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IMPLEMENTATION ASSISTANCE PROGRAM (IAP)
PHASE 1

THE INTERRELATIONSHIPS BETWEEN SPEED LIMITS, GEOMETRY, AND DRIVER BEHAVIOR

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INTRODUCTION

Speed management has been an extensive focus of traffic safety research dating back to seminal work from the 1960's that showed crash risk (i.e., the probability of being involved in a crash) to be higher among vehicles traveling at speeds significantly above the average speed of traffic [*1-2*]. Various studies have shown that increases in average speed and speed variance each tend to be associated with increased crash or fatality rates [*3-8*]. These results provide support for maximum statutory speed limits, which are posted to inform drivers of the highest speed that is considered safe and reasonable for ideal traffic, road, and weather conditions.

The existing research literature has consistently shown fatalities to increase with higher limits. A recent longitudinal study of fatality trends on rural interstates across the United States showed that states with 70-mph maximum limits experienced 31 percent more fatalities than states with 60-65 mph maximum limits and states with 75 mph limits experienced 54 percent more fatalities [*9*]. Research suggests these negative safety impacts may be due to differences in mean speed and speed variance across roadways where different speed limits are in place.

However, distinguishing the nature of these relationships is often challenging. For example, it is often difficult to determine the exact time at which a crash occurred, as well as the associated speed characteristics of the traffic stream immediately preceding the crash event. While research has shown both mean speed and speed variance to be affected by posted speed limits, most prior studies have been limited to using aggregate data for specific road segments where detailed driver information was not available. As such, it is difficult to infer how the behaviors of individual drivers may vary in response to different speed limits, as well as how these behavioral changes may impact crash risk.

In order to better understand the differences in driver behavior that may result from speed limit policies, a detailed assessment of the behavior of individual drivers is necessary. Such an assessment should consider how driver speed selection changes in response to the speed limit while controlling for important roadway, environmental, and driver characteristics. The second Strategic Highway Research Program (SHRP2) Safety Data provides unique resources to investigate the nature of these relationships. These data include information from the Naturalistic Driving Study (NDS), which resulted in real-time behavioral data from more than 5 million trips, as well related information from the Roadway Information Database (RID), which is a geospatial database providing detailed information for 25,000 miles of roadway across the NDS study sites.

Study Goals & Objectives

The goal of this study is to develop and demonstrate procedures for effectively leveraging the information from the NDS and RID in order to examine the interrelationships between driver, vehicle, and roadway factors with driver speed selection and crash risk. The integration of data from the NDS and RID allows for a detailed examination of these issues, which is generally impractical through alternative study designs. Two specific research questions addressed as part of this proof-of-concept:

1. How does speed selection vary for specific drivers, as well as across different drivers?
2. How does the risk of traffic crash or near-crash events change with respect to speed?

This Phase 1 proof-of-concept study focuses primarily on freeways, where the design standards are higher and, thus, there is a higher range in operating speeds. The research begins with an analysis of general trends in driver speed selection and crash/near-crash risk as they relate to the posted speed limit. A series of statistical models are estimated to determine where significant differences in these measures exist with respect to posted speed limit, roadway geometry, and driver characteristics. Additional data are collected for the purpose of a more detailed comparison of vehicle dynamics and driver behavior during crash, near-crash, and baseline (i.e., control) driving events. Methods are developed and pilot tested to determine how the SHRP2 data may be used for the purposes of speed management, including the establishment of maximum speed limits and the identification of appropriate countermeasures for speeding-related crashes. The methods developed as a part of this proof-of-concept will ultimately allow for subsequent research that is able to:

- Determine how driver speed selection is affected by roadway geometric characteristics, posted speed limit, and driver characteristics; and
- Compare the risk of crash- or near-crash involvement as it relates to geometry, speed limit, and driving behavior.

LITERATURE REVIEW

Numerous studies have examined the relationship between posted speed limits and the frequency and severity of traffic crashes. Much of the research in this area was conducted following the introduction of the 55-mph National Maximum Speed Limit (NMSL) in 1974. Collectively, these studies found that lower speed limits tended to result in safety benefits [*10-12*], which were attributed to lower average speeds and speed variance [*13*]. The speed limit issue was revisited by subsequent research and legislation. Additional evaluation studies showed increases in traffic crashes and/or fatalities in states where speed limits had been increased [*14-24*].

Despite these findings, nineteen states have increased speed limits on rural freeways since 2010 and several additional states have considered such increases. In contrast to earlier increases, which were often implemented on a system-wide basis, many of the recent speed limit policy changes have affected specific road segments. In such instances, states have considered a range of factors in determining whether speed limit increases were appropriate at a given location. These factors include the existing mean and 85th percentile speeds, speed variance, and recent crash history.

The American Association of State Highway and Transportation Officials (AASHTO) notes that driving speeds are affected by the physical characteristics of the road, weather, other vehicles, and the speed limit [*25*]. Among these, road design is a principal determinant of driving speeds. Geometric factors tend to have particularly pronounced impacts on crashes. Ultimately, many factors affect speed selection beyond just road geometry and posted limit as shown by prior research in this area [*26-39*]. Research has generally shown that speed limit increases result in changes in the observed mean and 85^{th} percentile speeds that are less pronounced than the actual speed limit increases [*21,40-44*]. A meta-analysis of research from European countries and the United States [*45*] concludes that drivers ultimately choose their speeds based on perception of safety rather than posted speed limits.

These findings are largely reflective of driver opinions on speed limits. A survey of freeway users found that, on average, respondents drove 11 mph over the speed limit on roads posted 55 mph, 9 mph over the speed limit on roads posted at 65 mph, and 8 mph over the speed limit on roads posted at 70 mph [*46*]. Research also shows that drivers believe the most influential factors dictating their speed selection are weather conditions, their perception of what speeds are "safe", the posted speed limit, traffic volume levels, and the amount of personal driving experience they have on a particular road [*47*].

METHOD OF ANALYSIS

Collectively, available empirical data and information from drivers suggest that the posted speed limit is just one of several factors that play an important role in driver speed selection, as well as the related crash risk. This research leverages the data from the NDS and RID to provide a framework for better understanding the relationships between speed, crash risk, and other factors. For the purposes of this proof-of-concept, data are collected at two levels of detail. First, information was obtained as to the general characteristics associated with each event (crash, near-crash, or baseline) from the NDS InSight database. Subsequently, more detailed information are obtained from the NDS InDepth database (e.g., speed, acceleration, and GPS location information), as well as the RID (e.g., roadway geometry, traffic control, speed limit, etc.). These data were utilized to assess two primary questions of interest:

1. How does driver speed selection vary among freeways with different posted speed limits? Speed data are available at 0.1-s intervals from the NDS, allowing for an investigation of differences in driver speed selection as a function of the posted speed limit while accounting for the effects of roadway geometry, traffic characteristics, and other factors associated with each driving event.
2. How do rates of crashes/near-crashes vary among freeways with different speed limits? Prior research has demonstrated substantive differences in fatal crash rates with respect to maximum freeway speed limits. However, due to differences across states in reporting practices, research into the effects of speed limits on total crashes or surrogate events (e.g., near-crashes) has been more limited. As a part of this proof-of-concept, one of the primary initiatives was to compare the rate of crash/near-crash events as they relate to posted speed limits, as well as driver speed selection.

In order to examine these questions, regression models were estimated to examine three primary metrics of interest:

1. the average speed of vehicles during the time preceding each crash, near-crash, and baseline event;
2. the variation in travel speeds for vehicles leading up to each event as quantified by the standard deviation of speeds over this period; and
3. the rate of crash or near-crash involvement among study participants included in the sample of events.

Details of the statistical methods used to analyze these data are briefly described in the following section of the report.

Statistical Methods for Driver Speed Selection

The focus of the speed data analysis was to determine the effects of speed limit policies on the mean and standard deviation of travel speeds. To analyze these speed characteristics, separate multivariate linear regression models were estimated for both measures. These models were estimated using the NDS event and time series data, as well as the RID information.

One concern that arises within the context of this study is the anticipated correlation in speed selection behavior among the same individuals and particularly within a single driving event. For example, Figure 1 demonstrates four speed profiles for two different drivers from the NDS. Each speed profile corresponds to an event that occurred on a freeway with a 70-mph posted speed limit under low traffic volumes (level-of-service A or B as per InSight database). Visual examination of these figures shows that driver 2 generally tends to drive at higher speeds (mean speed of 78.5 mph vs. 72.0 mph for driver 1). Driver 2 also tends to exhibit greater variability in travel speeds (standard deviation of 3.5 mph vs. 1.4 mph for driver 1). From an analytical standpoint, it is important to account for the fact that specific drivers may tend to driver faster (or slower) than others (i.e., their general travel speeds are correlated across events). Failing to account for such correlation would underestimate the variability in travel speeds and potentially lead to biased estimates for the impacts of specific factors, such as the speed limit or geometric characteristics.

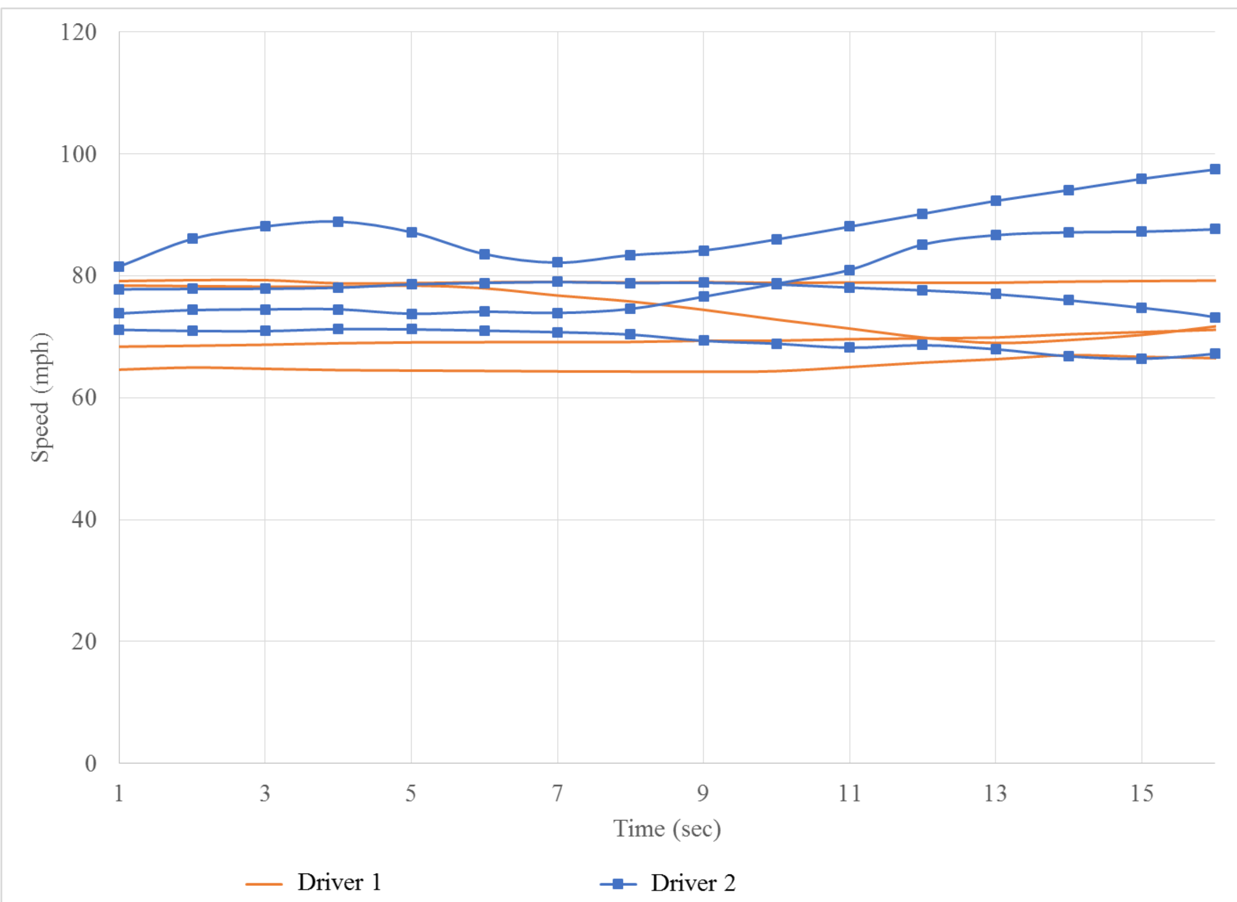

Figure 1. Speed Profiles for Baseline and Near-Crash Events at 70-mph Speed Limit

For the purposes of these speed-related models, two additional parameters are added to each model:

- A participant-specific intercept term is introduced, to account for the fact that specific drivers may tend to drive faster (or slower) than others due to factors that are not captured by the information from the NDS or RID. These may include differences in driving styles, risk perception, or other factors that affect speed selection. This participant-specific term retains the same coefficient for each driver in every event (assuming the driver has multiple events in the database) and, thus, is able to capture general differences in speed selection behavior.
- An event-specific intercept term is also introduced, which is allowed to vary across events, but maintain the same value for each individual driving event. This parameter accounts for unobserved factors that are unique to each event. Continuing from the preceding discussion, individual drivers are likely to travel faster (or slower) during individual trips due to similarly unobserved factors.

In essence, these terms capture the effects of important, unobserved variables that would otherwise lead to biased or inefficient parameter estimates. Adding these terms to the models results in what are commonly referred to as random effects model. While these effects are specific to each event or study participant, they are a random sample from the broader driving population (hence the random effects nomenclature).

Statistical Methods for Crash/Near-Crash Involvement

In addition to analyzing driver speed selection, a companion objective in this study is to assess those factors affecting crash risk. To this end, logistic regression models were estimated to examine trends in crash/near-crash involvement among study participants. Logistic regression presents an appropriate modeling framework since the dependent variable is dichotomous in nature (involvement versus non-involvement in a crash or near-crash).

Similar to the linear regression models that are estimated for driver speed selection, the logistic regression model assumes that crash or near-crash involvement is independent (i.e., not correlated) across events. This is potentially problematic as there is the potential for correlation in the rate of crash/near-crash events among study participants. That is, some individuals may inherently be at higher or lower risk for crash-involvement due to unobserved factors such as driving skill, perception-reaction time, etc. To accommodate this concern, a participant-specific intercept term is added to the logistic regression model. This constant term is allowed to vary across participants to capture the effects of such factors (this is also a random effects model).

DATA USED

For the purposes of conducting the analyses of driver speed selection and crash/near-crash involvement, data are drawn from three primary sources. These included the InSight and InDepth databases from the NDS, both of which are maintained by the Virginia Tech Transportation Institute (VTTI), as well as the RID maintained by Iowa State University (ISU). For the purposes of the proof-of-concept, the primary focus was on events occurring along freeway facilities. As neither the NDS nor the RID datasets provide a specific indicator variable to identify freeway segments, a combination of several fields were utilized to identify likely freeway events. Details of each dataset, as well as the data integration procedure are described in this section of the report.

The NDS includes information from approximately 3,150 volunteer drivers, who were monitored for up to two years, resulting in data for more than 5 million trips and nearly 50 million vehicle miles of travel. These data were collected in six geographic areas of the country and resulted in detailed time series data for more than 36,000 crash, near-crash, and baseline driving events.

NDS InSight Event Data

The InSight database provides general information about each crash, near-crash, and baseline events from the NDS. Data are aggregated into four tables, which provide details of each event, the related trip (of which the event was a subset), the involved vehicle, and the participating driver. There is a locality field in the database, which designates the type of roadway on which the event occurred. Candidate events were identified where the locality field was "Interstate/Bypass/Divided Highway with no traffic signals". Upon identifying these candidates, data were obtained from the four tables noted above:

- Event Detail Table: 6,023 unique events were identified (each event has a unique "anonymous event ID" field) and a total of 73 different fields were provided through a data sharing agreement with VTTI. The Event Detail Table includes details as to the general characteristics associated with each event (e.g., lighting condition, horizontal and vertical alignment, etc.).
- Trip Summaries Table: 5,925 unique trip IDs were included among the 6,023 events. This table included 122 fields, which provide descriptive information about each trip (e.g., trip length, min/mean/max speed, time-of-day, etc.). These 5,925 trips comprise all 6,023 events as there were some instances where multiple events (i.e., crash, near-crash, and baseline) occurred as a part of the same trip.
- Vehicle Detail Table: 2,323 records are detailed in this table, which includes 27 different fields. This table is considerably smaller than the Event Detail and Trip Summaries tables due to the fact that a number of vehicles were involved in multiple events. Unique records in this dataset were identified using a combination of the vehicle ID and participant ID fields as some vehicles were used by multiple study participants.
- Vehicle and Driver Survey Table: 2,290 unique records were included in this table, which was comprised of 133 fields that describe the participant's behavior and demographic characteristics. Each record from this table corresponds to one participant from the Event Detail and Trip Summaries tables. As with the Vehicle Detail table, specific drivers/vehicles were involved in multiple events, which is why this dataset has fewer records.

At the onset of the study, the tables described above were aggregated into a comprehensive database that included details of each event, trip, driver, and vehicle. The full database included an in-depth inventory of 355 fields from these 6,023 unique events. This included 656 crash or near-crash events, as well as 5,367 baseline events, which were randomly selected from the same types of roadways. Summary statistics are provided in Table 1 for these 6,023 events. These statistics are broadly representative of general travel characteristics across the six study areas where the NDS was conducted (Florida, Indiana, North Carolina, New York, Pennsylvania, and Washington). The primary exception is with respect to the driver age distribution as oversampling was conducted among the younger and oldest age groups as detailed in a recent SHRP2 report [*48*]. It is also important to note that sample sizes were relatively small across several categories of interest (e.g., heavy congestion, wintry weather, and the oldest age group).

Table 1. Summary Statistics for Event Data from NDS InSight Database

Variable	Category	Count	Variable	Category	Count
Gender	Male	3020	State	Florida	1346
	Female	2965		Indiana	291
	Unknown	38		North Carolina	985
Age	16-19	645		New York	1238
	20-24	1637		Pennsylvania	348
	25-29	705		Washington	1815
	30-34	398	Relation to Junction	Non-junction	3612
	35-39	233		Interchange/intersection	2023
	40-44	246		Entrance/exit ramp	384
	45-49	287		Other	4
	50-54	273	Alignment	Straight	4953
	55-59	277		Curve left	491
	60-64	223		Curve right	579
	65-69	308	Grade	Level	4989
	70-74	240		Grade down/dip	328
	75-79	238		Grade up/hillcrest	706
	80-84	180	Lighting	Daylight	4682
	85-94	46		Dawn/Dusk	375
	Unknown	87		Dark, lighted	566
Seatbelt Use	Proper use	5824		Dark, not lighted	500
	Improper or non-use	191	Weather	Clear	5417
	Unknown	8		Rain/Mist/Fog	580
Vehicle Type	Car	4305		Snow/Sleet	26
	SUV Crossover	1225	Surface Condition	Dry	5176
	Pickup Truck	295		Wet	822
	Van/Minivan	198		Snowy/Icy	25
Prior Crashes	0	4221	Level-of-Service	LOS A: no lead	888
	1	1323		LOS A: leading traffic	2221
	2 or more	404		LOS B	2035
	Unknown	75		LOS C	466
Prior Violations	0	3715		LOS D	255
	1	1429		LOS E	132
	2 or more	813		LOS F	26
	Unknown	66	Work Zone	Not work zone-related	5599
Event Type	Crash/Near-Crash	656		Occurred in work zone	255
	Baseline	5367		Other work zone-related	169
TOTAL		**6023**	**TOTAL**		**6023**

NDS InDepth Time Series Data

Beyond the event-specific information provided through InSight, further data are obtained from the InDepth database. The InDepth data are of a time-series nature, providing details of the geographic location, speed, and acceleration of the study vehicles during each event. Among the 6,023 candidates, time-series data were obtained for 5,687 events. Data were unavailable for the remaining 336 events, which were primarily comprised of crashes where the associated GPS data could have potentially allowed for the identification of specific drivers and crash locations.

The InDepth data are comprised of a series of comma-separated values (CSV) files (one file for each event). Each file includes GPS location information at 1.0-s intervals, as well as speed and acceleration data at 0.1-s intervals. In either case, data are provided for the 20 seconds preceding each crash or near-crash, as well as for the 10 seconds immediately following each crash or near-crash. Similar data are provided for 20-second snapshots from the baseline driving events.

Preliminary analyses showed that one-second intervals were generally sufficient for speed and location data. Consequently, the data were aggregated and complete speed, acceleration, and latitude/longitude information was determined at one-second intervals. This resulted in a dataset with 90,961 records (reduced from more than 1 million records for 0.1-s intervals). The data from the InDepth database were combined with those from the InSight database using the event ID field. As the data from InSight were of a general nature (i.e., the same information applied to each one-second interval), this information was copied to all intervals from the same events.

Roadway Information Database (RID)
Support information for the trips made as a part of the NDS are provided through the Roadway Information Database (RID), which is a geospatial database that provides detailed data for 25,000 miles of roadway across the six study states (Florida, Indiana, New York, North Carolina, Pennsylvania, and Washington). The RID is comprised of road characteristics, which were collected through a combination of existing roadway data from public and private sources, as well as supplemental data collected by ISU using a mobile van. The primary purpose in RID development was to provide a database that could be linked directly to the data from the NDS, which was done as a part of this proof-of-concept study. The RID is ultimately comprised of the following shapefiles:

- Lighting
- Lane
- Median Strip
- Shoulder
- Rumble Strip Links
- Intersections
- Signs
- Barrier
- Location attributes
- Alignment
- Section

Once the NDS datasets were assembled, geographic information system (GIS) software was used to plot the point data from the NDS databases on base maps for each of the study locations. There were a limited number of events that fell outside the boundaries of the six states (Florida, Indiana, New York, North Carolina, Pennsylvania, and Washington) where the NDS was conducted. These records were removed from the dataset since no roadway data were available from the RID.

The available geospatial data from the NDS (based on X and Y coordinates) were in point format and were conflated (i.e., linked) to the linear referencing system network upon which the RID is based. Once the event data were conflated to the appropriate shapefile for each state, the relevant roadway geometric information was assigned to each point datum. A dynamic segmentation process was utilized, where relevant attributes were queried from each shapefile based route ID and mile point.

In order to derive the information as to speed limit on each segment, a "signs" shapefile developed as a part of the RID was queried to identify those signs that included statutory speed limit information. The output from this query included location information (route ID and mile point), as well as the associated sign message (i.e., the posted speed limit). In contrast to the other roadway geometric data from the RID, the speed limit information (and all other sign data) were in point format. Speed limit was assumed consistent between consecutive signs, meaning that the begin mile-point for each sign was the end mile-point for the previous sign. Table 2 provides summary statistics for the data that were extracted from the RID for the purposes of this proof-of-concept study. With the exception of degree of curvature and percent grade, the other variables are binary indicator variables based upon the range of values for the specific characteristics of interest.

Table 2. Summary Statistics for Data Extract from Roadway Information Database

Variable	Minimum	Maximum	Mean	Std. Dev.
Lane width ≥12 ft	0	1	0.283	0.450
Lane width ≥11 ft, < 12 ft	0	1	0.478	0.500
Lane width <11 ft	0	1	0.239	0.427
Percent grade (upgrade)	0	5.7	0.591	0.959
Percent grade (downgrade)	0	5.9	0.595	0.995
Tangent segment	0	1	0.667	0.471
Curve to the left	0	1	0.170	0.376
Curve to the right	0	1	0.158	0.365
Degree of curve	0	5.9	0.473	0.854
Lighting present	0	1	0.399	0.490
55-mph speed limit	0	1	0.148	0.355
60-mph speed limit	0	1	0.375	0.484
65-mph speed limit	0	1	0.262	0.440
70-mph speed limit	0	1	0.215	0.411

Conflation Issues

While the dynamic segmentation process described previously provides a reasonably accurate means to extract the data, several issues were identified as a part of this process that needed to be addressed. The primary issue identified after linking the RID and NDS was a difficulty in identifying those events that actually occurred on a freeway segment. As noted previously, candidate events were first identified using the locality field from the InSight database. Events were retained where locality was equal to "Interstate/Bypass/Divided Highway with no traffic signals". As the name of this field implies, these events may also include divided, non-limited access facilities. As there was not a specific field in the NDS or RID that directly indicates freeway segments, additional criteria were considered to screen the database. Ultimately, after assessing several candidates, the following criteria were found to be most effective in distinguishing between freeway and non-freeway segments:

- Two or more through lanes in the event direction;
- Presence of a median in the event direction; and
- No intersections along the segment where the event occurred or up to 5 miles upstream.

The first two criteria (number of lanes and median presence) restricted the dataset to freeways, expressways, and divided multilane highways. To eliminate the non-freeway segments, the boundaries of each event segment were first extended by five miles upstream of the first event data point. Once these new segments were created, the intersection shape files from the RID were overlaid on these extended segment data. Subsequently, any such extended segment that included an at-grade intersection was removed from the dataset.

One complication that arose as a part of this process was that the number of lanes and median presence attributes sometimes changed over the course of several extended segments (as noted previously for the normal event segments). Hence, summary data were examined for all instances where these attributes changed. Segments were eliminated if these attributes varied over the extended event segment. After applying these QA/QC procedures, the final time series dataset included information for 2,963 unique events that covered 55,667 seconds (i.e., time series events). A manual review was subsequently conducted of each route ID using Google Earth in order to verify whether the segment was actually a freeway. Among the candidate events, 94.7 percent were verified to have occurred on freeways. Among the total sample, 1.8 percent of the events occurred on expressways and 3.4 percent occurred on other high-speed divided roadways that were neither freeways nor expressways. The subsequent analyses were conducted on those events that were verified to have occurred on freeways. After removing cases with missing data, the final sample included 1,969 freeway events.

RESEARCH RESULTS

After the data were assembled, three general questions of interest were investigated:

1. How did speed limit and other roadway, driver, vehicle, and environmental factors affect the mean vehicle speed during each of the events?
2. How did speed limit and other factors affect the standard deviation of speeds for drivers/vehicles during each event?
3. How did speed limit, mean speed, and standard deviation in speeds affect the risk of crash/near-crash events while controlling for other pertinent factors?

First, an explanatory analysis of the data was conducted to ascertain general trends in driver speed selection. Table 3 provides data related to the mean speeds among the 1,969 unique events in the final dataset. Speed data were examined for only the first 15 seconds of each event. Subsequent data were excluded because of concerns as to downward bias in speeds for the crash and near-crash events (as vehicles may have slowed down immediately before these safety-critical events).

Table 3. Summary Statistics for Mean Speed by Posted Speed Limit

Speed Limit	Average of Mean Speeds (All Events)	Std. Dev. of Mean Speeds (All Events)	Average of Mean Speeds (LOS A Only)	Std. Dev. of Mean Speeds (LOS A Only)
55	58.38	13.56	63.28	6.93
60	56.40	15.04	63.62	7.25
65	67.67	8.95	69.11	5.66
70	69.49	12.17	71.48	8.41

The information in Table 3 provides details of the average value and the standard deviation of the mean speeds across the entire sample of events. To clarify, the mean speed over the first 15 seconds of each event was calculated. This table presents the averages and standard deviations of these mean speeds as it relates to the four posted speed limits that were considered. Separate summaries are provided for the full sample, as well as a restricted sample that includes only those events that occurred under level-of-service A according to the traffic density variable in the NDS data.

When examining these aggregate-level data, a few points stand out. First, the mean speeds tended to be relatively consistent among those roadways posted at 55 and 60 mph, as well as among those roads posted at 65 or 70 mph. These mean speeds are also not found to be monotonically increasing (e.g., the mean speed at 60 mph is greater than at 55 mph). There are several reasons for this result. First, these data summaries do not consider the effects of the various other factors that impact speed selection behavior and were included in the subsequent multivariate regression models that were estimated. Secondly, the samples are unbalanced with respect to the six site locations from the NDS. As prior research has shown significant differences across jurisdictions [*9*], this is likely to explain some of this difference. It is also interesting to note that the standard deviation among these speeds is relatively large compared to what is generally found at specific roadway locations. This is due to the fact that these summary statistics are calculated over all events and all roadway locations. Consequently, there is significantly higher variability because the speeds are not measured on the same road segments. However, this variance is reduced considerably when considering only LOS A conditions.

Table 4 provides similar summary statistics for the standard deviations in travel speeds over the duration of the 1,969 events. For each event, the standard deviation was calculated from the first 15 seconds of available speed data. Separate summaries are provided for both the total sample of events, as well as for free-flow (i.e., LOS A) conditions. In contrast to the overall variability in speeds presented in Table 3, the standard deviations for individual trips is much smaller. This is reflective of the fact that driver speeds tend to be quite consistent when considering 15-s snapshots. In general, speeds are shown to be more variable under lower speed limits, which is consistent with the broader empirical research literature in this area. The variability in speeds tends to be similar among freeways posted at 55 mph and 60 mph, as well as among those posted at 65 or 70 mph. As noted previously, it is important to recognize that some of this variability is due to the presence of other factors that are not accounted for in presentation of these raw data.

Table 4. Standard Deviation of Speeds over Events

Speed Limit	Average Of Std. Dev. Data (All Events)	Average of Std. Dev. Data (LOS A Only)
55	1.90	1.17
60	1.92	1.22
65	1.20	0.97
70	1.31	1.07

To gain a better understanding as to driver speed selection, random effects linear regression models were estimated for both mean speed and standard deviation in speeds as described previously. Table 5 provides results of the random effects models for mean travel speed. Separate models are provided for the total sample, as well as for the subset of events that occurred under level-of-service A.

Starting with the entire sample, the results show that speeds were primarily affected by the level of traffic congestion that was present at the time of the event. Speeds were relatively stable across levels-of-service (LOS) A and B, within a range of 2.5 mph on average. Speeds began to drop significantly under LOS C and, particularly, in LOS D and E. Several driver and roadway characteristics were also found to affect speed selection behavior. Speeds were marginally lower (1.6 mph) on freeways posted at 65 mph versus 70 mph. In comparison, speeds were approximately 7.2 mph lower on facilities posted at 55 mph or 60 mph. Speeds tended to decrease on horizontal curves and along upgrades while speeds increased on downgrades (at similar rates to the speed reductions on upgrades). Speeds were higher among male drivers and particularly among those ages 16-24. The results are generally consistent for those events that occurred under free-flow conditions (i.e., LOS A), although a few notable differences were found. When considering only those events occurring during LOS A, significant differences are observed across all four speed limit categories. The difference in speeds between male and female drivers was not found to be statistically significant under LOS A.

Table 5. Random Effects Linear Regression Model for Mean Speed

Variable	Total Sample			Level-of-Service A Only		
	Coeff.	**Std. Err.**	**t-stat**	**Coeff.**	**Std. Err.**	**t-stat**
Intercept	16.75	0.89	18.78	68.81	0.54	127.45
LOS A (no lead vehicle)	52.31	0.75	69.37	-	-	-
LOS A (lead vehicle)	53.26	0.74	72.22	-	-	-
LOS B	50.75	0.73	69.25	-	-	-
LOS C	40.20	0.75	53.85	-	-	-
LOS D	19.41	0.76	25.39	-	-	-
LOS E	11.64	0.78	14.86	-	-	-
Non-junction	1.20	0.12	10.16	0.72	0.11	6.50
Age 16 to 24	2.34	0.57	4.13	3.13	0.62	5.06
Age 25 to 59	1.70	0.58	2.93	2.43	0.64	3.79
Upgrade	-0.50	0.06	-8.81	-0.32	0.05	-6.19
Downgrade	0.63	0.06	11.26	-	-	-
Rain	-2.14	0.18	-11.69	-2.30	0.22	-10.65
Sleet or snow	-4.02	0.95	-4.24	-8.52	0.78	-10.93
Female	-0.86	0.44	-1.98	-	-	-
Work zone	-1.24	0.22	-5.59	-2.38	0.20	-11.84
55-mph limit	-7.22	0.24	-29.58	-7.53	0.23	-32.94
60-mph limit	-7.18	0.21	-34.86	-5.98	0.18	-33.58
65-mph limit	-1.61	0.24	-6.78	-2.62	0.19	-13.85
Degree of curve	-0.33	0.05	-6.14	-0.10	0.05	-2.06

Note: N/A = not applicable; - indicates a variable is not statistically significant at $\alpha = 0.05$

Table 6 presents similar results from the random effects linear regression model that was estimated to examine the standard deviations in travel speeds that occurred during study events. As expected, the variability in travel speeds was predominantly affected by congestion. The standard deviation was lowest under LOS A and highest under LOS E. Speeds were also highly variable on the approach to work zone environments and particularly within the work zone itself. As shown by prior research in this area, speeds also tended to become more consistent (i.e., decreased variability) as the speed limit increased. This is a possible reflection of the more rural nature of the higher speed facilities and/or a tendency of drivers to travel significantly above the lower posted speed limits.

Table 6. Random Effects Linear Regression Model for Standard Deviation in Speed

Model Term	Coeff.	Std. Err.	t-stat
Intercept	2.41	0.55	4.35
Non-junction	-0.36	0.08	-4.45
LOS A (no lead vehicle)	-1.36	0.56	-2.42
LOS A (lead vehicle)	-1.19	0.56	-2.14
LOS D	1.19	0.58	2.04
LOS E	1.42	0.61	2.35
Work Zone	0.82	0.18	4.60
Work Zone approach	0.63	0.23	2.71
55-mph limit	0.40	0.12	3.43
60-mph limit	0.30	0.09	3.45

After determining the relationships between travel speeds and various event characteristics, random effects logistic regression models were estimated to assess factors affecting crash/near-crash risk. Table 7 presents results of two random effects logistic regression model for crash/near-crash risk.

Table 7. Random Effects Logistic Regression Model for Crash/Near-Crash Risk

Model Term	Coeff.	Std. Err.	t-statistic	Odds Ratio
Intercept	-2.54	0.42	-5.99	N/A
Non-junction	-0.29	0.17	-1.77	0.75
Vertical curve	0.42	0.21	2.03	1.52
Age 35 to 74	-0.87	0.20	-4.39	0.42
LOS A	-2.22	0.26	-8.46	0.11
LOS B	-1.17	0.22	-5.21	0.31
LOS D	0.62	0.32	1.97	1.86
Mean Speed	0.02	0.01	3.25	1.02
Speed Std. Dev.	0.35	0.04	8.09	1.42

For each of the variables in the final model, the parameter estimate, standard error, and t-statistic are included, along with the odds ratio. A positive coefficient indicates the variable is associated with a higher risk of a crash/near-crash while negative coefficients are indicative of conditions that are associated with lower crash/near-crash risks. The magnitude of these impacts can be discerned by examining the odds ratios, which represent the average change in the odds of a crash or near-crash occurring as compared to the baseline condition to which these factors are compared. For example, the odds of a crash or near-crash occurring on a freeway were approximately 52 percent higher at locations where vertical curvature is present.

The results show that the risk of a crash or near-crash increased with both the average speed and the standard deviation in speeds over the course of each event. The odds of a crash/near-crash increased by approximately 2 percent for every 1-mph increase in speed and by 42 percent for a 1-mph increase in standard deviation. These findings are particularly noteworthy given the difficulty that is normally associated with relating crash outcomes with speed profile data. Most of the extant research literature has relied on traffic detector data, which is often difficult to link directly to the time a crash occurred due to time lags in these systems. These results provide compelling evidence that is based on speed profiles immediately preceding crash and near-crash events. Turning to the other variables of interest, consistent with prior results, crash risks were highest under heavy congestion (LOS D), as well as on vertical curves and lowest among middle aged drivers (ages 35 to 74).

In summary, this Phase 1 proof-of-concept study has provided important evidence in support of the stated research objectives:

- Drivers were found to adapt their speeds based upon changes in the roadway environment. Turning to the primary factor of interest, higher speed limits were found to result in higher travel speeds. However, the increases in travel speeds tended to be less pronounced at higher posted limits, which is consistent with recent research in this area [*9*]. Drivers tended to reduce their travel speeds along horizontal or vertical curves, under adverse weather conditions, and particularly under heavy congestion. The variability in travel speeds was also found to be influenced by several factors, including the posted speed limit, as well as the presence of congestion or work zone activities.
- These differences in average speed and standard deviation of speed were both found to affect crash risk. As either the average or standard deviation increased, so too did the probability of a crash or near-crash event. Specifically, the odds of a crash or near-crash was 2 percent greater for every 1-mph increase in speed and 42 percent greater for every 1-mph increase in standard deviation of speed.
- Differences in crash risk were also observed with respect to traffic congestion, geometric characteristics, and driver age. Specifically, crashes and near-crashes were more likely to occur on a freeway section where vertical curvature is present. Given resource constraints for this proof-of-concept, there remain several additional factors that may be considered as a part of future research.
- The random effects models presented herein were found to provide significantly improved fit as compared to simpler model formulation. In each case, the random effects model provided better fit at 99-percent confidence level (detailed results have been omitted due to space constraints). This result demonstrates that there are inherent differences in speed selection among drivers and also that some drivers tend to be more or less likely to be crash-involved than others. As some of these differences are due to unobserved factors, it is important that statistical methods are employed that are able to accommodate the correlation among the same drivers or events.

FUTURE DIRECTION

This Phase 1 proof-of-concept study has demonstrated how driver speed selection is impacted by the posted speed limit, traffic conditions, and roadway geometric characteristics. The study has also shown how the information from the NDS and RID can be leveraged to answer additional research questions as to how travel speeds affect crash risk. Perhaps most importantly, the research has established a framework that can be implemented at a larger scale as a part of subsequent research. This framework will allow for a more detailed assessment of several research questions related to speed management, including the following:

1. How is driver speed selection affected by roadway characteristics such as curve radius, curve length, superelevation, and grade?
2. How do speed limits affect driver behavior under comparable driving conditions?
3. Do roads in different states with the same speed limit elicit similar driver responses?
4. How do drivers respond to visual cues, such as curve advisory signs or lane merge signs, and over what dimensions (both temporal and spatial) do these effects occur?
5. How does driver behavior, in combination with roadway geometry and other environmental factors, affect crash risk?

Subsequent work in this area will allow for a more detailed examination of driver behavioral data to investigate how crash potential and driver speed selection are related to posted speed limit and other driver, traffic, and roadway characteristics. In addition to continuing the exploration of freeway facilities and, the NDS data will also allow for consideration of how these relationships vary across a broader range of high-speed roadways, including two-lane and multilane highways. Ultimately, the results of these analyses will lead to the identification of potential countermeasures, policies, and programs with the greatest potential to reduce traffic crashes and injuries on high-speed roadways. Future research may also leverage state-maintained safety and operational data from each of the six study states, which will allow for a better understanding of how driver speed selection affects crash risks. Investigating these research questions will provide critical insights to the transportation community. Of particular interest are several of the potential practical countermeasures and policy issues that may be impacted through such research:

- Setting of maximum speed limits - The 85th percentile speed is generally used as a primary factor in establishing maximum speed limits. However, research has suggested that roadway characteristics play a greater role than posted limit in affecting travel speeds. The SHRP2 data provide an excellent opportunity to address this issue, as the maximum freeway speed limits in the six states included in the study range from 55 mph to 70 mph. In addition, the speed limits also vary by state on the non-limited access system. As several states have recently increased speed limits selectively, it is critical that a soundly designed, quantitative analysis is able to inform agencies of the expected impacts of such policy decisions.
- Use of speed advisory signs - Limited right-of-way, frequent access points, and challenging geometry often require the use of speed advisory signs along segments that cannot be designed to satisfy the prevailing design speed. Prior research has shown that such areas are prone to increased crash rates. It is important to better understand driver response when approaching these locations (i.e., horizontal curves), particularly with respect to the location of advance warning signs.

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