM). Battelle is currently working on a primer for integrating information from the HFG and the HSM to conduct diagnostic assessments of problematic roadways and to identify effective solutions. We envision a similar complementary link between the guide and the HSM.

Once completed, the guide and tool will be pilot tested with the help of WSDOT. Where possible, we will evaluate the materials in the context of existing trouble-spots that are provided by participants in advance. This feedback will provide information about what changes and refinements are needed improve the applicability of the information and to better meet the engineers' information needs.

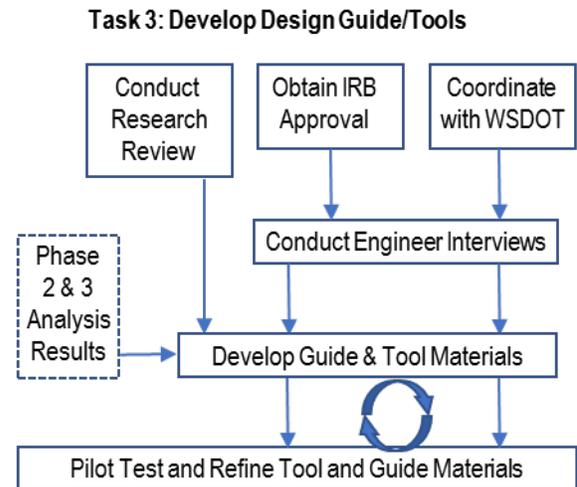


Figure 10. Overview of guide and tool development activities in Task 3.

Task 4: Develop Training Course

The objective of this task is to develop a 1-day training course to help engineers apply these resources to design problems they encounter or are currently dealing with. The course will be segmented into logical modules, with each module having a specific set of learning objectives and subtopics. The course will include a mix of lectures, case studies, group exercises, and quizzes. It will focus on the presentation of real-world problems and issues, as well as practical and implementable solutions. As we develop the training course, we will incorporate pictures, graphics, and videos – as appropriate – in order to engage and interest course participants. Candidate topics for the course include:

- Introductions and Course Objectives
- Fundamentals of Human Factors & Driver Behavior
- Roadway Factors Influencing Speed Perception, Speed Choice, and Speed Selection.
- Countermeasures to Address Speeding Problems

Battelle has developed a similar training course for state-, county- and local-level engineers, planners, and designers on how to incorporate Human Factors and information from the HFG (Campbell et al., 2012) into their design approaches (see also Campbell, 2015). Battelle will coordinate closely with WSDOT to design the initial course around their training requirements and policies. Relevant data and findings from Phases 1, 2, and 3 of this IAP project will be included, in addition to training on use of the guide and tools developed in Task 2. The training course will incorporate relevant elements from Context Sensitive Solutions. The training course will also include break-out discussion groups that address practical examples that participants will be asked to contribute prior to participating in the course. At least three pilot tests will be conducted at different offices throughout WA state, and nearby States such as Oregon and Idaho will be invited to participate. Course materials and presentations will be refined after each session (see Figure 11).

Task 5: Final Report

The project methods and findings will be documented in a final report. The report will include appendices that contain the final guide, tool, and training course scripts and materials. These materials will also be provided separately on digital media for distribution within WSDOT and FHWA.

Optional Data Collection Validation Task

This section describes an optional task that can be conducted to provide further validation of the Phase 2 results. (see Figure 12). Although this optional task is not essential to completing Phase 3, it addresses a missing piece in the overall project, which involves generalizing the findings obtained using the small SHRP2 driver sample to a broader sample of Washington State drivers.

The Phase 2 research involved roadway characteristics that already existed in the road network. This reliance on existing roadway features makes it possible to conduct follow-up data collection to validate the findings from the SHRP2 data. Specifically, although the SHRP2 data provided detailed information about drivers and trips, the number of traversals at each location was relatively small in comparison to spot-speed studies. Therefore, an important next step is to

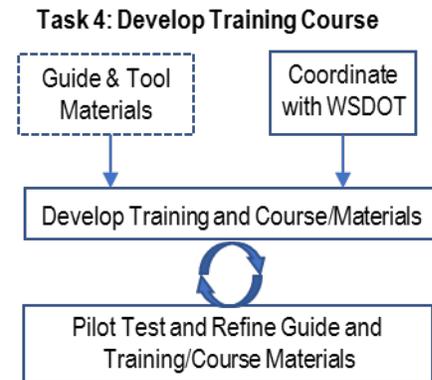


Figure 11. Overview training course development activities in Task 4.

validate some of the key findings with a greater number of observations from passing vehicles. This optional task will have two parts. In the first part, Battelle will work with WSDOT and some of the WA regions to obtain historical speed data on certain roads. If we can find suitable comparisons, we will analyze these data to directly validate some of the findings from Phase 2.

Another approach will be to identify a small set locations that currently have features of interest, along with suitable comparison locations that differ in terms of a key roadway characteristics.

The Battelle team will then coordinate with WSDOT to obtain spot-speed measurements at up to 15 test and control sites. Data collection would be coordinated to minimize avoidable differences across sites, such as time of day, seasonal effects, etc. Matched sites would be compared by using ANOVA. If we are unable to match key features across all sites, we will examine using methods such as ANCOVA to control for covariates. This approach will provide a low-cost natural experiment that will permit confirmation of patterns observed in the SHRP 2 data. Findings will be summarized and incorporated into the final report and training materials.

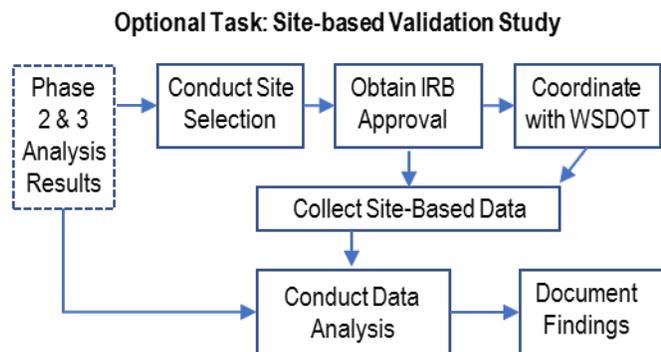


Figure 12. Overview of activities for conducting site-based speed validation in the Optional Task.

MANAGEMENT APPROACH AND MITIGATION RISK FOR PHASE 3

As part of our Risk Management approach, the Battelle team identified a series of potential risks inherent in the proposed Phase 3 activities. Each risk was evaluated based on its likelihood of occurring and its severity—the extent to which it would impair our ability to successfully meet the project objectives. The risks with the highest combination of severity and likelihood are listed in Table 5. For each of these risks, mitigations that would be effective in reducing either the severity or likelihood were identified, and corresponding changes were made to the Phase 3 plan. Based on these changes, the Battelle team is confident that risks have been sufficiently reduced to meet the project objectives with a high degree of certainty. Nevertheless, an essential component of our risk management plan will be to monitor the identified risks, and take proactive actions to ensure that stakeholders are made aware of any concerns--and more importantly, to have contingencies in place to avoid potential problems before they occur.

Table 5. Potential project risks, estimated impact, and corresponding mitigation strategies.

Task	Risk	Severity	Likelihood	Mitigation
3	Inadequate information from analyses to support guide/tool development	Medium	Medium	Supplement findings with information from research literature
4	Training course does not meet engineers needs	High	Medium	Pilot test training courses and collect feedback to improve training Work closely with WSDOT to ensure the materials conform with requirements
Opt.	Historical speed data does not provide suitable comparisons	Medium	Medium	Obtain spot speeds from locations selected to have suitable features
Opt.	Local conditions confound comparability of spot-speed data	Medium	High	Obtain operational data from WSDOT and scout locations in advance. Use statistical adjustments

In addition to the mitigations of specific risks described in Table 5, Battelle has operational procedures and experience that will ensure that project work is conducted on time and schedule.

General Project Management Procedures. Battelle is an experienced DOT contractor with the requisite experience and administrative infrastructure to manage projects containing the main elements of Phase 3, and has successfully managed numerous projects for DOT similar in size and scope. We are proposing the same organizational structure used successfully on other contracts performed in the past for DOT and other clients. A key component of this is the PM, Dr. Christian Richard. He will serve as a single point of contact between Battelle and the FHWA. Dr. Richard will be supported by experienced staff and Battelle tools and systems to track budgets and costs, monitor progress, anticipate problems, and identify solutions.

International Organization for Standardization (ISO) Management System. The Battelle organization executing this contract is ISO 9001:2008 certified (certificate FM 586660). Battelle is committed to providing services and products of the highest quality. Our Management System provides timely, professional, and quality performance results based on effective planning and management control during work performance. Performance is measured against quality, cost, and schedule targets, ensuring that all requirements will be achieved.

Procedures for Ensuring Adherence to Schedule and Budget. Dr. Richard's commitment to frequent communications with NHTSA is a key dimension of our capability to accommodate normal delays and problems. Dr. Richard, the proposed PM, will work with the FHWA to define any delays and problems that may arise. Normal delays and problems will be dealt with before they threaten technical quality, project schedule, or project budget. Dr. Richard will have access to the depth of resources available throughout Battelle to address schedule and resource needs and will be supported by a dedicated Project Administrator providing current budget information for proactive project management.

Quality Assurance Procedures. Battelle's staffing plan includes a Quality Assurance Reviewer (QAR) who will review draft and final versions of all reports. This will ensure they are clearly written, complete, and address all project objectives. Dr. John Campbell of Battelle, a senior technical staff member with strong research experience not participating in the project, will serve as QAR. Dr. Campbell is an expert in traffic safety and literature reviews with 30 years of Human Factors research experience.

The schedule for the Phase 3 activities is shown in Figure 13. The Period of Performance for Tasks 1-5 is 18 months. The 12-month Optional Task activities can be conducted after the base activities, and time is included at the end to update the tools and training course with the findings from the optional task. The work proposed in Phase 3 does not require actions by oversight and review agencies.

Task	2017			2018												2019												2020																		
	Oc	No	De	Ja	Fe	Ma	Ap	Ma	Ju	Ju	Au	Se	Oc	No	De	Ja	Fe	Ma	Ap	Ma	Ju	Ju	Au	Se	Oc	No	De	Ja	Fe	Ma																
1 Project Management	[Blue bar spanning all months from Oct 2017 to Mar 2020]																																													
2 Conduct Additional Data Analysis	[Blue bar]			[Blue bar]																																										
3 Develop Speed Control Tools and Guide				[Blue bar]																																										
4 Develop Training Course																[Blue bar]																														
5 Final Report																[Blue bar]																														
6 Optional CM Validation																[Blue bar]												[Blue bar]																		

Figure 13. Proposed Phase 3 schedule.

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APPENDIX A – LITERATURE SUMMARY TABLE

The preliminary assessment of the literature for this study indicated several patterns in the findings as well as areas in which findings were mixed or inconsistent (see Table 7 at the end of this section). Two variables in particular were notable for their consistent mentions in the literature: lane width and shoulder width. These are consistently cited as having a well-established effect on speed. Specifically, narrower lanes and shoulders reduces the safety envelope for drivers (Herrstedt 2005), forcing them to attend to the driving task and slowing speeds. In contrast, wider lanes and shoulders provides more maneuvering room for drivers and a larger envelope for error correction (Deller 2015, Hansen et al. 2007, Starkey & Charlton 2015). It should be noted, however, that this effect may not be as established as it appears. Of the research we reviewed related to lane and shoulder widths, only one involved a site-based study (Hansen et al. 2007). The remainder are guidelines, literature reviews, and simulator studies. This lack of recent site-based speeding studies to provide support for the variable may indicate that there is a more complex relationship between lane and shoulder widths and speed than is being represented.

Medians are represented in the literature as a traffic calming and speeding countermeasure (Fitzpatrick et al. 2001, Krammes & Sheldahl 2009, Lantieri et al. 2015, & Chen et al. 2016). Medians with curbs and landscaping in particular are used to calm traffic around high access locations. Landscaping is believed to perceptually narrow lanes by adding road furniture to the driver's left, where they typically experience more open space (Lantieri et al. 2015 & Chen et al. 2016). However, median covers a variety of features, not just features used for traffic calming, which introduces some inconsistency. Flush painted medians, such as center turn lanes, can produce perceptual lane widening similar to a wide shoulder. This left-hand widening provides an additional recovery area and can encourage faster speeds (Fitzpatrick et al. 2001).

Unlike medians, barriers do not demonstrate consistent effects, and do not have as large of a body of literature to support them. Studies have proposed different effects for barriers on speed. Some studies conclude that barriers provide an additional sense of safety, allowing drivers to confidently increase their speed (Starkey & Charlton 2015). In contrast, other studies have concluded that the proximity of barriers to the vehicle creates "side-friction" that slows drivers down (Lantieri et al. 2015).

Posted speed signs and other road markings have a complex relationship with speeding, with a substantial body of supporting literature. While observing a posted speed sign can temporarily increase speed compliance (Haglund 2001), especially in areas with salient speed enforcement, many studies have consistently found that altering the posted speed of a road section without any changes to the design speed has no effect on the operating speeds that drivers choose (Binkowski et al. 1998, Sluster et al. 1998, Roads and Traffic Authority 2000, & Agent et al. 1998). This ties into one of the primary assumptions of the current project; that driver's select an operating speed based primarily on roadway characteristics rather than the posted speed limit.

Roadside environment can be difficult to separate from other variables in a way that is meaningful for the current project. Many studies tend to use it synonymously with urban and rural roads. The studies that do examine it however, tend to show that heavily treed roads have lower operating speeds than roads surrounded by wide flat fields (Fitzpatrick et al. 2001, Fildes et al. 1987, & Ewing & Dumbaugh 2009). There are several potential causes for this. First, the

closer roadside objects, like trees, are to the driver the higher the risk to them in an off-the-road crash. Flat, wide terrain provides additional recovery space and poses less risk. Secondly, visually confined environments provide stronger optic flow and motion cues, and peripheral flickering of nearby object creates a sense of higher speed that is lost if there are no peripheral objects (Barron et al. 1994). Drivers may lose their sense of how fast they are traveling through flat environments, resulting in incidental speeding.

There are different aspects of the visual environment can induce a sense of confinement. The proximity of objects to the roadway being one of the most critical. Objects closer to the roadway produce more prominent optical flow cues and create a more confining driving environment. A related but distinct dimension is the height of the lateral environment. Taller roadside objects/environment will be more confining and produce stronger motion cues than short objects, particularly those below the driver's line of sight. Also related is the environment overhanging the roadway. Low hanging foliage, overpasses, and tunnel ceilings can all produce confinement along another dimension, though with less frequency and consistency than the roadside environment, and provide a more global optical flow field. Apart from those dimensions, geometric features of the roadway itself can produce the same effects. Medians can produce left-hand confinement in the form of landscaping or reduce confinement by increasing the width of the roadway in the form of a center turn lane. Barriers, likewise, can produce confinement due to close placement on the roadway. Barriers with posts can also produce regular flickering that provide speed cues. Shoulders can reduce confinement by reducing the proximity of the roadside environment to the driver. All of these dimensions of confinement were codified into the Visual Confinement Pictorial Estimation Guide (See Appendix C). This guide was designed to allow a reviewer to integrate these features into a holistic assessment of the visual confinement of a particular roadway section.

Another roadway characteristic that has been examined in detail is urban/rural nature of roadways. The differences between urban and rural roads are manifold and not necessarily captured in speeding studies. Urban roads tend to have a greater number of access points, lower posted speed limits, and greater traffic speed variability (Ewing & Dumbaugh 2009, Roads and Traffic Authority 2000). Rural roads are less affected by congestion due to commuting traffic, time of day, and frequently have higher posted speed limits (Fildes et al. 1987, Rakha et al. 2006, & Hansen et al. 2007). This is not categorically the case, however, as high speed arterial routes may be grouped in with urban roads. The terms "urban" and "rural" are not consistently defined between studies, when they are defined at all. Population density, distance from urban centers, land use types, and more can be used to differentiate an area as "rural" or "urban". Environmental considerations, such as the impact of severe weather, may have different effects on urban and rural roads as well. Lower population rural areas are less served by snow plows during the winter, have longer wait times to remove debris after storms, and are less frequently repaired and renovated than urban roads. Road condition then affects the speeds at which drivers choose to travel. Along with this multitude of factors, subtler human differences may be at play. Several studies identified cultural differences between urban and rural communities as having a major impact on safety (Rakauskas et al. 2007, Saka & Perrino 1998, & Dhungana & Qu 2005). These differences, such as propensity for drunk driving, sensation seeking behavior or compliance with safety messaging campaigns, could have a significant impact on speed in different areas that would not necessarily be captured by a speeding study.

The literature review conducted in the current project also examined methodologies used in previous studies. While literature review, meta-analyses, and simulator studies have value in demonstrating trends and effects, more weight was given to the results of site-based studies because of their greater external validity. Simulator studies particularly, lack the fidelity to capture the holistic nature of roadway geometry that the current project was intended to study. Literature reviews and meta-analyses were primarily useful for establishing the consistency of the effects of interest for the current study.

Within the site-based studies themselves, there was a high degree of variability in terms of applicability to the current research. A number of studies focused on interventions and treatments at one or more sites (Lantieri et al. 2015, Rakha et al. 2006, Chrysler & Schrock 2005, Van Houten & Van Hutten 1987, & Krammes & Sheldahl 2009). The experimental nature of these studies provides reliable results, however those treatments tended to be simple or low cost such as signage or pavement markings, which are not of primary interest for the current study. Furthermore, some site-based studies used crash data as the outcome measure, which is only an indirect measure of operating speed (Olson et al. 2013 & Chen et al. 2016). A reduction in crashes implies lower speeds but does not conclusively demonstrate it. Of the studies that did use speed as a primary measure, the majority did not use continuous speed measures but rather spot speed (Krammes & Sheldahl 2009, Appelt 2000, Van Houten & Van Hutten 1987, Rakha et al. 2006, Chrysler & Schrock 2005, Binkowski et al. 1998, & Lantieri et al. 2015). This is problematic because it does not provide a clear picture of how individual geometric features influence speed in the same way that a continuous measure does. At any given spot, the effect of roadway geometry may be overwhelmed by an uncontrolled variable, requiring many sites to produce definitive results. Conversely, continuous speed measures, such as instrumented vehicles or laser arrays, are expensive and cumbersome so studies which employ them were generally limited in number of sites, rendering it unclear if the results are due to the consistent effects of geometric features or are due to the peculiarities of those sites (Fitzpatrick et al. 2001, Hansen et al. 2007, & Turner et al. 2015). The results of the literature analysis demonstrate the need for a large-scale, multi-site, continuous speed measure study as the best way to disentangle the numerous effects of different roadway features and geometries on driver behavior.

Table 7. Summary of research findings from the literature.

Variable	Description	Sources
Lane Width	As lane width decreases, drivers tend to slow down due to the reduced distance between them and hazards.	Fildes, B. N. et al. (1987). Herrstedt, L. (2005). Ewing, R., & Dumbaugh, E. (2009). Deller, J. (2015). Melo, P. et al. (2012). Hansen, G. et al. (2007).
Shoulder Width	As shoulders narrow driver speeds tend to decrease. Can be perceptually the same as a narrower lane. Wide shoulders may encourage faster speeds because they provide a recovery area.	Deller, J. (2015). Starkey, N. J., & Charlton, S. G. (2015). Melo, P. et al. (2012). Hansen, G. et al. (2007).
Medians	Landscaped medians and medians with curbs tend to calm traffic by limiting access and bringing road furniture closer to the driver, whereas flat medians can increase speeds by providing more room and recover options.	Fitzpatrick, K. et al. (2001). Krammes, R., & Sheldahl, E. (2009). Starkey, N. J., & Charlton, S. G. (2015). Lantieri, C. et al. (2015). Chen, H. et al. (2016). Bham, G. H. et al. (2015). Olson, D. et al. (2013).
Roadside Environment	The presence of trees close to the road tends to encourage lower speeds while flat ground encourages higher speeds.	Fitzpatrick, K. et al. (2001). Rakauskas, M. et al. (2007). Fildes, B. N. et al. (1987). Stephan, K. L. (2016). Ewing, R., & Dumbaugh, E. (2009). Giles, M. J. (2004). Hansen, G. et al. (2007). Abele, L., & Møller, M. (2011). Chen, H. et al. (2016).
Speed Limits and Signage	Speed limit signs can temporarily increase the probability of compliance with the speed limit of a road, however selecting a posted speed that is much lower than driver's preferred operating speed does not result in lower observed speeds.	Fitzpatrick, K. et al. (2001). Herrstedt, L. (2005). Krammes, R., & Sheldahl, E. (2009). Sluster, J. et al. (1998). Roads and Traffic Authority. (2000). Ewing, R., & Dumbaugh, E. (2009). Deller, J. (2015). Van Houten, R., & Van Hutten, F. (1987). Chrysler, S. T., & Schrock, S. D. (2005). Saka, A. A., & Perrino, C. S. (1998). Haglund, M. (2001). Hansen, G. et al. (2007). Agent, K. et al. (1998). Binkowski, S. et al. (1998). Dhungana, P., & Qu, M. (2005). Fildes, B. et al. (2005).
Barriers	Results are mixed. Barriers seem to create side friction which lowers speeds, but can create a sense of safety which can increase speed.	Starkey, N. J., & Charlton, S. G. (2015). Lantieri, C. et al. (2015). Chen, H. et al. (2016). Bham, G. H. et al. (2015). Olson, D. et al. (2013).
Rural Roads	Results mixed. Rural roads can have either lower or high posted speed limits/design speeds than urban roads. Poor pavement conditions and greater effects of adverse weather can reduce speeds; lack of enforcement can increase speeds. Cultural differences can affect speeds as well.	Fildes, B. N. et al. (1987). Herrstedt, L. (2005). Krammes, R., & Sheldahl, E. (2009). Appelt, V. (2000). Rakha, H. A. et al. (2006). Melo, P. et al. (2012). Hansen, G. et al. (2007). Turner, B. et al. (2015). Rakauskas, M. et al. (2007). Saka, A. A., & Perrino, C. S. (1998). Dhungana, P., & Qu, M. (2005).
Urban Roads	Results mixed. Urban roads tend to have lower design speeds, but also include high volume and speed arterials. The higher density roadside environment in built urban areas may reduce speeds. Time of day plays a greater role. Cultural differences may play a role as well.	Tarris, J. (1996). Fitzpatrick, K. et al. (2001). Fildes, B. N. et al. (1987). Stephan, K. L. (2016). Rakha, H. A. et al. (2006). Hansen, G. et al. (2007). Edquist, J. et al. (2012). Roads and Traffic Authority. (2000)

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APPENDIX B – VISUAL CONFINEMENT PICTORIAL ESTIMATION GUIDE

Visual Confinement Pictorial Estimation Guide:

Using this Document: The purpose of this document is to help the reviewer assess the visual confinement of a particular roadway. Visual confinement is an emergent property of the geometric and environmental features of a roadway. It consists of individual roadway features that separately influence a drivers' sense of visual confinement. These features include:

- Roadside Environment-Lateral Environment
- Roadside Environment-Lateral Proximity
- Medians
- Barriers
- Shoulders
- Overhead Environment
- Additional Variables (described below)

To assess the visual confinement of a site using this document, find the pictures that most closely resemble the features of the site on each of the rating scales. If the site primarily aligns with the high confinement features of each scale or primarily aligns with the low confinement features, then that is how the overall level would be rated. The site can be said to have a medium level of confinement if the site contains a mixture of high and low confinement features, or falls mainly in the middle of each scale, examples are provided at the end. Certain roads will contain features not shown here but those features should be incorporated into the reviewer's estimation as well. Additionally, other features may affect speed.

Motion Cues: Roadside features also contribute motion cues that can affect the driver's perceived speed. Peripheral motion cues created by roadside objects can alter the driver's perceived speed and cause them to change their operational speed. Objects like trees, fence posts, and signs that create peripheral motion and flickering should be considered as increasing visual confinement.

Safety Envelope: The safety envelop of a roadway can be defined as how forgiving the road is of driver errors. Forgiving roads provide room to correct errors with lower chance of hitting objects, or minimizes the speed and severity of any impacts that do occur. Non-forgiving roads are more challenging to drive on, have low tolerance for mistakes, and severe potential consequences.

Roadside Environment: Roadside environment comprises the environmental context of the roadway. Whether the road passes through a built urban area of tall buildings, low grassy hill, dense forest, etc. Roadside environment comprises both the type of environment, the density of that environment, and other visual aspects such as the amount of visible horizon and skyline.

The two primary dimensions of interest are lateral environment and proximity. Combining these dimensions demonstrates that tall objects which directly abut the road produce significantly more confinement than low objects placed far back.

Lateral Environment: Lateral environment is the height of the objects that populate the roadside.

Scope of variable: The height/size of the objects that make up the immediate lateral profile, including roadside furniture and sidewalks.

HIGH (4)	MEDIUM-HIGH (3)	MEDIUM-LOW (2)	LOW (1)
			
<ul style="list-style-type: none"> - Tall buildings and trees - Average of 3 stories or greater - Height is driven by tall buildings and trees 	<ul style="list-style-type: none"> - Mostly high lateral environment that includes visible overhead sky - Average of 2 stories or greater - Height is variable and intermitent 	<ul style="list-style-type: none"> - Low lateral environment with visible sky and some features beyond the immediate road - Average of 1 story - Height is intermitent low-medium 	<ul style="list-style-type: none"> - No lateral environment (Barriers are a separate category) - Low, mainly fields/water - Some spares objects

Proximity: Proximity is how closely the objects encroach upon the roadside.

Scope: Objects that encroach immediately upon the road are of greatest interest. The further back the objects are placed, the taller they need to be to produce the same sense on confinement.

HIGH (4)	MEDIUM-HIGH (3)	MEDIUM-LOW (2)	LOW (1)
			
<ul style="list-style-type: none"> - Roadside environment begins immediately after pavement - Doesn't support pedestrians 	<ul style="list-style-type: none"> - One side walk worth of offset; sidewalk may include sparse furniture - Intended for pedestrians 	<ul style="list-style-type: none"> - Clear zone free of objects beside roadway - Usable by pedestrians - Approx. 10-20 ft. 	<ul style="list-style-type: none"> - Clear zone, parking, and other features set well back from roadside

Median: Roadway medians are strips that separate travel lane directions on a roadway either with a physical barrier or pavement markings. Visually confining medians include vertical features that block line of sight such as trees and shrubs. Low confinement medians such as center turn lanes and grassy highway medians widen the roadway without adding vertical features making the environment more open.

Scope: Medians covers geometric markings and structures that separate travel lanes. While barriers can act as medians, they should be rated based on the barrier scale presented later.

HIGH (4)	MEDIUM-HIGH (3)	MEDIUM-LOW (2)	LOW (1)
			
<ul style="list-style-type: none"> - Tree limbs can overhang the roadway, increasing confinement - Raised bed brings ground cover close to driver's eye level - Foliage abuts or encroaches roadway, no clear zone 	<ul style="list-style-type: none"> - Raised bed brings ground cover close to driver's eye level - Foliage abuts roadway, no clear zone - No trees - Concrete barriers in center of roadway 	<ul style="list-style-type: none"> - Adds additional lane that widens roadway - Infrequently used, adds cross-section without increasing traffic - Continuous Center Turn Lanes 	<ul style="list-style-type: none"> - Significantly widens roadway without adding any traffic or vertical environment

Barrier: Barriers are walls that range in height placed either in the center or along the edge of a roadway to restrict movement. Visually confining barriers are taller and solid whereas non-confining barriers are shorter, visually permeable, or entirely absent.

Scope: Barriers for this project are generally placed on the side of a roadway, though in certain cases a road may have a barrier and a median, or multiple barriers. Short concrete walls are counted as barriers.

HIGH (4)	MEDIUM-HIGH (3)	MEDIUM-LOW (2)	LOW (1)
			
<ul style="list-style-type: none"> - Visually non-permeable - Solid lane demarcation 	<ul style="list-style-type: none"> - High poles create peripheral motion cues - Visually permeable - Top above eye level for many drivers 	<ul style="list-style-type: none"> - Posts create peripheral motion cues - Below eye level for many drivers 	<ul style="list-style-type: none"> - Low, visually permeable - Small visual impact - Below eye level for many drivers

Shoulder: Shoulders include bike lanes, HOV/transit lanes, and other additional lanes that widen the side of the road. Shoulders that experience traffic such as bike and HOV lanes can increase the mental workload of drivers in through lanes. Visually confining shoulders are small or absent whereas non-confining shoulders are broad with little traffic, such as transit lanes, they expand the roadway cross section.

Scope: Shoulder includes any additional pavement that is part of the roadway, which vehicles (Cars, buses, bicycles, etc.) could travel up. Sidewalks and non-paved clear areas are part of roadside environment.

HIGH (4)	MEDIUM-HIGH (3)	MEDIUM-LOW (2)	LOW (1)
			
<ul style="list-style-type: none"> - Limited clear zone - Brings roadside closer to vehicles - 0-2ft. width 	<ul style="list-style-type: none"> - Widens roadway - Introduces intermittent bike traffic - 3-6ft. width 	<ul style="list-style-type: none"> - Widens roadway and clear zone without adding traffic - 6-10ft. width 	<ul style="list-style-type: none"> - Widens roadway significantly - Adds transit traffic - 10 - +12ft. width

Overhead Environment: Objects that hang over the roadway above drivers increase visual confinement. Low ceilings, such as in tunnels, are highly visually confining while large open sky is minimally confining. Other objects, such as tree branches, overpasses, roadside advertisement, and large signs produce intermittent confinement but increase confinement overall if they are present consistently and actively block sight. The amount that overhead environment affects visual confinement is dependent on the frequency of overhead features within the roadway section of interest. A lack of overhead environment can reduce total visual confinement, so a clear overhead environment should be rated at the “Low” end of the scale.

Scope: Overhead environment must be sufficiently close to the vehicle to have a potential impact on speed. Power lines, for example, would be too greatly elevated with high visual permeability to have a significant impact. Structures designed to attract attention (Signs, billboards) and structures large enough to support vehicles or pedestrians, as well as foliage dense and close to the car are all within the scope of overhead environment.

OVERHEAD ENVIRONMENT	NO OVERHEAD ENVIRONMENT
	
<ul style="list-style-type: none"> - Extends for a distance above the roadway (significant depth) - creates peripheral motion cues - Sign area increases occlusion - Color and message may capture attention - The posts create peripheral motion cues - Generally occurs with other factors that increase visual density 	<ul style="list-style-type: none"> - Clear and visible sky - Reduces available motion cues

Additional Variables: Other variables of interest that affect visual confinement are either taken from the RID directly or are not encompassed by the above definitions or examples.

Number of Lanes:

High visual confinement areas tend to have fewer lanes, 1-2 lanes per travel direction, which decrease the roadway cross-section

Medium to low confinement areas tend to have greater than 2 lanes per travel direction with low confinement areas tending to have the most lanes, which increases the size of the roadway cross-section

Lane Width:

Some roads have travel lanes of different sizes or that narrow or widen depending on the environment the road passes through. Roads with wide lanes tend to be less visually confining than roads with narrow lanes

Turn lanes:

The presences of turn lanes tend to increase the size of the roadway cross-section and reduces visual confinement

Parking lane:

On-street parking puts objects in closer proximity to the roadway then they might be otherwise, creating additional visual confinement

Signage:

Signage that hangs over the roadway can increase visual confinement and distract from the driving task. Commercial signage and billboards should be counted if they are present for half of the road section or more with consistency. Note should be made of navigational signs, guidance signs, and variable message/speed signs so the data on them can be extracted from the RID.

Visual Confinement: Taken together, the scales presented here can be combined to examine the emergent property called Visual Confinement. Characteristics of high visual confinement environments are close proximity to the roadway, densely clustered objects, and occluded distant objects/horizon. Characteristics of low visual confinement are objects recessed back from the roadway, sparse objects in the environment, unobstructed view of distant objects/horizon. It is important to note that some of these variables should be weighted more heavily than others. Roadside environment, number of lanes, and shoulders are present on all roads and should be weighted more heavily. Overhead environment, though less common, has a large impact. Medians and barriers are not always present and should be weighted less heavily. If the roadway features as asymmetrical, then using the side of the road closest to the travel direction to determine the features and evaluate the other travel direction separately.

Scope: Visual confinement encompasses all the variables discussed so far. Any additional variables are left to the rater's discretion.

OVERALL HIGH (3) - Example	OVERALL MEDIUM (2) - Example	OVERALL LOW (1) - Example
		
<ul style="list-style-type: none"> - Roadside Environment: Dense foliage (High proximity, high lateral) - high - Median: Landscaped with trees – high - Barrier: None - medium - Shoulder: Small – high - Overhead Environment: Overhanging foliage - Travel Lanes: 2 – high - Turn Lanes: 0 – high 	<ul style="list-style-type: none"> - Roadside Environment: Industrial/commercial (Medium-high proximity, medium-low lateral) - Median: Center Turn Lane – Medium-low - Barrier: None – medium - Shoulder: Small – Medium-high - Overhead Environment: None - Travel Lanes: 2 - Turn Lanes: 1 	<ul style="list-style-type: none"> - Roadside Environment: Grassy/low hills (Low proximity, low lateral) - low - Median: Wide Grassy - low - Barrier: Wire/fence - low - Shoulder: Standard (Both sides) - low - Overhead Environment: None - Travel Lanes: 3 (Separated by barrier) - medium - Turn Lane: 0 – high

Safety Envelope: Safety Envelope is a theoretically distinct emergent roadway feature that may affect driver speed choice. Roads that are more tolerant of errors facilitate faster driving as compared to roads where any error could be very costly. For this study, safety envelope is a different concept than visual confinement and is described here to help keep the ideas distinct. Safety envelope is also impacted by transient roadway features including weather, presence of bicyclists, access to pedestrians, and high volume of on street parking.

Large Safety Envelope - Example	Small Safety Envelope - Example
	
<ul style="list-style-type: none"> - Straight road, oncoming traffic visible from a distance - Few roadside objects - Flat roadside environment 	<ul style="list-style-type: none"> - Curving road with blind corners - Many roadside objects - Cliff

APPENDIX C – VARIABLES USED

This section lists the variables that were used in the analysis of speeding. Data sources included SHRP2 NDS time series variables and roadway data from the RID database.

NDS VARIABLES

Table 8 lists the Time series variables used in the analysis of speeding. These data consist of GPS location and associated attributes, captured at a sample rate of one sample per second using nearest neighbor sampling.

Table 8. Time series variables received from the SHRP2 data contractor.

Variable Category	Variable
Tracking/Maintenance Variables (one value per traversal)	Subject ID, File ID ⁸ , Event ID ⁹ , System Time Stamp, Link ID ¹⁰ , Traveled Way ID
Speed Measures (continuous measures)	Longitudinal Acceleration, Lateral Acceleration, GPS Speed, Network Speed, Accelerator Position, Brake Pedal State
Position Measures (continuous measures)	Lane Marking Type (left and right), Lane Marking Probability (left and right), Lane Position Offset, Lane Width (from camera), Latitude, Longitude, Steering Wheel Position
Environment (continuous measures)	Ambient Illuminance, Computed Time Bin (Time of Day), Wiper State
Proximity (Radar-based) (continuous measures)	Forward Range (X and Y; two tracks), Forward Range Rate (X and Y, two tracks), Target Identification (two tracks)

RID VARIABLES:

Table 9 lists the roadway variables from the RID database that were used in the analysis of speeding. Note that these data are coded in the RID as continuous measures that change with location, but they were aggregated across traveled way and treated as single values in the early findings analysis.

Table 9. RID (roadway) variables.

Variable Category	Variable
Alignment (continuous measures)	Curvature, number of through lanes, lane width, shoulder width, center turn lane, presence of median, median type
Road type (continuous measures)	Functional Class code
Environment (continuous measures)	Presence of barriers, percentage of traveled way length with barriers, presence of lighting, presence of posted speed sign within the site

⁸ File ID is a unique identifier per trip. Generally, a file is created when the driver turns the key to start the vehicle and terminated when the key is turned off.

⁹ Event ID is a unique identifier per traversal across a specific traveled way. Because a driver can traverse more than one traveled way in a single trip, this variable provides a method for identifying and tracking individual traversals.

¹⁰ Link ID identifies the road segment on which the GPS point is located. Battelle used this variable to snap the GPS points to the road and to obtain the requisite information necessary to identify and extract the roadway variables from the various data tables in the RID.

APPENDIX D – REGRESSION MODEL ODDS RATIOS

This section includes four figures including four multivariate models' odd ratios with 95% confidence interval (for episodic speeding) and coefficients with 95% confidence interval (for maximum delta speed) with/without the *Traveled Way*. While key statistics were reported in the “Findings to date and a description of the significance of those findings” section, the figures can provide supplementary information for the model outputs.

For the logistic regression models (i.e., models with episodic speeding outcomes), coefficients were converted to odds ratio, which can be interpreted more practically (Figure 14 and Figure 15). Predictors without statistical significance are displayed in a lighter shade and 95% confidence intervals were presented as horizontal bars. Colors represent direction of coefficients (red: negative, blue: positive). Given that coefficients were converted to odds ratio, red represents odds ratio between 0 to 1 (variable associated with lower odds of speeding), whereas blue represents odd ratio greater than 1 (variable associated with higher odds of speeding) Note that dotted vertical line represents a null hypothesis point.

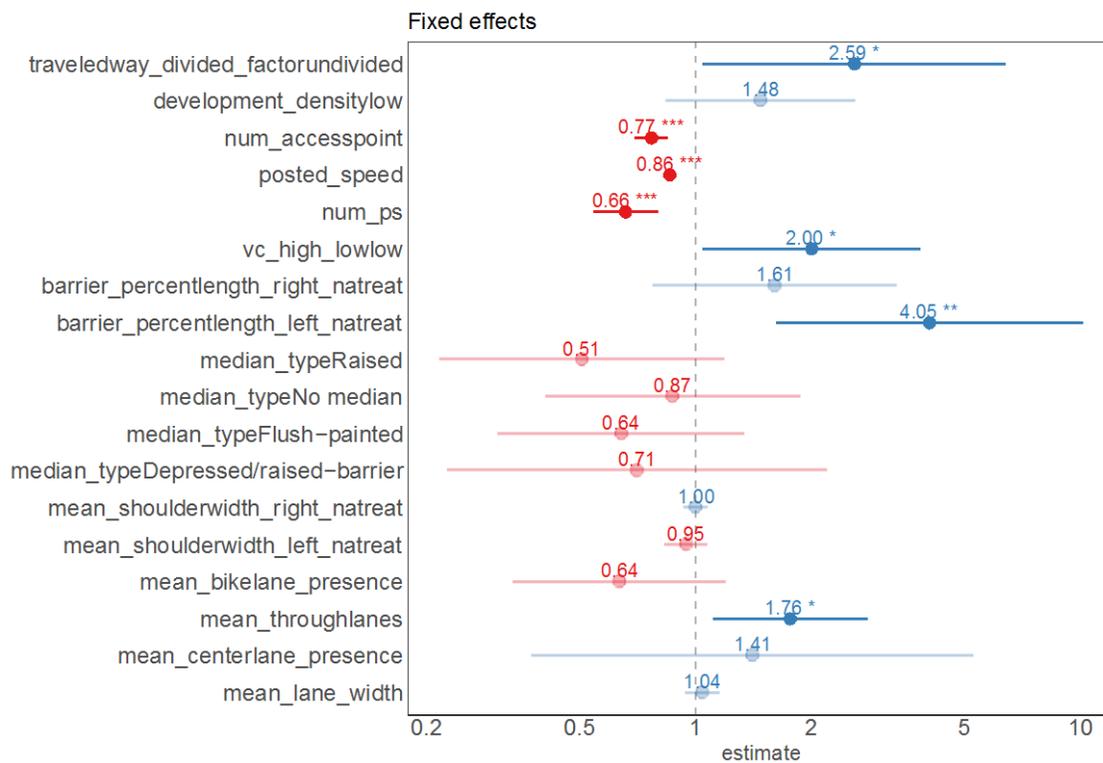


Figure 14: Multivariate models with Traveled Way as a random effect for episodic speeding.

Fixed effects

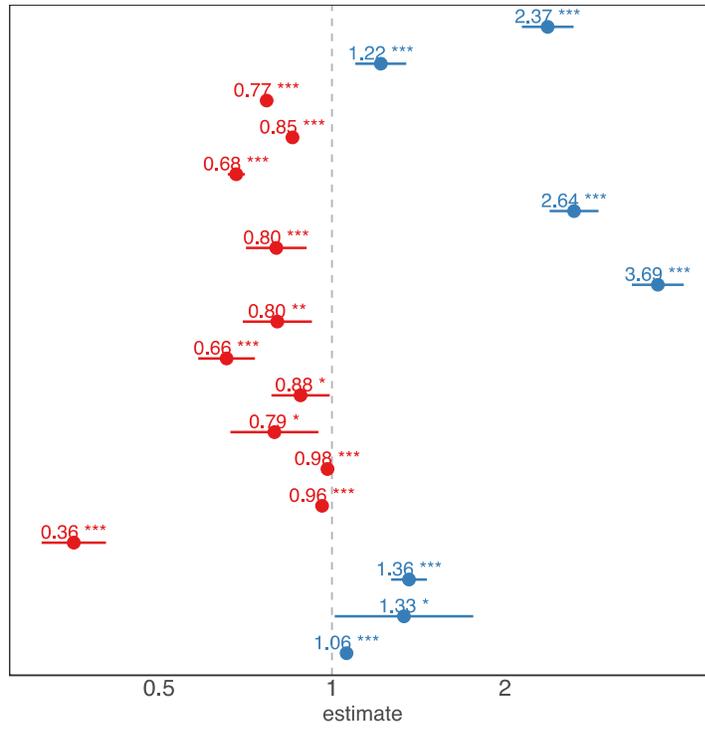


Figure 15: Multivariate models without Traveled Way as a random effect for episodic speeding.

For liner regression models (Figure 16 and Figure 17), coefficients and 95% confidence interval were presented (rather than odds ratio in the previous figures). Note that for the coefficients, the null hypothesis point is 0 (dotted lines in Figure 16 and Figure 17). The color coding to represent confidence intervals were the same as with logistic regression models.

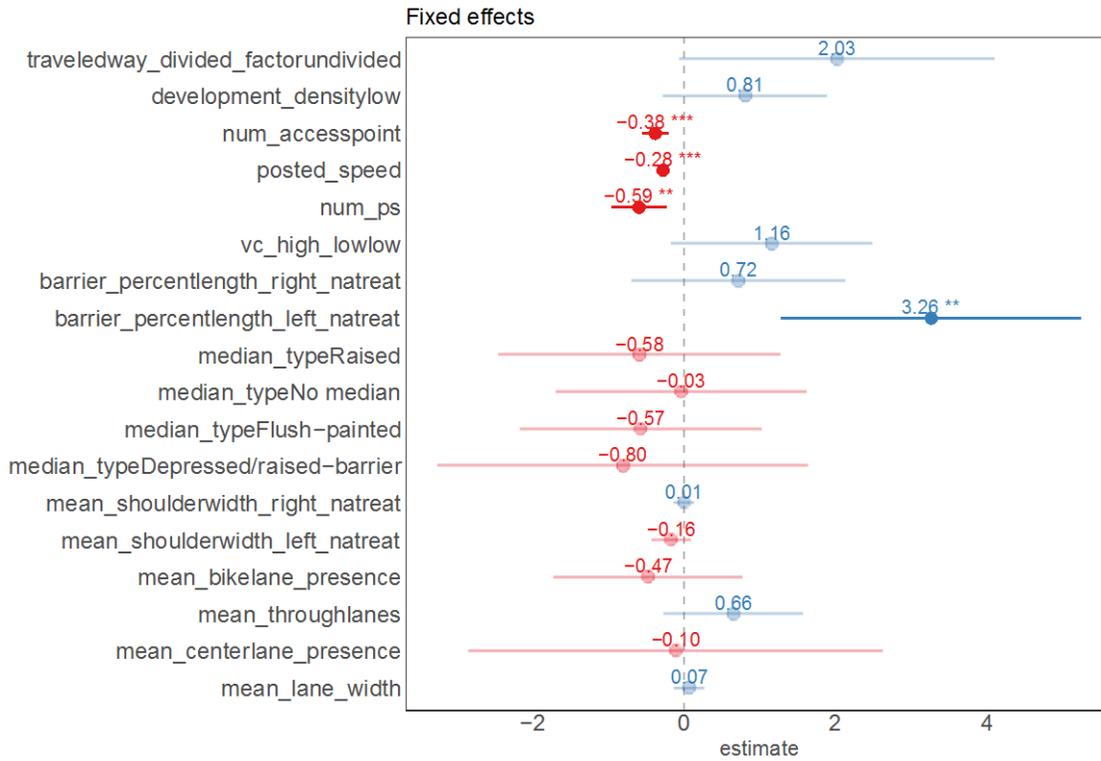


Figure 16: Multivariate models with Traveled Way as a random effect for maximum delta speed.

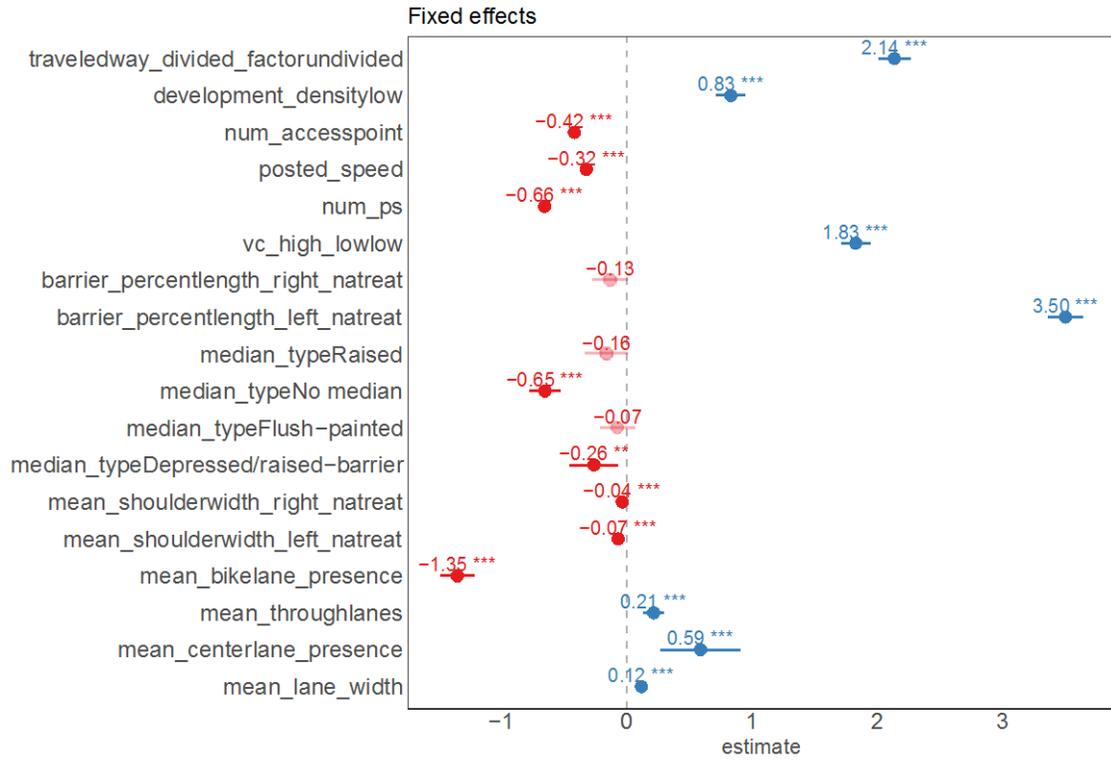


Figure 17: Multivariate models without Traveled Way as a random effect for maximum delta speed.