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

FINAL REPORT

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1 INTRODUCTION

This Phase 1 Implementation Assistance program (IAP) research project conducted preliminary analyses of the SHRP 2 Naturalistic Driving Study (NDS) data to examine the effects of **specific roadway locations** and **infrastructure features** on **episodic speeding** by NDS participants in and around Seattle, WA.

PROBLEM STATEMENT

Speeding-related crashes continue to be a serious problem, and for over a decade, there has been little change in the proportion of speeding-related fatal crashes while crashes related to seatbelt use and impaired driving have steadily declined (NHTSA, 2013). Various studies have found that a range of factors are associated with speeding, including a range of demographic, personality, roadway, environmental, vehicle, and situational variables (see also, Richard et al., 2011). An unexamined aspect of speeding is the influence of infrastructure on speeding data obtained from naturalistic driving studies. Small-scale studies have been done (e.g., see Fitzpatrick et al., 2001), but a recent NCHRP report (Campbell et al., 2012) concludes that "the empirical record is far from conclusive with respect to the ability to predict drivers' speed choices associated with relevant geometric, environmental, and traffic factors."

The SHRP 2 NDS data provide a unique opportunity to examine speeding behaviors in Washington state, to collate speeding events across drivers and trips, and to determine if specific aspects of the infrastructure, such as grade, lane width, access density, roadside parking, number of lanes, visual cues to motion, and shoulder width seem to be consistently associated with higher speeds, once other factors (e.g., personality factors, demographics, time-of-day) have been accounted for. Since the effects of roadway design features are the focus of the analysis, the results have great potential for identifying features that may be associated with excessive speeding and for countermeasures (e.g., changes in geometry, additional traffic control devices, signs, enforcement, or education) that could be applied. Pedestrians and bicyclists are at particular risks at some locations associated with excessive speeding, and countermeasures aimed at protecting these road users may emerge from this research as well.

OBJECTIVES

The goal of the Phase I project was to conduct proof-of-concept analyses using a small SHRP2 dataset to develop, test, and validate the feasibility of several analytical approaches that could be used to address the following question: *Can the SHRP2 data be used to identify and assess the effects of specific roadway (e.g., geometries, grades, lane widths, etc.) and traffic engineering features (signs, curves, lighting, etc.) on driver's speeding choices and speed-relevant behaviors?* To this end, we identified five sub-questions to assess the feasibility of conducting a larger Phase 2 research study. These feasibility questions include:

- *Is the research question methodologically tractable using SHRP2 data?*
- *Can the predictor and dependent measures be adequately quantified?*
- *Do appropriate analytical approaches exist to answer the question?*
- *Is there an underlying behavioral effect that can be examined?*
- *Is there a benefit to conducting this study?*

This report describes the pilot study that was conducted to address these feasibility questions. The questions are answered at the end of Section 5.

2 LITERATURE REVIEW

SUMMARY OF KEY LITERATURE[1]

It is clear from both everyday observation and research data that most drivers do not comply with posted speed limits. For example, Harkey, Robertson, and Davis (1990), collected and analyzed speed data from 50 locations in four states to determine travel speed characteristics. 70.2% of drivers did not comply with the posted speed limits, specifically: 1) 40.8% exceeded posted speed limits by more than 5 mi/hr, 2) 16.8% exceeded posted speed limits by more than 10 mi/hr, and 3) 5.4% exceeded posted speed limits by more than 15 mi/hr. TRB (1998) conducted a broad review of current practices in setting speed limits and provided guidelines to state and local governments on appropriate methods of setting speeds limits and related enforcement strategies. With respect to driver perceptions of speeding and speed limits, the review found that most drivers: 1) do not perceive speeding as a particularly risky activity, 2) will drive at what they consider an appropriate speed regardless of the speed limit, and 3) advisory speeds have modest to little effect on driver speed, particularly for drivers who are familiar with the road. Taken together, these attitudes result in generally low compliance with posted speed.

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 Campbell et al. (2012), and in Table 1 below. As seen in the table, some relationships between speeding and infrastructure features are well-established (such as the effects of higher design speeds and grades), but others are unclear (i.e., mixed) or without sufficient data to draw conclusions.

Table 1. Summary of the effects and strength of the empirical evidence regarding infrastructure effects on speed (from Campbell et. al., 2012).

Factors Associated with HIGHER Free-flow Speeds	**Strength of Empirical Evidence**	
	Rural Highways	**Low-speed Urban Streets**
Higher Design Speed	Solid	Solid
Grade	Solid	Solid
Wider Lane Width	---	Mixed
Higher Access Density	Solid	Mixed
Separated bicycle lanes	---	Mixed
Less Pedestrian/ Bicycle side friction	---	Mixed
No Roadside parking	---	Mixed
Number of Lanes	Solid	---
Shoulder Width	Mixed	---

[1] Note that a formal literature review was not conducted as part of this Phase I project, though the research team is quite familiar with the literature in this area (see also Richard et al., 2011).

3 METHOD OF ANALYSIS

This section describes the process used to prepare the data and perform the analysis. Our overall approach was to develop a set of reduced variables derived from NDS time-series data and RID roadway variables and to perform a series of analyses, including descriptive statistics and inferential analyses using linear and logistic regressions, based on this reduction. This section also describes a pilot study that was conducted in support of the larger data analysis.

PRE-PILOT STUDY

A pre-pilot study was conducted in order to determine the most appropriate sample rate at which to vehicle data (e.g., 1 vs 10 Hz). Capturing vehicle data at a high sample rate provides better information about the timing of events (i.e., brake presses with 100 msec temporal resolution), and can be useful for identifying rapid changes in speed around critical events, heavy braking, etc. However, the finer temporal resolution yields a substantially larger dataset with important tradeoffs with respect to the cost of acquiring, managing, and processing the data. In the pre-pilot study, vehicle variables were examined to determine the most appropriate sample rate with which to acquire these data.

The test site for the pre-pilot study was selected from a list of locations provided by WSDOT that identified sites that were overrepresented in terms of speed-related crashes. A site that had relatively high crash rates and interesting physical characteristics was chosen for examination in the pilot study. This site, located on SR-9 in Arlington, WA, consisted of a rural road with a long, moderately-steep grade. The site included a curve with tall trees on both sides of the road, a speed limit change, and limited visibility of an intersection downstream of the site.

Time series data for all traversals at this site were requested, and 79 traversals were received, with key vehicle data sampled at 10 Hz. Other, less critical variables were sampled at 1 Hz. Comparisons of the 10 Hz versus 1 Hz data suggested that differences were minimal. Moreover, basic kinematic analyses of vehicle speed changes in different scenarios indicated that using 1-Hz data would likely result in minimal loss of key vehicle information since the inertia of vehicles during speed changes resulted in meaningful changes vehicle dynamics occurring over longer time scales. This indicated that sampling at 10 Hz was unnecessary for this study. Another consideration was that only a subset of vehicles had CAN speed available at 10 Hz, and GPS speed was only available at 1 Hz. Also, vehicle acceleration data was too noisy to be usable at 10 Hz, and was actually more accurately represented by computing it from speed changes. Thus, 1 Hz was selected as the sampling frequency.

Another important finding in the pre-pilot study was that the actual amount of speeding observed in SHRP2 data at the test site was much lower than expected. This had important implication for site selection because our approach requires at least low-to-moderate amounts of speeding (i.e., exceeding +10 mph) at most locations. The challenge was that the resources for obtaining site data in this project were limited to a single query, so we only had one attempt to obtain a sufficient amount of speeding for the primary feasibility study. However, posted speed limit data were not available in the NDS to aid with site selection. Therefore, we needed a strategy for maximizing the likelihood that the locations we selected would have speeding without being able to confirm in advance that speeding was actually present.

To address this, we conducted a secondary analysis using naturalistic driving data that we had on hand from a previous speeding study (Richard et al., 2013). The most promising candidates identified using the secondary data were sites that had a downhill grade exceeding 10%. Note that driving on grades likely represents a specialized application of our overall approach for examining infrastructure effects, since driving behavior differs somewhat from diving on flat roads (e.g., more frequent braking downhill, and more active accelerator control uphill). However, there are advantages to focusing on grades, such as reduced variability in driving behavior (since it is constrained by the grade), and more reliable availability of fast driving (at least downhill). Moreover, grade should provide a clearly detectable effect on speed, which would provide a base criterion for determining if our analytical approach is sensitive to the effects of roadway features on speed—that is, if our approach cannot find significant effects of grade, than it probably will not work for other more subtle effects. Thus, the focus on grades as a primary variable across sites had several advantages for conducting the pilot analysis and examining feasibility of the overall approach.

PRIMARY STUDY

This section describes the approach used to conduct the primary investigation of the feasibility of this research. Figure 1 outlines the steps performed in the conduct of the study: site selection, acquiring the data from the SHRP2 data contractor, preparing the data for analysis, and performing the analysis. This section provide details about the site selection, data acquisition, and data preparation methodology; details of the analysis approach are provided in Section 5.

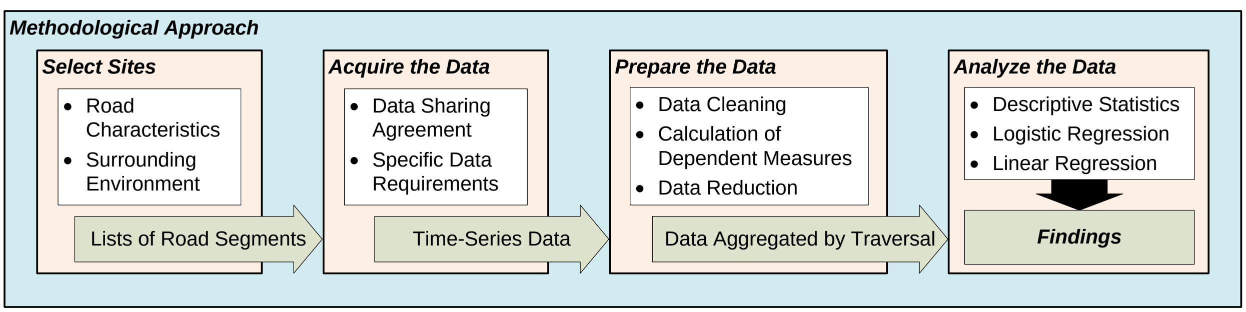

Figure 1. Methodology for conducting the research.

Overview

Data from the SHRP2 NDS were selected in which drivers traversed a series of road segments located on grades. Traversals were examined at nine sites[2], with a single traversal crossing a single site. A traversal begins on secondary road segments—streets that funnel traffic to the roads on the hill. These road segments on the hill—primary road segments—comprise the primary area of interest, and the analyses included driving only on the primary road segments. To complete a traversal, the driver crossed all primary road segments contiguously (most sites have at least one intersection within the primary road segment zone). Drivers' speed behaviors were analyzed in conjunction with variables that describe the characteristics of the roads at each site. Traversals were analyzed using logistic and linear regression techniques to identify road characteristics with significant effects on speeding behavior. Both uphill and downhill driving

[2] We requested and received data for ten sites; however, the GPS data at one site in downtown Seattle were not reliable because of multipath errors caused by travel through the urban canyon that comprised the site.

were considered in the analysis. Figure 2 illustrates a typical traversal site, with examples of some of the variables included in the study. Note that in this document, a GPS fix refers to a location with longitude and latitude, and a waypoint refers to a GPS fix along with the variables associated with it.

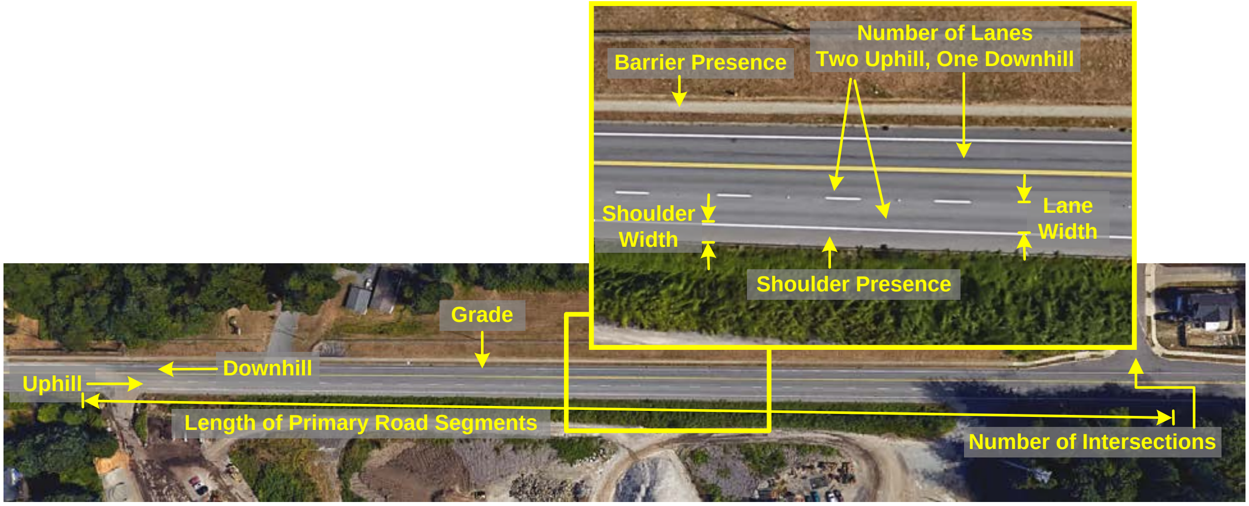

Figure 2. Examples of variables examined at a typical site[3].

Site Selection

A key requirement for developing an insightful analysis was to identify locations with characteristics that could potentially influence drivers' speed choices. Because the NDS data does not have posted speed limit data at each waypoint, it was not feasible to directly request waypoints at which drivers were speeding. Instead, we used in-house speeding data from an earlier project to identify types of locations at which speeding had been previously observed.

The main focus of the site selection process was to identify sites with differing roadway and environmental characteristics in order to obtain sufficient variability in terms of key predictors of speeding. To that end, we employed a strategy of selecting roadway sections on grades of at least 10%, based on our findings from the pilot study that grade is likely to be a primary predictor of speeding. In addition to grade, other variables that were expected to be key speeding predictors included: speed limit (25, 30, 35 mph); curvature (tangent and curve);

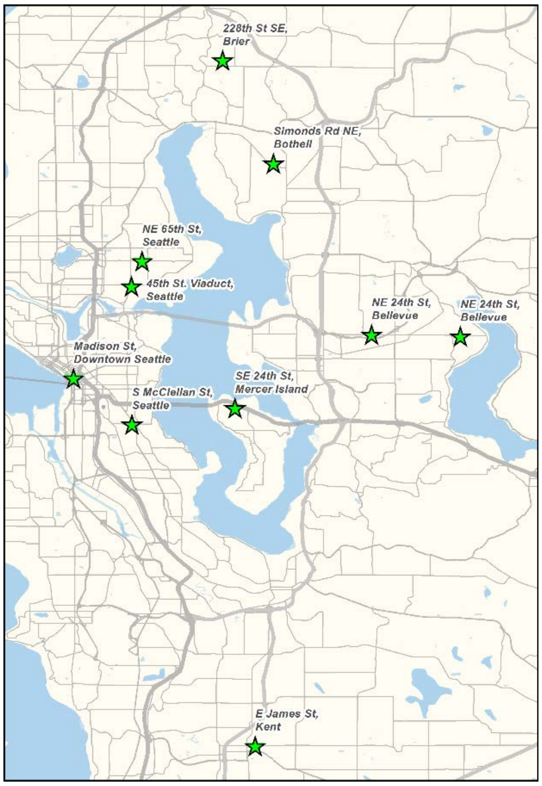

Figure 3. Locations of sites.

[3] 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.

number of lanes (1 or 2); and presence of shoulders, medians, center turn lanes, and roadside furniture (e.g., trees, barriers, tall buildings, etc.). These variables formed the basis criteria for site selection. Ten sites[4] that met these criteria were chosen by carefully reviewing maps in ArcGIS and satellite images in Google Earth, and composing a set that had as much variation across roadway characteristics as practical.

Acquiring the Data

The process of acquiring the data began with preparing an initial data sharing agreement (DSA) with the SHRP2 data contractor. Based on the pilot study results, we obtained a modification to the DSA to reflect changes in our approach. The final DSA and corresponding data query included all traversals—uphill and downhill—across all primary road segments at each of 10 sites, with 30 seconds of driving before and after traversing the primary road segments. The final variable list included those variables that were most likely to be key predictors of speeding. A full list of these variables is found in Table 2 in the following section.

Data Used

Two primary data sources were used to support the analysis: the NDS time series data and the RID roadway data. These sources were augmented by videos from the RID mobile-van and Google Earth, two supplementary—but important—data sources. Following are details describing the data used from these sources.

NDS Variables: The variables in the NDS dataset included a rich and varied source of data for speeding analysis. Each variable in the dataset we received was closely examined in detail to determine both quality and utility for addressing the problem of speeding. Overall, we found that the data in dataset were of sufficient quality and availability to develop a comprehensive and robust analysis of speeding. Table 2 lists the variables we requested and received from the SHRP2 data contractor.

Table 2. Time series variables received from the SHRP2 data contractor.

Variable Category	Variable
Tracking Variables	Subject ID[5], Trip ID, File ID[6], Event ID, System Time Stamp
Speed Measures	Longitudinal Acceleration, Lateral Acceleration, GPS Speed, Network Speed, Accelerator Position, Brake Pedal State
Position 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	Ambient Illuminance, Computed Time Bin (Time of Day)
Proximity (Radar-based)	Forward Range (X and Y; two tracks), Forward Range Rate (X and Y, two tracks), Target Identification (two tracks)

Although we did encounter some technical challenges with some of the variables, we were able to develop solutions to overcome each of those challenges. One such challenge involved the availability of variables, such as network speed, that were only available from the

[4] One site was chosen with 9.9% grade, slightly less than the 10% criterion. The site was included in the study, however, because it met all the other criteria, and we expected it to be over-represented in terms of speeding events.
[5] Subject ID was combined with Vehicle ID and anonymized to protect participant privacy.
[6] File ID uniquely identified trips, which could traverse more than one site. Event ID uniquely identified traversals at the site level.

vehicle's onboard computer. Because some vehicles in the SHPR2 NDS data collection effort did not have an onboard computer port (OBD2), these variables were not available for all vehicles. For variables such as network speed, this was not a problem because other variables provided redundant information (e.g., speed from both the GPS and the vehicle CAN bus were available). Similarly, lane width from the forward camera was replaced by lane width from the RID. Another challenge involved the low availability of radar data, which we had hoped could be used for identifying free-flow traffic conditions. Although radar data were not available for the majority of traversals, we developed a surrogate measure (free-flow threshold) as a proxy for opportunity to speed (see pages 9–9 for details). Despite these challenges--none of which were insurmountable--we found that the SHRP2 dataset was well suited for analyzing speeding.

RID Variables: A wide variety of roadway variables are available in the RID dataset. Many were useful, but some required additional data sources to interpret them in the context of human factors. Although the physical measurements and descriptions of roadway elements are precise and fine-grained, often it was difficult to judge what drivers experience perceptually from the RID data. In order to enhance our understanding of each site from a driver's experiential perspective, a virtual "drive-through" of each site was performed using the iVision web-based video utility. This tool provides video captured by the mobile data-collection van while gathering the RID data, providing a snapshot of the environment encountered by drivers at the time the data were collected. The video was invaluable not only for gaining insights into what drivers will likely perceive, but also for validating the RID data (e.g., determining on which side of the road a PS sign was located). Table 3 lists the RID variables considered in the analysis.

Table 3. RID (roadway) variables.

Variable Category	Variable
Alignment	Grade, curvature, number of through lanes, lane width, shoulder width, center turn lane, presence of median
Road type	Federal Functional Class code
Environment	Presence of barriers, presence of lighting, presence of posted speed sign within the site

One challenge with using the RID data was that several variables indicated the presence of a feature, but gave little or no information relative to speeding. One such variable was lighting. The presence of a luminaire was indicated, but the intensity and coverage of the light was not provided. Another variable was barriers. Although the RID lists lengths, type of treatment at the start and end of the barrier, and even the type of posts supporting the barrier, it was difficult to assess the perceptual impact of a given barrier from the available information. The iVision video utility was invaluable for gauging the perceptual impact of key road features.

The RID does provide information that can be used directly to identify countermeasures. For example, the Route Intersection feature class identifies roundabouts, which can be used for traffic calming. Extracting countermeasures from some variables may be challenging because the data are not if a form that can be easily accessed (e.g., some relevant information is only provided in the field comments).

Additional Data sources: The iVision utility and Google Earth were used to provide additional insight into the environments around the sites and confirm that our understanding of the RID variables was correct. A subjective measure called "Perceptual Confinement" 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. To accomplish this, two researchers independently viewed a virtual "drive" through each site using the video from the iVision utility and Google Earth. A binary score that identified the site as confining or restrictive versus open or less restrictive—as potentially perceived by a driver while traversing the site—was assigned to the site.

Data Cleaning

The data needed to be reviewed and cleaned prior to the data reduction in order to ensure high quality in the subsequent data reduction. Data cleaning activities included removal of erroneous or poor quality data, computing travel speed based on the two travel-speed variables provided, and removal of traversals that did not conform to target behavior (e.g., interrupted traversals and traffic-bound driving). Figure 4 illustrates the process used to clean the data, followed by brief details regarding each step in the process.

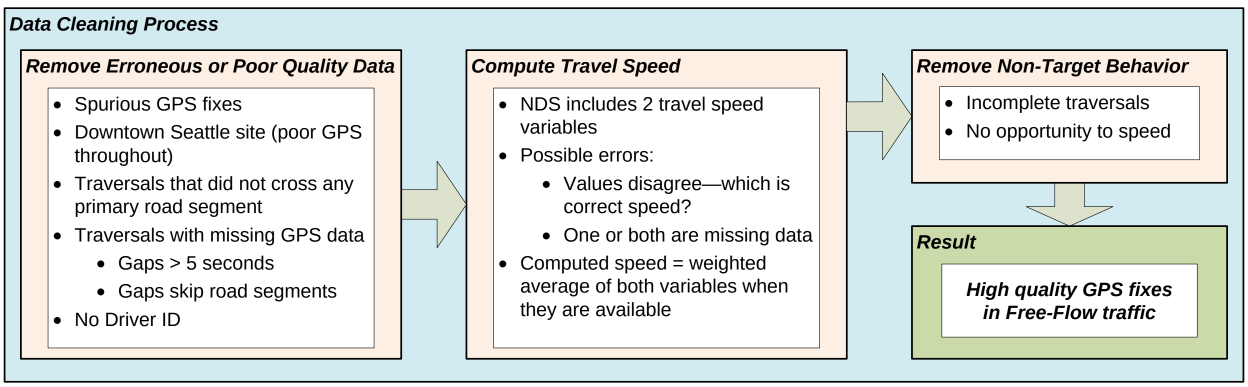

Figure 4. Data cleaning process.

Removal of Erroneous or Poor Quality Data

An initial cleaning of the dataset was performed to ensure that the data used in the subsequent reduction was as free of errors as possible. These data cleaning activities included the following:

- Removed poor quality GPS fixes
  - Deleted spurious GPS fixes with incorrect longitude and latitude (small number of fixes at each site)
  - Eliminated entire downtown Seattle site due to problematic GPS fixes from traveling through urban canyons
- Removed traversals that did not cross any of the required road segments at the associated site
  - Primary cause was that the GPS fixes were linked to the wrong road segment at the SHRP2 data contractor
  - Occurred at two sites resulting in loss of 38% of traversals across the two sites
- Removed traversals with missing data
  - Exclusion criteria:
    - Gap in the data longer than five seconds
    - Gap in the data skips one or more road segments

- Removed traversals for which the anonymized Driver/VehicleID was not provided
    - Driver/VehicleID required to examine repeated measures and to facilitate comparisons between drivers
    - Affected a relatively small number of traversals

Computing Travel Speed

Knowing the vehicles' accurate travel speeds is essential to conducting an analysis of speeding. The SHRP2 dataset contains two measures that provide travel speed. The GPS speed variable contains travel speed gathered from the GPS unit, while the network speed variable contains travel speed from the vehicles' onboard computer. Unfortunately, network speed was not available for vehicles that did not have an onboard computer (OBD2 port). In addition, both the GPS speed and network speed had occasional gaps in the data. Finally, the GPS speed and network speed differed—sometimes by as much as 5 mph—in their reported values. In order to compensate for these data challenges, travel speed for each waypoint in which both speed variables were available was calculated as the average of the GPS and network speeds, adjusted by the average, over the entire traversal, of the difference in the two speeds. This adjustment was made to minimize rapid or spurious shifts in speed caused by intermittent gaps in one of the variables.

Removal of Traversals That Do Not Conform to Target Behavior

A final step in the data preparation was to remove traversals that did not represent target behavior. Specifically, traversals that were not contiguous across the entire site and those in which drivers did not have the opportunity to speed. A small number of drivers turned at intersections within the primary road segments, made a U-turn, re-entered the primary segment zone, and continued through the site. Because these traversals violated the requirement of contiguous travel across all primary road segments within the site, they could not be directly compared with contiguous traversals and were excluded from the final dataset.

It is often the case in urban environments that, even if drivers wish to speed on a road, they may be unable to do so because they are boxed in by other traffic. When possible, these cases should be excluded from analysis of speeding behavior, because it leads to an underestimation of the prevalence of speeding (e.g., Richard et al., 2013). Therefore, another objective in the data cleaning process was to remove traversals in which drivers clearly had no opportunity to speed. With SHRP2 data, the ideal way to do this would be to use radar data to exclude traversals in which a lead vehicle was detected within a certain range. Unfortunately, radar data were unavailable for a large proportion of traversals, ranging from 16% to 65% (average of 39%) availability across sites.

Instead, we used a proxy for opportunity to speed known as "free-flow" driving, which simply represents travel above a minimum speed threshold. A threshold of 5 mph below the posted speed limit has previously been used (Richard et al., 2013) because it represents a speed that drivers would be unlikely to voluntarily adopt unless constrained by other traffic or TCDs. While this measure is imperfect, since drivers traveling above the free-flow threshold may still be constrained by fast traffic, it at least eliminates most of the cases in which drivers are unlikely to have an opportunity to speed. A traversal across the primary road segments was considered a free-flow traversal if the majority of driving across the primary road segments was at free-flow speed. Because the primary road segments at most sites were terminated at each end by an intersection, travel speed at the beginning and ending of the primary road segments was ignored when determining if the traversal was considered in free-flow. This "free-flow zone"—i.e., the region across the primary road segments in which driving was required to be at free-flow speed—was established based on kinematic and statistical measures unique to each site.

Data Cleaning Results

The data cleaning effort resulted in a set of high-quality GPS fixes in free-flow traffic.

Calculation of Dependent Measures

Two speed-related dependent measures were calculated from the NDS driving data for the regression analyses. The first was the occurrence of a *speeding event*, which was a binary outcome measure that indicated if a traversal contained at least five-seconds of driving in excess of ten miles-per-hour (mph) above the speed limit (see Figure 3). This measure was comparable to how speeding events have been defined in other research, and it generally represents driving at a speed at which most drivers believe they can get a speeding ticket, but still represents traveling at a speed that does not feel unsafe (e.g., Book & Smigielski, 1999; Richard et al., 2013). There is a non-linear aspect to speeding events because 10 mph above the posted speed has psychological significance to drivers, and often serves as a demarcation point between "acceptable" and "unacceptable" speeding (Richard et al., 2013).

The second dependent measure was called *speed exceedance*, and it was a continuous measure computed as the difference between the posted speed limit and the 90th percentile speed within a particular traversal. This measure is analogous to maximum driving speed; however, its value is less sensitive to random "noise" error, which can occur in GPS and CAN speed measurements, and which can artificially elevate maximum speed. Speed exceedance also provides a more direct measure of the influence of certain factors on overall speed (i.e., the comfortable driving speed, or speed afforded by the roadway). And while it represents the high end of the speed range, this value could still be below what most drivers would consider to be speeding if the typical travel speeds on a particular roadway were generally lower.

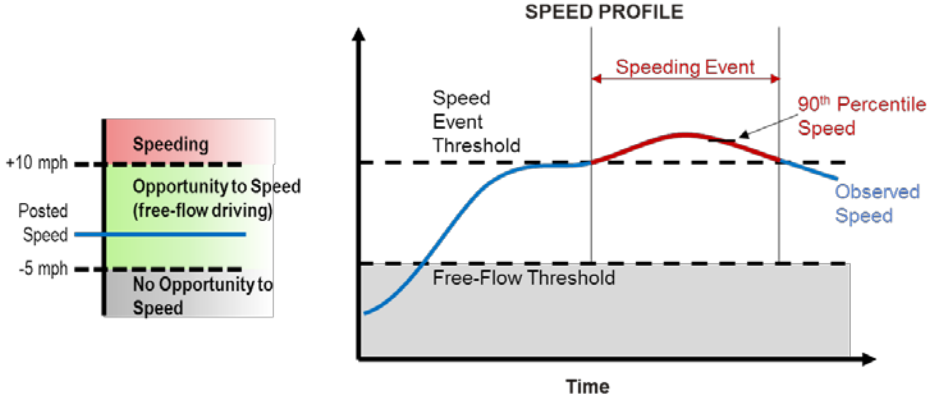

Figure 5. Illustration depicting how free-flow and speeding measures were calculated from traversal data.

Data Reduction

The final step in preparing the data for analysis was to reduce the variables into aggregate form that described driving within a traversal. Table 4 lists the variables that were included in the reduced dataset. This data reduction table was used as input to the STATA statistical software for analysis. Descriptive statistics that characterize the speeding at each site were developed using the statistics functions in the PostgreSQL relational database manager. PostgreSQL is an enterprise-class relational database management system with both GIS capability and the ability to execute R statistical software functions. This tool was used to parse traversals and calculate descriptive statistics.

Table 4. Reduced variables used in the analysis.

Variable Category	Variable
Speeding Traversals	5, 10, and 15 mph above posted speed (3 variables); number of speeding episodes at 5, 10, and 15 mph, max speed; 85th percentile, 90th percentile, and max speed
Environmental	Median light level, time of day (morning commute, mid-day driving, afternoon commute, and nighttime driving), time of day (day, night), travel direction (uphill, downhill)
Roadway Variables (RID)	Grade category (3 levels); max grade; functional class; length of traversal (absolute and categorical); number of through lanes; change in number of through lanes; median lane width; median shoulder width; presence of shoulder, center lane, median, barrier, lighting, and posted speed limit sign; and number of intersections within the primary traversal zone

Summary of Methodological Feasibility

During the conduct of this research, several challenges and questions arose related to the feasibility of conducting large-scale research from a methodological standpoint. Table 5 provides a brief summary of methodological issues that may affect the tractability of addressing speeding using the NDS data and implications for the large-scale data analysis in Phase 2.

Table 5. Summary of methodological issues and potential solutions for addressing feasibility.

Feasibility Issue / Challenge	Phase 2 Solutions
Data Extraction	
Identifying tradeoffs in various aspects of the data required extensive, iterative consultation with VTTI in order to maximize the amount of data relative to cost	▪ We gained a clear understanding of how to efficiently request data that meet our objectives, which allowed us to increase the number of sites from three-to-four to ten.
There is some uncertainty about the amount of available data at each site because of data loss due to PII protection	▪ Tallies from the Phase 1 data extraction can be used to estimate the expected reduction of cases caused by PII issues ▪ Data loss due to PII issues can be mitigated by eliminating secondary road segments from the data request
Data Quality	
Extracted data contains errors and missing data (e.g., intermittent gaps in speed, missing data for vehicles with no CAN bus, traversals incorrectly assigned to wrong road segment, etc.)	▪ We developed data cleaning methods and tools in Phase 1 that should address most data quality issues
A high proportion of traversal lack adequate radar data to objectively determine driver’s opportunity to speed	▪ The Phase 2 data sampling plan will include strategies for compensating for missing radar data for estimating free-flow (e.g., develop hybrid approach that incorporates both radar data and free-flow threshold).

Feasibility Issue / Challenge	Phase 2 Solutions
	▪ Our current approach of relying solely on the free-flow driving proxy for opportunity to speed was effective
Visual characteristics/impressions of the environment that may affect driver perception of the roadway are not captured in RID	▪ We can include Phase 2 tasks to use other data sources (e.g., van video, Google Earth) to manually capture qualitative data not defined in the RID
Analysis Issues	
A minimum amount of free-flow travel is required at each site, and posted speed data to directly query this from NDS is unavailable	▪ A separate task involving pre-screening sites using NDS driving data (e.g., median speed) and external GIS/Map data will be included to estimate amount of free-flow travel at a site. ▪ Should be based on speeding events at site
RID does not include adequate posted speed data for calculating speed-related dependent measures	▪ Other data sources, such as Navteq, Google Earth, and RID video data can be used to substitute for missing RID data if posted speed does not become timely available in the RID
There were an insufficient number of sites included in Phase 1 to directly compare locations with existing countermeasures to those without.	▪ Phase 2 will involve enough sites so that this is feasible for a small number of existing countermeasures. This aspect could be scaled up if it is a priority.

The challenges associated with the feasibility of validating, cleaning, and analyzing the data, as described in Table 5, are consistent with the imperfect nature of data commonly collected in the field. Despite these technical challenges, we have identified and employed methods for addressing each of these challenges, indicating that the SHRP2 NDS and RID data are eminently suitable for examining speeding behavior and the processes for preparing and analyzing the data are clearly feasible.

4 DATA USED

See page 6 in the *Data Used* subsection of the Methods for discussion.

5 RESEARCH RESULTS

DESCRIPTIVE FINDINGS

This section provides descriptive statistics that describe speeding at each site. Table 6 lists the number of free-flow traversals and the percentage of free-flow traversals that had speeding events. Also shown is the mean 90th percentile speed, which was used within traversals to calculate the speed exceedance.

Table 6. Count of free-flow traversals, speeding traversals, and percent of speeding events.

			Downhill			Uphill		
Site	**Posted Speed Limit**	**Max Grade**	**Number of Free-Flow Traversals**	**Percent Speeding Events**	**Mean 90th Percentile Speed**	**Number of Free-Flow Traversals**	**Percent Speeding Events**	**Mean 90th Percentile Speed**
A	30	12.4%	451	24.2%	38.0	739	30.3%	37.4
B	35	15.5%	417	17.7%	39.7	629	9.06%	41.8
C	30	14.6%	5	40.0%	34.0	79	5.06%	33.1
D	30	16.0%	513	20.1%	34.9	71	7.04%	37.4

			Downhill			Uphill		
Site	Posted Speed Limit	Max Grade	Number of Free-Flow Traversals	Percent Speeding Events	Mean 90th Percentile Speed	Number of Free-Flow Traversals	Percent Speeding Events	Mean 90th Percentile Speed
E	35	9.9%	641	13.7%	41.0	881	27.0%	41.6
F	25	19.1%	208	2.40%	28.6	144	2.78%	28.7
G	30	18.9%	54	0.00%	29.2	28	0.00%	29.4
H	30	11.9%	10	0.00%	33.4	21	0.00%	33.5
I	35	14.1%	678	23.5%	40.0	649	21.1%	41.2

REGRESSION ANALYSIS

This section describes the regression analyses conducted to examine the effects of roadway-characteristic on speeding events and speed choice. Regression allows statistical control of confounding factors that would otherwise require stratification of the sample data. All analyses were carried out on speed measures derived from driver traversals at each site, and they used the outcome and predictor measures listed below in Table 7. For binary variables, the presence of a feature was coded as 0 for absent and 1 for present.

One set of regression analyses was conducted for each of the speed-related dependent measures. The primary reason for examining these measures separately is that they generally represent different aspects of speeding. Specifically, the occurrence of speeding events represent driving situations in which drivers are not being vigilant about keeping near the posted speed for various reasons, including times when drivers deliberately choose to speed. In contrast, speed exceedance may capture a more direct relationship between roadway factors and speed by way of "unconscious" influences or "natural" speed level afforded by a roadway environment. Although the 90th percentile speed is on the high end, it may not constitute actual speeding if travel is generally slower on those roads, so this measure does not necessarily correspond directly to speeding events.

Table 7. Variables used in regression modeling.

Outcome Measures	
Speeding	This binary outcome measure was tabulated if a traversal contained five-seconds of driving at ten miles-per-hour (mph) over the speed limit.
Speed Exceedance	This is a continuous outcome measure was computed as the difference between the speed limit on the traversed road segment and the 90th percentile speed within the traversal.
Predictor Measures	
Grade Category	Three categories of grade were generated using the measured maximum percent grade. The categories were lowest (10-12%), middle (14-15.5%), and highest (16-19%). Each road segment was assigned to a grade category.
Median Lane Width	Median of segment lane with in feet. Range was 10 to 18.5 feet.
Shoulder Presence	Binary variable to indicate if a shoulder was present or absence.
Barrier Presence	Binary variable to indicate if a barrier (e.g., Jersey barrier) was present or absent.
Perceptual Confinement	Binary variable that represents the perceptual narrowness of the road segment. This was subjectively derived by two experimenters.
Intersection Count	Count of intersections within the road segment.
Posted Speed	Posted or per se speed limit for the road segment.
Posted Speed Sign Presence	A binary variable that represents the visibility of the posted speed sign for the road segment. Visibility was confirmed using SHRP2 RID sign data, mobile-van videos in iVision, and Google Earth.

Uphill/Downhill	Indicates the direction of travel of the driver relative to the grade.
Day/Night	Indicates if the traversal occurred during the day (6:00 AM to 6:00 PM) or night (6:00 AM to 6:00 AM). Included in all models because traffic volumes and general lighting conditions differ between day and night.
Control Variables	
Sites	This variable represents the road segments, and was used for two reasons: (1) to examine speeding events and speeding exceedance effects at the road segments, and (2) to control for random variance unaccounted for by the measures listed above.
Driver	This variable represented drivers and was used to control for multiple traversals by the same driver with the dataset.

Statistical Models: Multiple logistic regression, and multiple linear regression models were developed to examine relationships between the predictor and outcome measures. Logistic regression allows for analyses of binary variables, and was used to model the probability of a speeding event given different sets of predictors. Linear regression was used to model speed exceedance, which was coded as a continuous variable.

Different types of models were used to statistically control for 1) drivers' repeat traversals, and 2) large differences in the number of available traversals across sites. The distribution of trips for any one driver at a site ranged from 1 to as many as 431 traversals, depending on the site. Similarly, free-flow traversals per site ranged from a minimum of 31 to a maximum 1500. Three types of regression models were used to examine the effect of predictors on the speed measures, with different adjustments for driver and site effects. The three model types are listed below:

- Model 1: Basic regression on predictors, no statistical control for participant and site effects.
- Model 2: Random effects regression to control for drivers' repeat traversals (i.e., random effects of driver).
- Model 3: Multilevel regression to control for drivers' traversals and random effects attributable to sites (i.e., effects not captured by the predictor measures listed in Table 7).

The rationale for using the three models described above was supported by results from the exploratory regression analyses conducted with the same data. Results from these initial models showed site-differences for the dependent measures, which led to the inclusion of site as a random effect in Model 3. This also allowed us to test the stability of the significant findings from Models 1 and 2. Since the objective of the project was to examine the effects of infrastructure elements on speed and speed exceedance, it was important to tests the sites for effects of speeding prior to assessing the predictor terms that were selected. As described below, there are likely speeding effects at the locations that were not adequately captured by the predictor terms.

Pilot regression analyses also indicated an effect of grade direction (travelling uphill vs. downhill), and that the effects of grade were non-linear (i.e., speeds on moderate grades were greater than on shallower and higher grades). Given that these differences likely represented different driver behaviors, downhill and uphill travel were analyzed separately, and grade was coded as a categorical variable.

Findings

This section primarily describes the results of regressions conducted with the predictor measures. Separate regression models were developed for uphill and downhill traversals with speeding events and speed exceedance as dependent measures (resulting in four different combinations of grade and dependent measure). Different predictors were added and removed in an iterative fashion with Model 2 as a base case until only significant predictors remained in the final model. The exception was Day/Night, which was included in all models to adjust for differences in day and nighttime driving. Models 1 and 3 were then run using the final Model 2 variable list. Note that all categorical variables show only relative comparisons to the base level. For example, Speed Limit has three levels, but only two levels are shown in the results.

Table 8 shows the coefficients and significance levels for basic, random and multilevel regressions (Model types 1 to 3) on downhill data only. The significance levels and direction of effects are relatively stable across models for all but a few predictors. Grade category and barrier presence show significant effects for both speeding events and speeding exceedance, which are consistent across models and in sign (negative/ positive coefficient).

The results for grade category suggest that speeding events may occur more often at middle levels of grade, and less often when grade is steepest. This can be seen in Table 8 by looking at the change of sign from the middle level to the highest level. This pattern likely represents different driving behaviors on different grades. Specifically, on steeper grades, drivers may be braking more frequently, making sustained periods of speeding (i.e., >5 sec as per the speeding event definition) less likely than on shallower grades. A different pattern is evident for speed exceedance as the sign is positive for both levels of grade. Specifically, both the middle and highest grade categories are significantly greater than the lowest grade category, but there is no clear linear trend. This points to a similar behavioral explanation as with speeding events. In particular, it may be the case that drivers are only willing to exceed the posted speed limit by a set amount, regardless of how much steeper grades may be facilitating higher speeds.

Table 8. Downhill Model Results - Coefficients and significance for downhill data only.

	Speeding			**Speed Exceedance**		
Predictors	**Model 1**	**Model 2**	**Model 3**	**Model 1**	**Model 2**	**Model 3**
Middle Grade	0.711***	1.099***	1.113*	5.66***	6.55***	6.37***
Highest Grade	-0.809***	-1.757***	-1.833**	5.42***	5.73***	4.61**
Barrier Presence	0.517***	1.477***	1.529***	3.68***	4.83***	4.75***
Median Lane Width	--	--	--	22.76***	23.06***	20.69***
Speed Limit 30	1.726***[3]	0.014	0.026	-8.27***	-9.92***	-9.25***
Speed Limit 35	0.540	-1.985*	-2.034	-13.65***	-16.35***	-15.53***
Perceptual Confinement	--	--	--	-41.32***	-41.82***	-37.35***
Night/Day	-0.017	0.013	0.010	-0.24	-0.10	-0.10
Fixed Effects Constant	-2.892***	-1.800*	-1.872*	-224.57***	-226.55***	-202.33***

* p < 0.05 ** p < 0.01 *** p < 0.001

Table 9 shows the coefficients and significance levels for basic, random and multilevel regressions (models 1 to 3, respectively) for uphill data only. The results for median lane width shows the greatest consistency across models in significance and direction of effect (e.g., the coefficients are of the same sign). Similarly, shoulder presence, barrier presence, and speed limit are consistent within speeding event and speed exceedance. As expected, the effects of grade category are different than for the downhill models. Specifically, the coefficients imply that the odds of speeding events decrease as grade category increases, which may result from greater difficulty countering the slowing effects of gravity for sustained periods while traveling uphill. With regard to speed exceedance, only the middle-grade category is significantly faster than the lower-grade category. This could indicate that drivers on these middle grades might be overcompensating with their accelerator presses to overcome the slowing effects of the uphill grade, whereas on steeper grades, they are more effective in balancing these forces.

Table 9. Uphill Model Results – Coefficients and significance for uphill data only.

	Speeding			Speed Exceedance		
Predictors	**Model 1**	**Model 2**	**Model 3**	**Model 1**	**Model 2**	**Model 3**
Middle Grade	-1.74***	-1.54*	-1.50	4.50***	5.02***	4.18**
Highest Grade	-3.21***	-2.59**	-2.91**	0.05	-0.95	-1.84
Median Lane Width	0.52***	0.91**	1.08*	1.98***	1.61***	1.23**
Shoulder Presence	1.27***	2.21***	2.51***	--	--	--
Barrier Presence	--	--	--	11.34***	10.44***	8.29**
Intersection Count	--	--	--	2.42***	1.72**	1.25
Speed Limit 30	--	--	--	-2.93**	-3.74**	-3.42*
Speed Limit 35	--	--	--	-4.50**	-6.92**	-6.53**
Perceptual Confinement	--	--	--	6.19**	3.87**	3.05
Day/Night	-0.16	-0.49**	-0.46**	-0.16[5]	-0.39**	-0.36*
Posted Speed Presence	3.35**	5.10*	5.87	--	--	--
Fixed Effects Constant	-9.55***	-17.49**	-20.20*	-28.16***	-19.88**	-13.10

* p < 0.05 ** p < 0.01 *** p < 0.001

Discussion

Although the number of sites was limited, the overall approach was effective in identifying interpretable relationships between roadway characteristics and speed measures. The use of single and multi-level random effects regressions (models 2 and 3) permit conclusions that are more likely robust to Type I and II error. Differences between models 2 and 3—which may represent error—were more prominent in the uphill data than in the downhill data. Error was also more prominent for analyses of speeding events than for speed exceedance. However, it should be noted that multiple sites in Model 3 were omitted in the analysis because of collinearity with certain predictors. This is a limitation of having few sites overall, and can be avoided in Phase 2. For the purpose of the discussion, the results from Model 2 are used to interpret the findings.

Several of the predictors have implications for design and countermeasures development. The findings are preliminary, and may change with a larger set of more deliberately selected locations. However, they provide an idea of some basic applications to countermeasures, as described below:

- *Median Lane Width*: This generally let to higher speed exceedance in both uphill and downhill directions, and with higher odds of speeding events in the downhill direction. Phase 2 could more closely examine the effects different ways in which lane widths can differ (e.g., wider pavement markings, increasing shoulder width, etc. and their respective effects on speed.

- *Barrier Presence*: This generally let to higher speed exceedance in both uphill and downhill directions, and with higher odds of speeding events in the downhill direction. At this stage, the effects of barrier presence could be related to protection from cross traffic (e.g., driveways) and other hazards. Some types of barriers could also affect the perception of visual confinement, but this was not apparent in the current data. These aspects of barriers (e.g., size, prominence, visibility, etc.) could be more closely examined in Phase 2 to identify elements that discourage faster driving.
- *Shoulder Presence*: This predictor was associated with higher odds of uphill speeding events. This variable may have captured some aspects of perceptual confinement because the presence of a shoulder may have visually opened the roadway.
- *Perceptual Confinement*: On downhill traversals, greater subjective perceptual confinement was associated with a lower speed exceedance values, but the opposite pattern occurred on uphill traversals. Lower speeds would be expected based on existing research. On uphill traversals, there may have been an interaction with shoulder presence that caused the reversal. There is the potential to investigate this characteristic in more detail with a larger number of sites, and this factor can be coded in a more fine-grained manner to identify which aspects of perceptual confinement are most effective in slowing drivers.
- *Posted Speed Sign Presence*: This predictor was marginally associated with higher odds of speeding events on uphill traversals. However, it is unlikely that the presence of these signs encourages speeding. This effect could be due to other aspects of the roadway design that were not included in the analysis, and which could have been associated with both more signage and greater likelihood of speeding. Alternatively, placing more speed limit signs at certain locations may have been used as a speeding countermeasure on these roads if they were already experiencing elevated levels of speeding. In this case, they do not seem to have been effective at slowing drivers. These alternatives could be examined in Phase 2.

These results are illustrative of the types of information that could be extracted using the current research approach. Given the small number of sites, and the rudimentary subjective predictor codings used in the current analyses, it is likely that we would see different results using a more systematic and comprehensive analytical approach afforded by Phase 2. Nevertheless, the basic patterns of results are interpretable and generally consistent with previous research (i.e., see Campbell et al., 2012), which suggests that the basic approach is sensitive to the underlying relationships between roadway characteristics and speed.

ASSESSMENT OF FEASIBILITY QUESTIONS

Is the research question methodologically tractable using SHRP2 data?

The Phase 1 work identified a path forward that can be feasibly implemented within the framework of the SHRP2 data acquisition process. At the end of the data processing phase, the data were in a format that supported meaningful statistical analyses. A key challenge in Phase 1 was identifying suitable locations that also had a sufficient amount of speeding, which was hindered by the absence of posted speed limit data linked to road network. However, we believe that there are approaches we can take in Phase 2 to efficiently resolve this limitation. Section 7 describes a viable process for obtaining the data required to conduct Phase 2 analyses. We have developed the full set of analytical steps and supporting tools to obtain the data and process it as needed to conduct the analyses.

Can the predictor and dependent measures be adequately quantified?

The results from the Phase 1 work indicated that useful roadway variables are available, and that their coding in the RID is useful. However, there are clear limits to the RID data, both in terms of the availability of certain roadway information, and in terms of the applicability of the RID data coding scheme to speeding behavior. For example, the roadside "barrier" variable in the RID does not provide adequate information about the dimensions of barrier to describe how it visually appears to drivers, and if it can impact their perception of the roadway. Nevertheless, this variable still has indirect value as an indicator of reduced exposure to hazards (i.e., from driveways). In a larger Phase 2 project, it would be possible--and recommended--to supplement RID data with subjective coding of site characteristics using mobile-van video data.

Do appropriate analytical approaches exist to answer the question?

The regression modeling approach used in the analysis was suitable for the hypotheses and data in this research. Random effects models make it possible to deal with the uneven distribution of trips across sites, and site-specific factors that cannot be captured by the predictor variables. In the current analysis, the small number of sites hindered the multi-level regression model; however, this should not be a problem in a larger Phase 2 study. Importantly, with a large number of participants and traversals, we expect sufficient data to examine sub-models (e.g., downhill vs. uphill) to obtain a more nuanced understanding of factors affecting speeding.

Is there an underlying behavioral effect that can be examined?

The findings from the regression analyses indicate that even with the limited pilot data set, there were significant and interpretable infrastructure-based predictors of speed. The different behaviors related to driving uphill and downhill were captured in distinct models, as were correlations between certain roadway characteristics and speeding behavior and speed choice. Although the analyses were clearly preliminary, they still suggests that the overall approach is able to identify relationships between roadway characteristics and speed.

Is there a benefit to conducting this study?

Speeding remains an important traffic safety problem. The number of speeding fatalities has remained basically unchanged in the past 10. Since the typical focus on behavioral interventions is largely proving ineffective in addressing the speeding problem, it presents an opportunity to identify new infrastructure countermeasures that can provide a more localize approach to addressing speeding in problem areas. This is very important as more transportation agencies move towards performance-based practical design and to multimodally integrated systems where controlling speeds becomes a necessity. The SHRP2 data are well suited for addressing the speeding problem because the rich data set can allow us to examine speeding in terms of more fine-grained and situational behaviors that might be influenced by roadway characteristics in different ways. Also, many of the basic infrastructure characteristics are common across a wide range of roadways, which makes basic findings highly generalizable across regions. Finally, as discussed in the Future Directions section, our overall approach provides a way to identify and evaluate infrastructure-based countermeasures.

In conclusion, the answers to the feasibility questions posed above indicate that there is a viable technical and analytical approach for examining the effects of roadway characteristics on speed, and that the corresponding findings can inform development of new countermeasures.

6 FUTURE DIRECTION

Phase 2 would involve the development of a large dataset of approximately 100 sites that systematically differ in terms of key infrastructure and operational characteristics. Each site would include data on driver free-flow travel speed, and information on driver speeding behavior. This dataset would provide a “mini-laboratory” to examine difference in roadway features across test locations. Since the effects of roadway design features are the focus of the analysis, the results have great potential for identifying features that may be associated with excessive speeding and for countermeasures (e.g., changes in geometry, additional traffic control devices, signs, or education) that could be applied. Pedestrians and bicyclists are at particular risks at some locations associated with excessive speeding, and countermeasures aimed at protecting these road users may emerge from this research as well. Some of the specific applications to countermeasures could include:

- A better understanding of effects of roadway elements on driver speeding behavior and travel speed, which has the potential to inform the development of new countermeasures that target underlying driver behaviors or perception of the roadway. Moreover, if a greater number of sites are included from a single study location (e.g., Seattle), it may be feasible to include driver factors (e.g., demographics) in the regression models, since there will be a better balance of drivers across sites, and more traversals by the same drivers at different sites (i.e., repeated measures).
- There would likely be findings that have implications for roadway design guidance documents, such as the *Human Factors Guidelines for Roadway Systems* (Campbell et al., 2012). This information provides roadway engineers and designers with additional methods for influencing speed by selecting design parameters (e.g., lane widths, roadway furniture) that are consistent with operating speed goals.
- The proposed research approach can also lead to a more detailed understanding of countermeasures and their effectiveness. In particular, it is possible to include sites that have certain countermeasures present (e.g., dynamic speed signs; speed calming measures), and compare them to similar sites that lack the countermeasures to identify differences in driver behavior. Also, this approach provides an opportunity to examine certain factors a finer level of detail. For example, our gross measure of “perceptual confinement” seems to be an initial predictor of speed. It could be possible to parse out these effects into different aspects of perceptual confinement by using coding specific dimensions separately (e.g., visual “openness” vs. perceived hazard density, etc.).

In general, the SHRP2 data analysis approach examined in the current project provides several ways identify factors that influence driver speed behavior and use that information to develop and examine potential infrastructure-based countermeasures.

7 PHASE 2 PROPOSAL

An outline of the proposed Phase 2 activities is provided below.

Task 1: Project Management, Briefings, and Coordination with Project Advisory Group

- Conduct project management and briefing activities
- Establish and coordinate with project advisory group

Task 2: Formulation of Hypotheses

- Conduct focused literature review to obtain a detailed understanding of the specific relationship between infrastructure elements and speed, including detailed information about specific parameters
- Develop multi-factor hypotheses based on individual predictors (based on specific parameters) and their interactions with other predictors
- Consult with the advisory group to identify a set of infrastructure elements and key safety-related scenarios that lead to design changes or countermeasure modifications that can be practically implemented
- Develop site requirements that specify a target range of infrastructure parameters (which are candidate for countermeasure development) and driving scenarios (which reflect safety priorities)

Task 3: Site Selection

- Catalog site characteristics and revise list of suitable NDS variables (from Insight Portal)
- Develop site selection strategy that reflects priorities identified in Task 2 site requirements
- Develop sampling plan for allocating sites across roadway characteristics of interest
- Conduct initial RID and NDS data pre-screening queries to identify sites that 1) match the sampling plan requirements, 2) have sufficient number of traversals and possibly driver demographics, and 3) provide a sufficient range of speeding across sites
- Prioritize sites and develop final site list

Task 4: Primary data acquisition

- Finalize variable list
- Obtain IRB approval and establish Data-Sharing Agreement with VTTI
- Conduct analysis of sites with video data and coding of new variables
- Acquire and validate NDS driving traversal data

Task 5: Data processing

- Implement the same basic data processing approach as described in this report but scoped across the larger set of sites.
- Develop additional data processing tools that support new or modified analysis approaches

Task 6: Data analysis and Hypothesis testing

- Conduct descriptive and regression analyses using same basic approaches as described in Section 5
- Implement additional analysis approaches

Task 7: Countermeasure Development

- Countermeasure identification and cataloging
- Obtain and incorporate Advisory group input on CMs
- Conduct CM evaluation based on analysis results

Task 8: Project Documentation

- Prepare and submit draft and final project reports

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