Research Utilizing SHRP2 Data to Improve Highway Safety: Development of Speed–Safety Relationships

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FOREWORD

In 2016, the Federal Highway Administration posted a broad agency announcement (BAA) to conduct research on potential safety improvements using the Naturalistic Driving Study (NDS) and the Roadway Information Database (RID), resources developed from data collected during the research phase of the second Strategic Highway Research Program. Phase 1 served as a proof of concept to determine if meaningful conclusions or countermeasures could be developed using the NDS and the RID. Phase 2 enabled researchers to conduct more indepth analyses, leading to specific highway safety improvements.

The following final report describes the methodology and results of one of six BAA projects to evaluate the relationship between speed and safety of urban and suburban arterials affected by roadway and roadside characteristics. In this study, researchers used the NDS and the RID to correlate speed with several roadway and roadside variables and found that the crash likelihood increases as the variance of mean speed increases for a given roadway segment. Furthermore, the inclusion of the speed term in the existing *Highway Safety Manual* safety-prediction models for urban and suburban arterials does not improve the predictions.

This report will be of interest to State and local department of transportation safety professionals interested in relationships between roadway design, speed, and safety.

Brian P. Cronin, P.E.
Director, Office of Safety and Operations Research and Development

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16. Abstract

The objective of this research was to examine the link between driving speed and crash experience on roadway segments, taking into account roadway characteristics that influence speed and crash frequency and severity. A potential outcome of the research was improved safety performance functions that included a speed term or crash modification factors (CMFs) based on speed for use in a safety-prediction methodology for urban/suburban arterials. Using the second Strategic Highway Research Program Naturalistic Driving Study data and the Roadway Inventory Database (RID), the research examined individual drivers' speeds along 100 study segments. Variations within individual trips as well as among drivers on the same roadway segment over a few years were evaluated. Also, using the RID and roadway and roadside characteristics obtained from aerial and street-view imagery, relationships between speed choice and roadway characteristics were explored. The research found that a number of roadway characteristics are related to speed and crash experience for a roadway segment and that a higher measure of speed variance between trips was frequently correlated with higher crash frequency (especially for multivehicle crashes). Most other speed measures evaluated had no correlation with crash frequency or had a negative correlation. The research did not find that including a speed term into existing safety performance functions or developing a speed CMF would substantially improve the existing crash-prediction methodology for urban and suburban arterials presented in the *Highway Safety Manual*.

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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
		NOTE: volumes greater than 1000 L shall be shown in m^3		
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact degrees)		
^oF	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	^oC
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
		TEMPERATURE (exact degrees)		
^oC	Celsius	1.8C+32	Fahrenheit	^oF
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

*SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380.
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LIST OF ACRONYMS, ABBREVIATIONS, AND SYMBOLS

Acronyms and Abbreviations

2U	two-lane undivided
4D	four-lane divided
85-SL	85th-percentile space mean speed minus posted speed limit
AADT	annual average daily traffic
AASHTO	American Association of State Highway and Transportation Officials
BAA	broad agency announcement
CMF	crash modification factor
DDS	driveway density score
DOT	department of transportation
FFS	free-flow speed
FHWA	Federal Highway Administration
FI	fatal and injury
GC	gradual curve
GIS	geographic information system
GPS	Global Positioning System
HSM	*Highway Safety Manual*
iRAP	International Road Assessment Programme
KABCO	crash-severity scale, where K is fatal injury, A is incapacitating injury, B is nonincapacitating injury, C is possible injury, and O is no injury
ln	natural log
MMM	mean of trip maximum spot speed minus trip minimum spot speed
MV	multiple vehicle
NCHRP	National Cooperative Highway Research Program
NDS	Naturalistic Driving Study
PDO	property damage only
PSL	posted speed limit
RID	Roadway Inventory Database
SD	standard deviation
SHRP2	second Strategic Highway Research Program
SMS	space–mean speed
SV	single vehicle
T	tangent
TRB	Transportation Research Board
usRAP	United States Road Assessment Program

Symbols

b_0	regression coefficient for intercept
b_1	regression coefficient for first term
b_2	regression coefficient for second term
Crashes after	number of crashes during study period before change
Crashes before	number of crashes during study period after change
C_{maj}	number of major commercial driveways
C_{min}	number of minor commercial driveways

DDS_{2U}	DDS for 2U sites
DDS_{4D}	DDS for 4D sites
e	Euler's number
F	F distribution
I_{maj}	number of major industrial driveways
I_{min}	number of minor industrial driveways
L	length of site (mi)
N_{Crash}	crashes per mile per year
Pr	p-value
R_{maj}	number of major residential driveways
R_{min}	number of minor residential driveways
$Speed$	speed measure
SS	number of side-street access points
V_{final}	mean speed of traffic after change
$V_{initial}$	mean speed of traffic before change

CHAPTER 1. INTRODUCTION AND BACKGROUND

BACKGROUND

The number of safety-management tools available to highway agencies has greatly increased in recent years with the publication of the American Association of State Highway and Transportation Officials (AASHTO) *Highway Safety Manual* (HSM) and the development of Safety Analyst software tools (AASHTO 2010; AASHTO 2019). However, a major limitation of these tools is the inability to account for the influence of traffic speed on safety. Simple physics shows that crash forces increase in proportion to the square of speed, so crash severity has an important dependence on speed. There is also an influence of speed on crash likelihood, but this relationship is more complex and not as well understood.

Conventional wisdom on the relationship between speed and safety suggests that decreasing speed variance on the road decreases crash likelihood and that if all vehicles traveled at the same speed, the opportunity for crashes would be low. This belief may be based on Solomon's 1964 research, which found that on rural highways crash likelihood increases as the difference between an individual driver's speed and the average speed on the road increases. This research produced a U-shaped curve showing that accident rates increased as speeds moved away from the average speed, with a steeper slope associated with slower speeds (Solomon 1964). This research was the first comprehensive look at the relationship between driving speed and crash risk; it is unsurprising that interpretations of the study's findings have been passed down through generations of traffic engineers. However, the study had limitations in methodology and in the precision of the data used. It was also only meant to be applied to rural highways. In addition to these limitations, the data collected for this study are now over six decades old; in that time, there have been substantial changes in driver demographics; driving behavior; vehicle safety features and performance; and, perhaps to a lesser extent, highway design.

The relationship between speed and safety has continued to be a popular research topic in the decades since Solomon's work, although much of the research has been international and not based on U.S. data. In general, these studies have found that increases in travel speed as well as increases in speed variance increase crash frequency—confirming the conventional wisdom to a certain extent.

U.S. researchers have had difficulty in documenting speed effects on crash frequency and severity in empirical modeling because only data on speed limits, rather than data on actual traffic speeds, are typically available, and speed limits are typically correlated with most other variables modeled. For example, in the research that led to the development of the crash-prediction models for urban and suburban arterials found in chapter 12 of the HSM, an inverse relationship was found between speed limits and crash frequency (i.e., more crashes at lower speeds) (AASHTO 2010, Harwood et al. 2007). The logical explanation of this counterintuitive finding is that lower-speed arterials also have more dense development, more driveways, and more intersections, often closely spaced. This correlation between speed limits and other independent variables in the model (referred to in statistical terms as "multicollinearity") makes it difficult for conventional statistical techniques to develop crash-prediction models empirically (i.e., through conventional statistical modeling techniques).

The second Strategic Highway Research Program (SHRP2) Naturalistic Driving Study (NDS) database provides a source of U.S. vehicle-speed data for many vehicles on multiple sites for several roadway types (Transportation Research Board [TRB] 2013a). The Roadway Inventory Database (RID) provides a means to link crash history to speed data, as well as to include important roadway characteristics into the speed–safety relationship model (TRB 2013b).

RESEARCH OBJECTIVE AND SCOPE

The overall study objective was to develop speed–safety relationships that can be used in the HSM and in other safety-management tools such as Safety Analyst and U.S. Road Assessment Program (usRAP) models. The speed–safety relationships consider vehicle speed, roadway characteristics, and crash data for two-lane undivided (2U) and four-lane divided (4D) urban and suburban arterials using data from five of the six NDS sites. The relationships have been developed using functional forms consistent with the safety performance functions presented in the urban and suburban arterial chapter of the HSM (AASHTO 2010).

The primary goal of the research was to provide practitioners with new information about the relationship between speed and crash frequency and severity to help them estimate the safety impact of changes to their overarching speed-limit policies and the PSLs on specific roadways.

RESEARCH APPROACH

The phase 1 research was conducted in 2016 and comprised a proof-of-concept study; research activities were focused on obtaining data samples, exploring the completeness and quality of relevant data elements, and developing methods for extracting the precise datasets desired for this research in terms of segments of time and length along the roadways of interest. In phase 2, the study was expanded to include a larger sample of study sites and trips and to develop statistical models that characterize the relationships between speed measures and crash frequency and severity.

This project briefing document presents a description of the work that was completed under phase 2 of this research, including study site selection, collection of site characteristic data, speed data acquisition, development of speed measures for use in the analysis, and analysis of the relationships between speed and crashes and between speed and roadway characteristics. The briefing document summarizes the findings, interprets the results, and provides recommendations for future research.

STATE DEPARTMENT OF TRANSPORTATION RESEARCH PARTNERS

The initial concept for this research was supported by three State departments of transportation (DOTs): Missouri DOT, Ohio DOT, and Utah DOT. In addition to keeping these DOT partners informed of the research plan and progress at various points throughout the project, the research team held a web conference with representatives from each of the partner State DOTs on February 19, 2019. During that meeting, a number of topics relevant to the research were discussed with the intention of shaping the research to best address the needs of State DOTs. Highlights from that discussion are summarized as follows:

- Speed data sources available to DOTs: The Missouri DOT and the Utah DOT have access to extensive traffic data. Both DOTs doubt the reliability of the data for urban arterials. The Missouri DOT will use armadillo traffic detectors placed on the pavement for 24-h to 48-h spot speed studies. The Utah DOT has side-fire radar units configured to gather vehicle-level data (not aggregated), but data take up a lot of space.
- Desired use of research results: These include using the results in public messaging to convince the public that higher speeds are not safe, improving the crash-prediction models that are used to analyze benefits and costs of projects, and understanding what design features influence speed choice to better design roadways that encourage appropriate speeds (self-enforcing roadways).
- Speed measures: The DOTs would like the research team to consider using variables that can be estimated or assumed by a highway agency rather than collected, such as measures that are a certain percentage or miles per hour above or below the posted speed limit (PSL).
- Sensitivity analysis: The DOTs would like to see how sensitive crashes are to speed and how sensitive speed is to roadway characteristics. The DOTs want to make sure it makes sense to include a speed term in crash-prediction models, rather than just assuming it should be included.
- Consideration of unintended consequences: Roadway features considered to reduce crash frequency or severity (e.g., buggy bypass lanes) may lead to increased speeds, which may lead to an increase in crash frequency or severity.

ORGANIZATION OF THIS DOCUMENT

This document is organized into six chapters, including this introduction chapter. Chapter 2 describes data acquisition and processing, including the procedure for selecting the phase 2 study site, the data-collection process for site characteristics, and NDS data requests. Chapter 3 presents a summary description of site characteristics and speed measures retrieved or calculated for each study site, and corresponding appendix A provides tables with details of each site's characteristics. Chapter 4 presents the statistical analysis methodology, and corresponding appendix B provides tables detailing full results of all statistical models. Chapter 5 presents a discussion of study results and their interpretation. Last, conclusions and recommendations for future research are presented in chapter 6.

CHAPTER 2. DATA ACQUISITION

Phase 1 study efforts were largely focused on understanding the data available through the RID and the NDS and ensuring that a combination of the data acquired through them and other available data sources could provide sufficient information to draw conclusions about the effect of speed on safety. In phase 2, the objective was to collect data from a sufficient number of study segments to conduct a meaningful statistical analysis of the relationship between speed and safety on 2U and 4D urban and suburban arterial roadway segments. This chapter discusses the site-selection process and the acquisition of NDS speed data (and other trip data), crash and traffic volume data, and site characteristic data used in the phase 2 analysis.

SITE-SELECTION METHODOLOGY

In phase 1, the research team identified urban and suburban arterials as the focus for this research effort because these facility types were the most prominent in the RID and because arterials were likely to have the widest range of PSLs and driving speeds. After narrowing the search to urban arterials, study sites were chosen based on the following criteria:

- A large number of trips made by many different study drivers were available for the site.
- Consistent cross-section design (lane width, shoulder width, median type and width) along the length of the segment.
- Sufficient length for free-flow speed (FFS) to be reached between potential stop conditions such as near stop signs or signals. (Sites that were at least 0.5 mi long were prioritized.)
- No horizontal curves sharp enough to warrant advisory speed limits or other curve warning signs.
- No railroad grade crossings.
- No midblock pedestrian crossings.
- No signed school zones with associated speed restrictions.

The RID was used as a starting point to identify roadway segments that could be potential study sites. The process for selecting sites for the study was conducted in the following steps:

1. Use dynamic segmentation procedures on the RID to identify available mileage of various roadway types.
2. Incorporate the number of trips made by NDS study drivers and the number of unique NDS drivers who made those trips into the segmented geodatabase.
3. Develop individual maps for each roadway type of interest, showing road segments that meet criteria for number of trips and unique drivers. Color-code segments based on associated speed limit from the RID speed-limit file. Figure 1 shows a portion of the map created for 4D roadways in North Carolina.
4. Use geographic information system (GIS) tools (such as Google® Earth™ aerial and street views) to gather characteristics of potential sites (PSL, lane width, shoulder width, horizontal curvature, access type and density, etc.).
5. Prioritize sites with desired physical characteristics and desired distribution of speed limits for inclusion in the analysis.

6. Send highest prioritized sites to SHRP2 NDS data manager to determine if quality speed and location data are available for a sufficient number of trips for each segment. Retain segments with sufficient quality trip data. Send additional potential study segments to NDS data manager until a sufficient number of sites are retained.

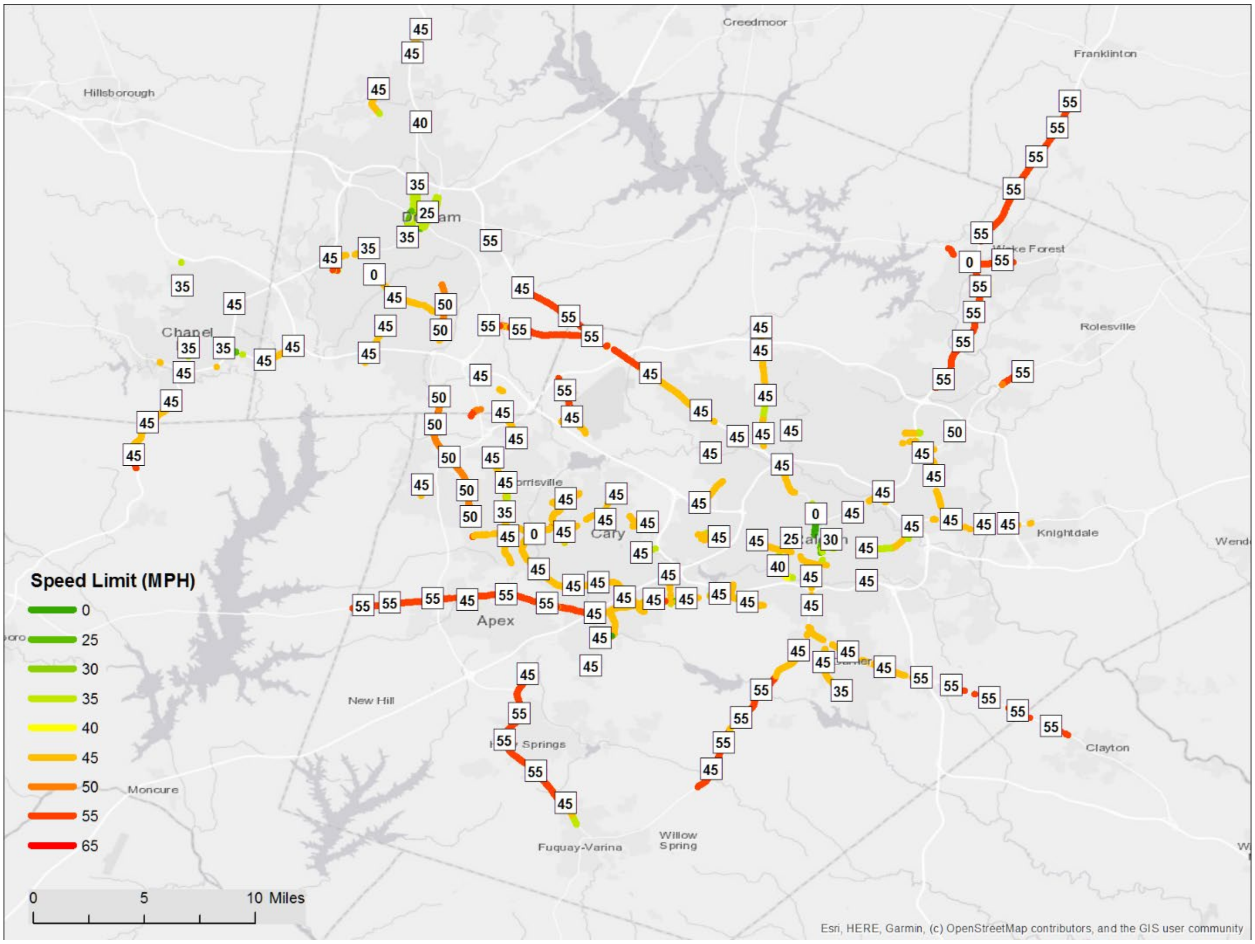


Figure 1. Map. Portion of map created for 4D roadways in North Carolina.

During the phase 1 pilot study, 20 study sites were selected, including 10 2U sites in Washington and 10 4D sites in Florida. These study sites were carried forward and used in phase 2, although they have data for fewer trips (approximately 300 for most sites) than the segments selected for use in phase 2, which included approximately 500 trips per site.

SITE CHARACTERISTICS DATA

Table 1 shows the total number of sites and trips for which data were obtained on 2U urban arterials for each State across both phases. Table 2 provides the same information for 4D sites. Overall, the data request included trips on 60 2U roadway sites and 54 4D sites.

Table 1. Number of 2U urban or suburban arterial sites by State (initial).

State	Number of Total Sites	Number of Total Trips
Florida	13	6,349
Indiana	10	4,792
New York	13	6,401
North Carolina	11	5,301
Pennsylvania	3	1,500
Washington	10	3,388
Total	**60**	**27,731**

Table 2. Number of 4D urban or suburban arterial sites by State (initial).

State	Number of Total Sites	Number of Total Trips
Florida	29	12,013
Indiana	7	3,500
New York	0	0
North Carolina	13	6,382
Pennsylvania	0	0
Washington	5	2,500
Total	**54**	**24,395**

For all 114 study sites, the site characteristics listed in table 3 were measured or observed and recorded using Google® Earth™; these data include the variables used in the HSM chapter 12 crash-prediction method for 2U and 4D urban and suburban arterials among other variables (AASHTO 2010).

Although the RID provides information on lane width and shoulder width, these values were found to be incomplete representations of actual field conditions. For example, lane width in the RID represents the width of the lane that the data collection van traveled, rather than an average lane width for the roadway cross section. Therefore, these data were gathered using aerial and street-view imagery. In past research, the research team has tested the accuracy of using aerial imagery in measuring roadway cross section elements by comparing measurements to actual field measurements. Results show that the accuracy is very high, and the method is adequate for measuring roadway elements.

Table 3. Site characteristics data elements collected.

Data Element	Categories
Presence of roadway lighting	Yes, no
Median width	Value in feet
Median type	N = no median or median treatment (cross section with double yellow centerline) R = raised median (separated from roadway by a curb) D = depressed median (grass median with no curbs) F = flush median (paved median flush with paved roadway surface)
Number of fixed objects	Count

Data Element	Categories
Fixed-object offset	Value in feet
Presence of on-street parking	Yes, no
Presence of bike lanes	Yes, no N = no bike lanes present Y = bike lanes present
Number of intersections with public roadways	Count
Area type	Residential, commercial, industrial/institutional, undeveloped
Shoulder type on each side of roadway	P = paved shoulder T = turf shoulder G = gravel shoulder C = composite shoulder VC = vertical curb at edge of traveled way MC = sloping or mountable curve at edge of traveled way CG = vertical curb and gutter at edge of traveled way MG = sloping or mountable curb and gutter at edge of traveled way PC = paved shoulder with curb at outside edge of shoulder N = no shoulder (and no curb or curb and gutter)
Shoulder width on each side of roadway, if applicable	Value in feet
Gutter width on each side of roadway, if applicable	Value in feet
Widths of each travel lane	Value in feet
Horizontal alignment	T = tangent GC = gradual curves SC = sharp curves
Number of major commercial driveways	Count
Number of minor commercial driveways	Count
Number of major industrial driveways	Count
Number of minor industrial driveways	Count
Number of major residential driveways	Count
Number of minor residential driveways	Count
Number of other driveways	Count

A total driveway density score (DDS) was calculated based on the multivehicle (MV) driveway safety performance function coefficients presented in the HSM (AASHTO 2010). Driveway and side street counts in each of the driveway categories were scaled based on the relative magnitude of the coefficient that corresponds to each driveway category. The equations in figure 2 and figure 3 were used to compute the DDS for 2U and 4D sites.

$$DDS_{2U} = \frac{10C_{maj} + 3C_{min} + 10I_{maj} + 1.5I_{min} + 5R_{maj} + 1R_{min} + 10SS}{L}$$

Figure 2. Equation. DDS calculation for 2U roadways.

$$DDS_{4D} = \frac{12C_{maj} + 4C_{min} + 11I_{maj} + 2I_{min} + 6R_{maj} + 1R_{min} + 10SS}{L}$$

Figure 3. Equation. DDS calculation for 4D roadways.

Where:
DDS_{2U} = DDS for 2U sites.
DDS_{4D} = DDS for 4D sites.
C_{maj} = number of major commercial driveways.
C_{min} = number of minor commercial driveways.
I_{maj} = number of major industrial driveways.
I_{min} = number of minor industrial driveways.
R_{maj} = number of major residential driveways.
R_{min} = number of minor residential driveways.
SS = number of side-street access points.
L = length of site (mi).

Note that there were no driveways on any of the sites that were categorized as "other."

CRASH DATA AND TRAFFIC VOLUME FOR STUDY SITES

In phase 1 of the research, crash data from the RID were used for the sites in Florida and Washington. During phase 2 of the research, the research team found that the crash data provided in the RID were not substantial enough for use in the other four States: Indiana, New York, North Carolina, and Pennsylvania. The research team reached out to the appropriate State agencies to acquire crash data for the sites in these four States. The goal was to acquire detailed crash data to derive the following fields:

- Crash severity (using the KABCO crash-severity scale, where K is fatal injury, A is incapacitating injury, B is nonincapacitating injury, C is possible injury, and O is no injury).
- Junction relationship.
- Number of vehicles involved.
- Crash type.
- Lighting condition.

Florida and Washington crash data from the RID were used again for the phase 2 analysis sites. For Indiana, the research team used the crash data layers in the RID to assign crashes to the analysis sites. However, the crash data layers in the RID did not provide adequate detail about the specific crashes. The research team provided crash identification numbers for the crashes on the analysis sites to the Indiana DOT, which provided detailed crash data for these crashes.

Similar to Indiana, the New York and Pennsylvania crash data in the RID did not provide adequate details needed for the analysis. The New York State DOT provided the research team with GIS-based countywide crash datasets. GIS-based crash data were available online from the Pennsylvania DOT. Crashes were assigned to the analysis sites using GIS processes. The North Carolina crash data in the RID do not cover the entire RID roadway network. The North Carolina DOT selected crashes for each analysis site and provided the research team with the detailed crash data.

For all analysis sites, it was necessary to collect annual average daily traffic volumes (AADT). The research team built an AADT database using traffic volume layers provided for each State in the RID (which included AADT for years 2011 through 2013) as well as traffic volumes acquired directly from transportation agencies when necessary. The research team developed an AADT database for 2008 to 2015 to match the years of crash data included in the analysis. Interpolation was used to fill in missing AADT values between years of known AADT. Where interpolation could not be used, the AADT value for the nearest year was used to fill in missing AADT values.

During the research project, a reduced AADT dataset became available to all RID users. The reduced AADT dataset provided one additional year of AADT data (2010). It also used a procedure to fill in previously missing years of data. Comparison of the AADT database created by the research team and the new AADT reduced dataset showed the two datasets to be nearly identical matches for the years for which AADT data were available in the original RID, as well as for most of the interpolated or otherwise filled-in missing years. The project AADT dataset was updated to include the new data for 2010 and adjust the years 2008 and 2009 accordingly. There were five analysis sites, however, where the project team's dataset and the reduced AADT dataset disagreed substantially. The research team worked with Iowa State University, the RID vendor, to resolve these issues.

NDS DATA REQUEST

After the list of study sites was finalized, data requests were submitted to the NDS data manager to obtain NDS data for trips that occurred on the study sites. Study sites were identified by the research team spatially using GIS mapping tools. To obtain data from the NDS data manager, the research team had to translate these physical locations to a series of Link IDs for which the data manager could retrieve trip data.

The research team requested that the NDS data manager use the following criteria in trip selection:

- Provide data only for trips that traversed all the Link IDs in the segment.
- Provide data only for trips that have good Global Positioning System (GPS) and speed data available (less than 20 percent missing data points).
- Collect approximately 250 trips in each direction of travel.

- Maximize the number of unique participants in the trip sample.
- Make the distribution of trips across the 24 h of the day in the sample of trips roughly match the distribution of trips made by NDS drivers over that segment across the hours of the day if possible.

The following NDS variables were requested for a sample of 500 trips on each of the segments:

- File ID.
- Anonymous vehicle ID.
- Anonymous driver ID.
- Vehicle classification.
- Driver age and gender.
- Year.
- Month and day of week.
- Time of day (binned in 3-h blocks).
- Time series data for the portion of the trip that occurred on the study segment, including the following:
    - Speed.
    - Latitude.
    - Longitude.
    - Processed forward-radar data.
    - Data acquisition system timestamp.

SPEED MEASURES

The NDS provided two measures of speed: GPS speed, calculated from location data being recorded by the NDS instrumentation (recorded each second), and network speed, reported to the driver through the vehicle's own speed-measurement instrumentation (recorded 10 times per second). These speeds were generally similar, but the network speed was recorded only to the nearest mile per hour, while GPS speed was reported to several decimals. The NDS data manager suggested to the research team that the GPS speeds were expected to be more accurate, so these were the speeds that were used in this research.

The research team explored several speed measures to understand the operational behavior of each study site:

- SMS: The SMS was calculated as the distance between the closest GPS data points nearest the defined end points of the segment divided by the elapsed time between those two trips.
- Average GPS speed: The numerical average of all the available GPS speed measurements within the defined segment.

- FFS: The FFS was measured using a moving window method. The window was 15 s (thus covered up to 15 possible speed data points). If there were at least 10 data points present within the 15-s window, the speeds were averaged. Then the window moved down the segment one data point at a time. The FFS of the trip was taken as the maximum 15-s average computed by the moving window.
- Maximum and minimum spot speeds: For a given trip, the maximum (or minimum) spot speed measured at any point along the trip between the segment endpoints. These speeds are obtained directly from the NDS and are not calculated or manipulated by the research team.

CHAPTER 3. SUMMARY STATISTICS

Chapter 2 outlines the site-selection process as well as database development for site characteristics, crash data, traffic volume data, and NDS speed data. This chapter provides an overview of these databases and presents summary statistics. Five sites were removed from the dataset (four 2U and one 4D) and were not included in further analysis and modeling efforts. Crashes could not be coded to two of the sites in Pennsylvania. Since only one site remained in Pennsylvania that could be used in the analysis, it was decided to remove all Pennsylvania sites. In addition, some trips associated with sites that were retained had to be removed from the analysis. In many cases, these were trips requested during phase 1, before the research team had included a verification of sufficient location and speed data throughout the trip as one of the trip selection criteria. In other cases, trips were discarded because the GPS location data for the trip either showed a detour from the segment or were not adequately aligned with the roadway. However, the number of trips that had to be discarded was very low. Table 4 shows the final number of 2U sites by State used in the analysis. Table 5 provides the same data for 4D sites. In total, nearly 50,000 trips were included across 109 study sites.

Table 4. Number of 2U urban or suburban arterial sites per State (final).

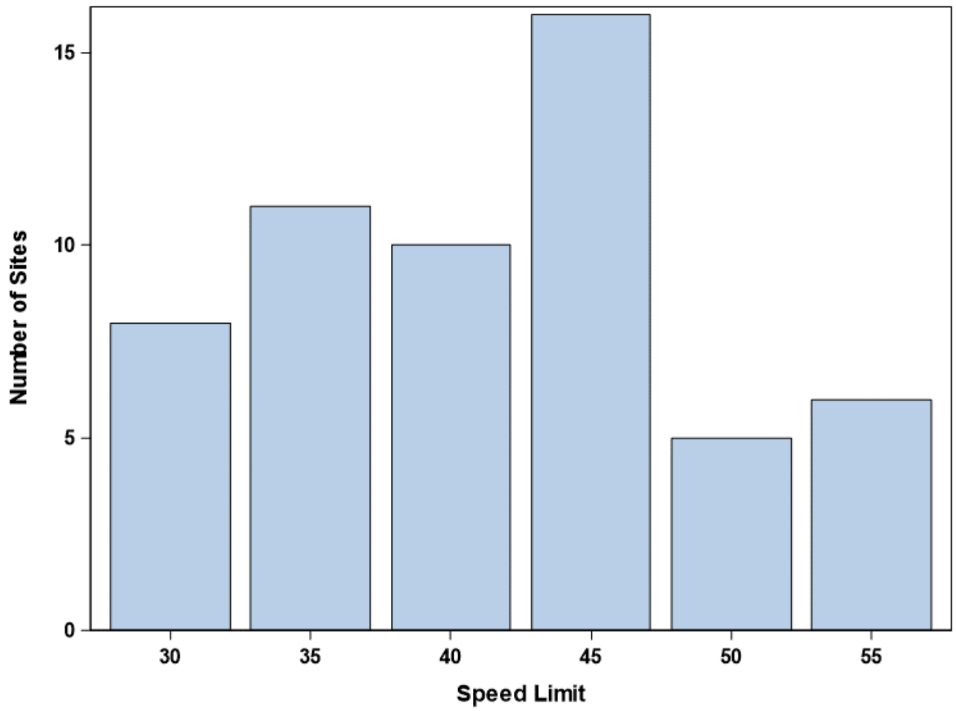
State	Number of Total Sites	Number of Total Trips
Florida	13	6,308
Indiana	10	4,786
New York	13	6,391
North Carolina	11	5,260
Pennsylvania	0	0
Washington	9	2,794
Total	**56**	**25,539**

Table 5. Number of 4D urban or suburban arterial sites per State (final).

State	Number of Total Sites	Number of Total Trips
Florida	28	11,700
Indiana	7	3,500
New York	0	0
North Carolina	13	6,381
Pennsylvania	0	0
Washington	5	2,499
Total	**53**	**24,080**

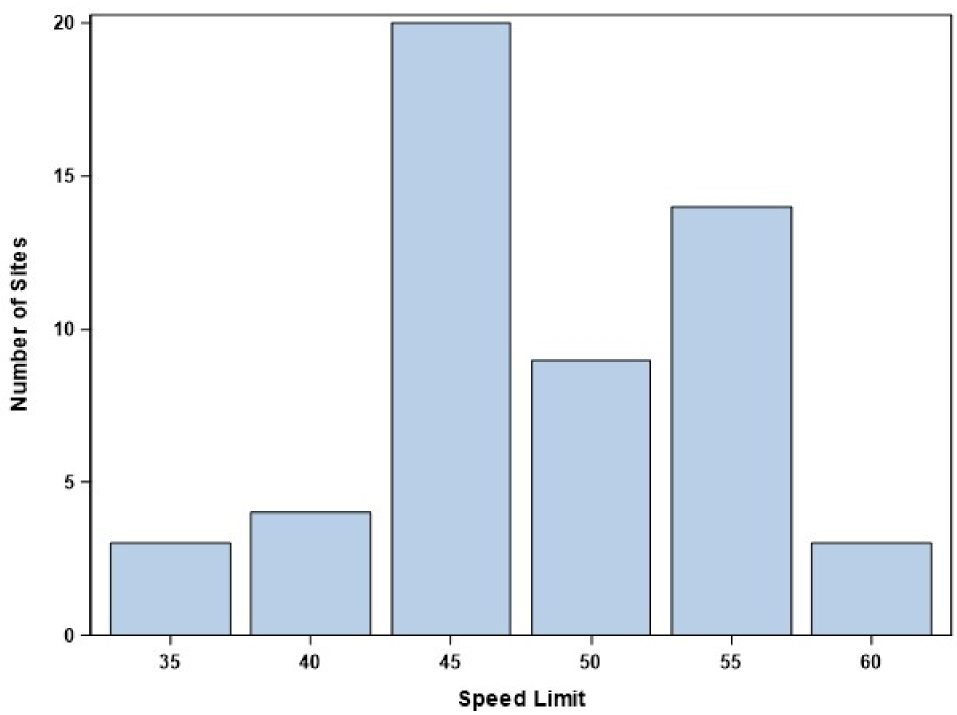
SITE CHARACTERISTICS

A total of 109 sites were used in this study. Chapter 2 discussed what data elements were collected for each analysis site. Figure 4 and figure 5 show the number of 2U and 4D sites by PSL, respectively. The majority of 2U sites had a PSL between 30 and 45 mph, with a few sites over 45 mph. However, most of the 4D sites had a posted speed between 45 and 55 mph.



Source: FHWA.

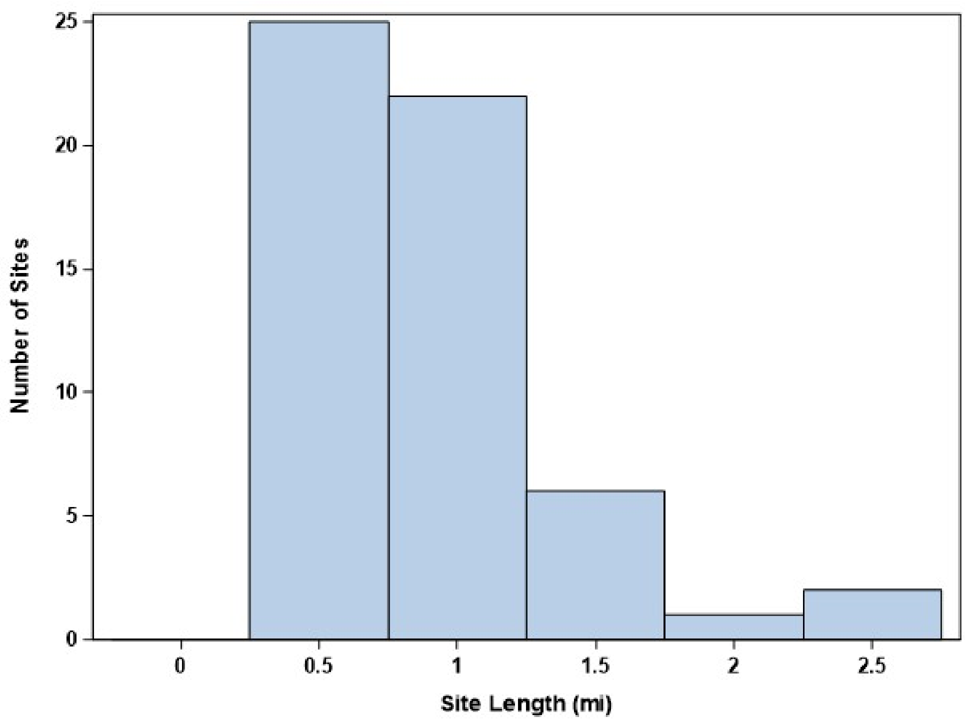
Figure 4. Bar Chart. PSL frequencies for 2U sites.



Source: FHWA.

Figure 5. Bar Chart. PSL frequencies for 4D sites.

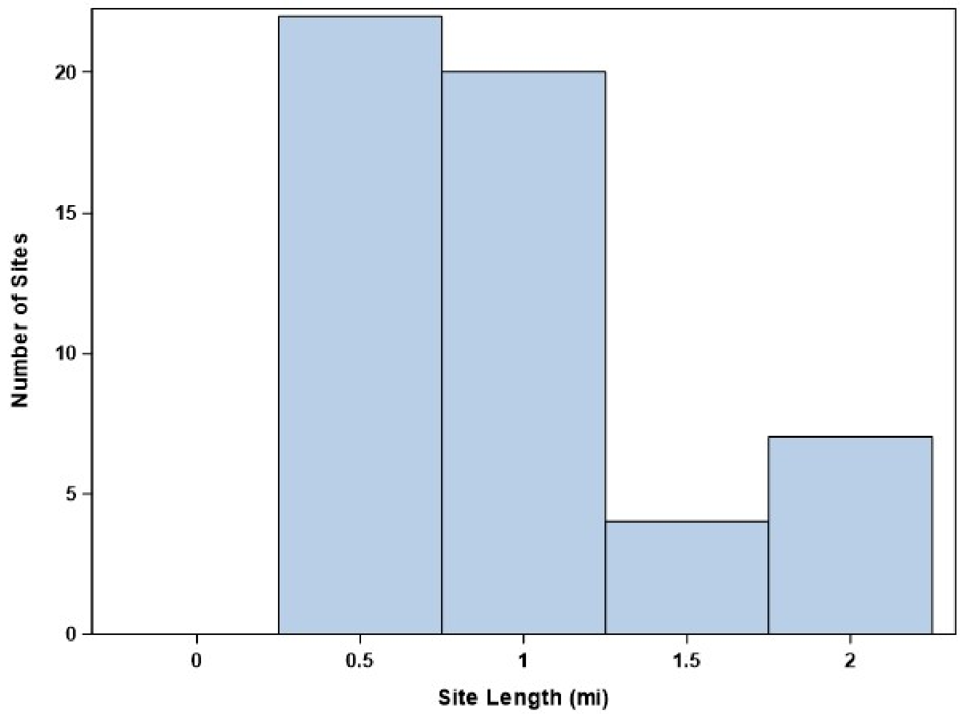
Figure 6 shows the distribution of site lengths for the 2U sites. The goal was to find sites that were at least 0.5 mi in length, but in the urban areas, this was not always possible. The frequency of signalized intersections and midblock pedestrian crossings limited the availability of long, uninterrupted segments. As a result, some of the sites were as short as about one-third of a mile. Most were between 0.5 and 1 mi in length. However, near the urban/rural boundary with less development, some longer 2U sites were available, including a few sites more than 2 mi in length. Figure 7 provides the same information for the 4D sites. Similarly, most sites were between 0.5 and 1 mi in length, with several longer sites. Site boundaries were determined by evaluating the speed data to subjectively identify the approximate point where the intersection traffic control no longer had a noticeable influence on travel speed approaching or leaving the intersection.



Source: FHWA.

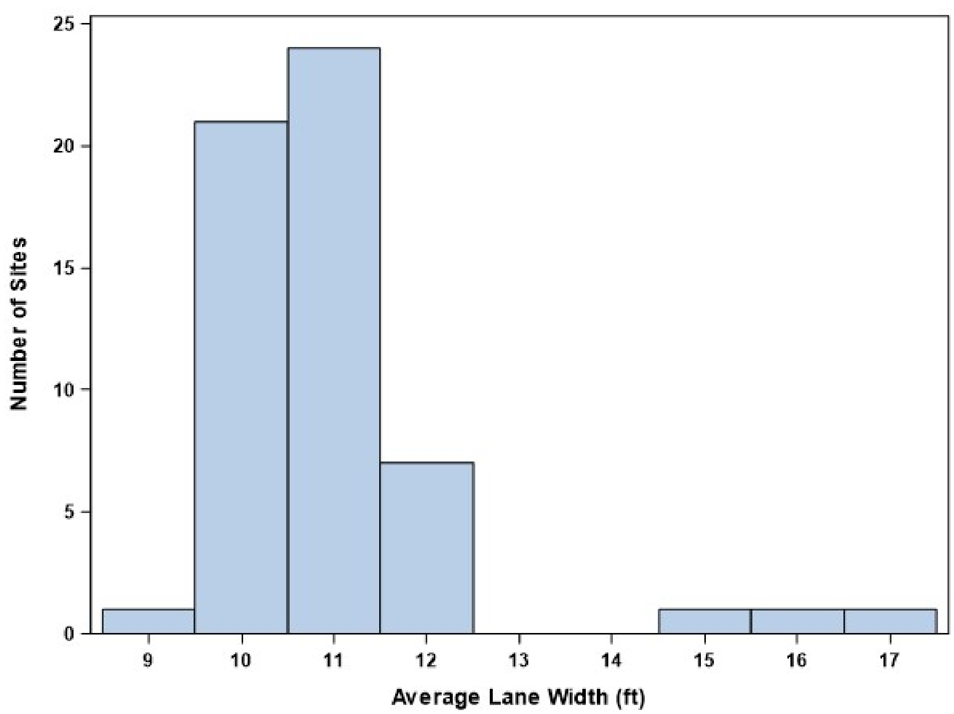
Figure 6. Histogram. Distribution of site length in miles for 2U sites.

Figure 8 shows the distribution of lane widths for 2U sites. Approximately 45 sites have lanes that fall between 9.5 and 11.5 ft wide. Three sites had much wider lanes (approximately 15 to 17 ft), and one site had a lane width less than 9.5 ft. Figure 9 provides lane width information for 4D sites. A majority of sites have lane widths between 10.5 and 11.5 ft, with a handful of sites having lane widths within a foot on either side of that bin. Only five sites fall outside of the range of 9.5 to 12.5 ft, and these sites all have lanes between 12.5 and 13.5 ft wide.



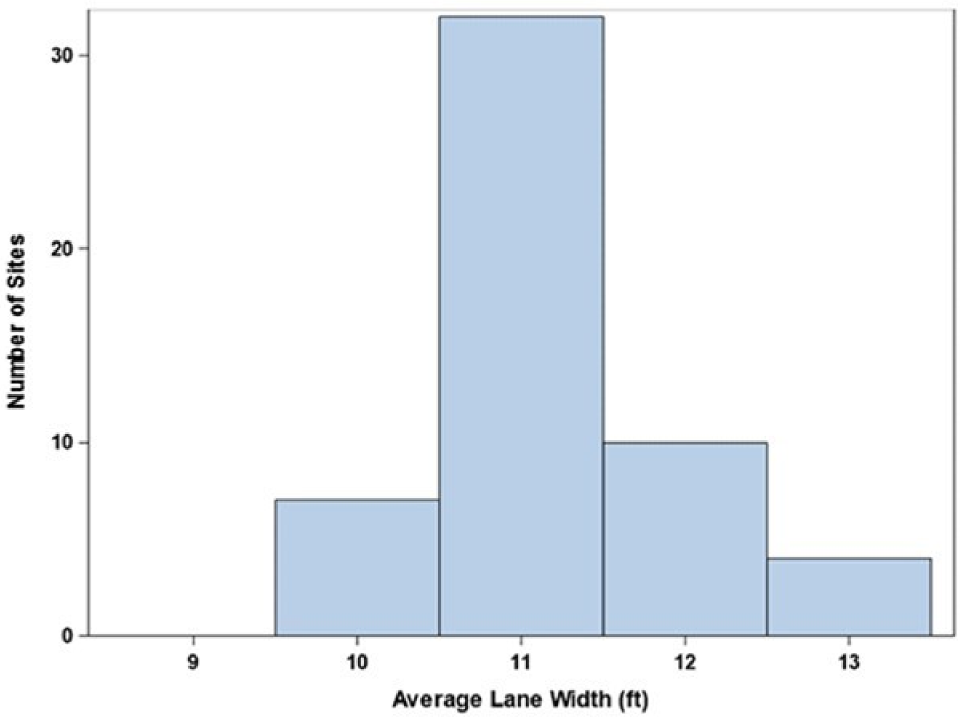
Source: FHWA.

Figure 7. Histogram. Distribution of site length in miles for 4D sites.



Source: FHWA.

Figure 8. Histogram. Distribution of lane width for 2U sites.



Source: FHWA.

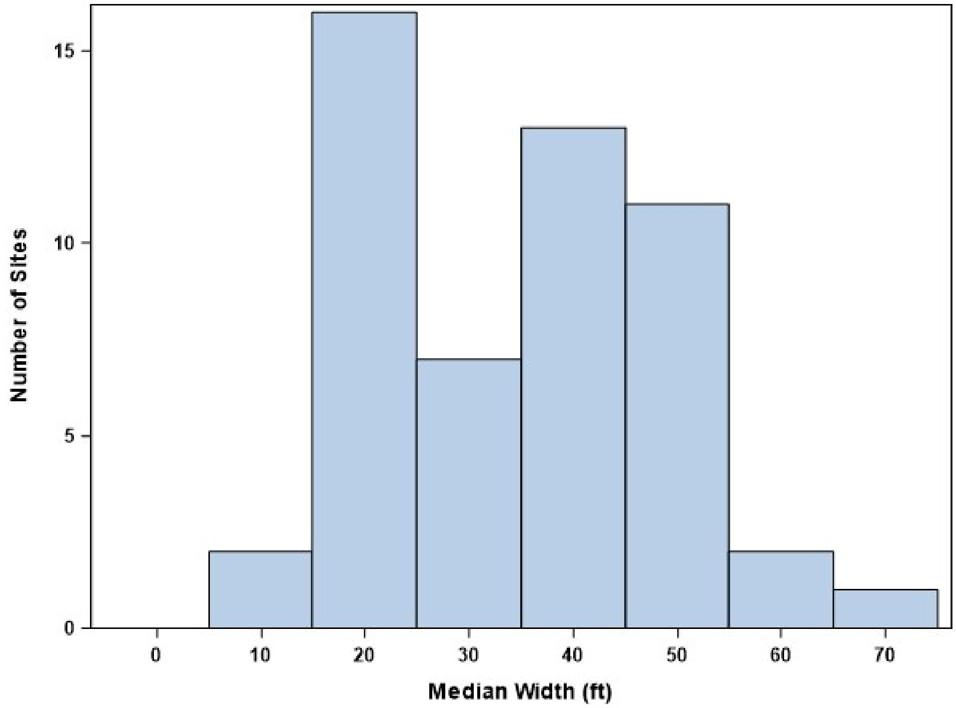
Figure 9. Histogram. Distribution of lane width for 4D sites.

Appendix A provides tables that show all the site characteristics collected per analysis site. One 2U and 16 4D sites have bike lanes present. Only 16 percent of 2U roadways were lighted, while 43 percent of 4D roadways were lighted. No 2U or 4D sites had on-street parking. All 2U and 4D sites were either straight sections of roadway or roadway sections with very gradual horizontal curvature. No sites contained sharp horizontal curves that would require driving speeds slower than the PSL (i.e., curves with advisory speeds or any type of curve warning signs were excluded).

Several shoulder types were present on the 2U and 4D sites, including paved shoulders, turf shoulders, vertical curb at the edge of the traveled way, vertical curb and gutter at edge of traveled way, and paved shoulder with curb at outside edge of shoulder. A few 2U sites had no shoulder at all, while all 4D sites had some type of shoulder. Shoulder width on 2U sites ranged from 0 to 16 ft, with an average of 4.0 ft. On 4D sites, shoulder width ranged from 0 to 12.4 ft, and averaged 4.6 ft.

For 2U sites, lane width ranged from 8.8 to 20.7 ft, but 90 percent of the individual lane widths were between 9.5 and 13.0 ft. For 4D sites, lane width ranged from 9.2 to 14 ft, with 90 percent of the individual lane widths between 10.0 and 13.1 ft.

Median widths on 4D sites ranged from 12 to 180 ft; however, 90 percent of the median widths fell within a range of 15 to 58 ft. Figure 10 shows the distribution of median widths for 4D sites up to 70 ft in width. One site had a much wider median (180 ft), which is not shown in the histogram.



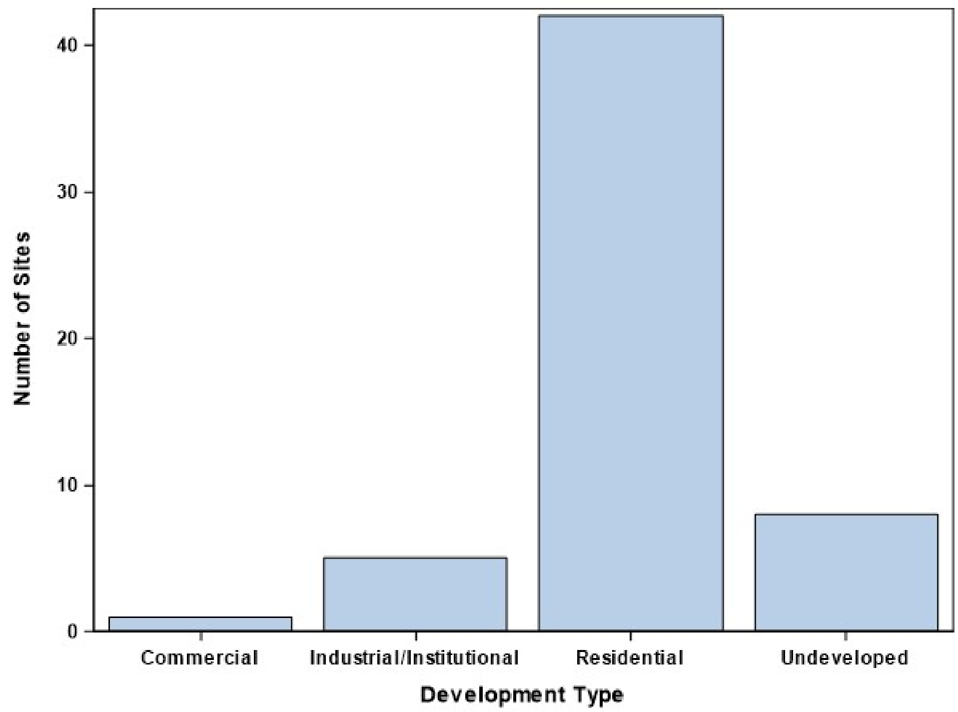
Source: FHWA.

Figure 10. Histogram. Distribution of median widths for 4D arterial sites.

Three quarters of 2U sites were in residential areas, while the remainder were in commercial, industrial/institutional, or undeveloped areas. Half of the 4D sites were in residential areas, while the other 50 percent of sites were nearly evenly split between commercial, industrial/institutional, and undeveloped areas. Figure 11 and figure 12 show these distributions.

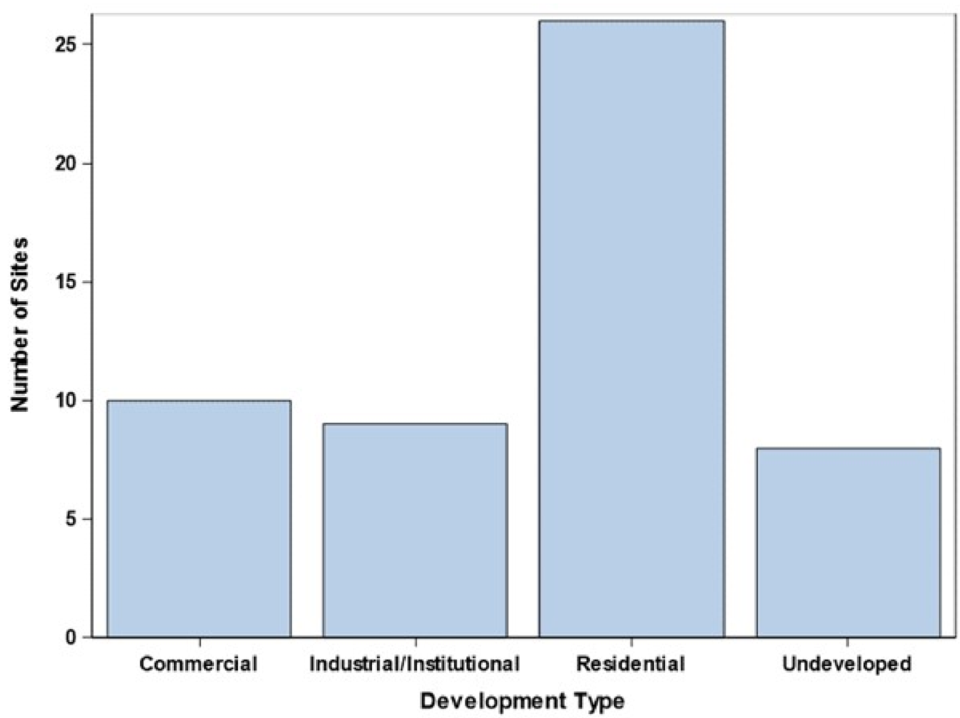
As discussed in chapter 2, a DDS was computed for each site. The average DDS for 2U sites was 103.8, while the average DDS for 4D sites was 66.2. This indicates that the 2U sites and 4D sites have an important difference in terms of the number of vehicles entering and exiting the roadway from driveways along the roadway. The number of access points and entering/exiting vehicles influences the types of crashes expected on the roadway segment. Vehicles turning left off the roadway can create rear-end crash situations, which become more difficult to avoid the faster the vehicles are traveling. Especially on 2U roadways, vehicles cannot get around a stopped or slowed left-turning vehicle without leaving the travel lanes. Figure 13 shows the distribution of DDSs for 2U sites, and figure 14 shows the distribution for 4D sites.

Similarly, the density of fixed objects along the roadside can play a role in the type of crashes expected along a roadway segment, and the speed at which those objects are struck plays a role in crash severity. Among the roadway sites included in this study, 2U and 4D sites had similar distributions of fixed-object density, as shown in figure 15 and figure 16.



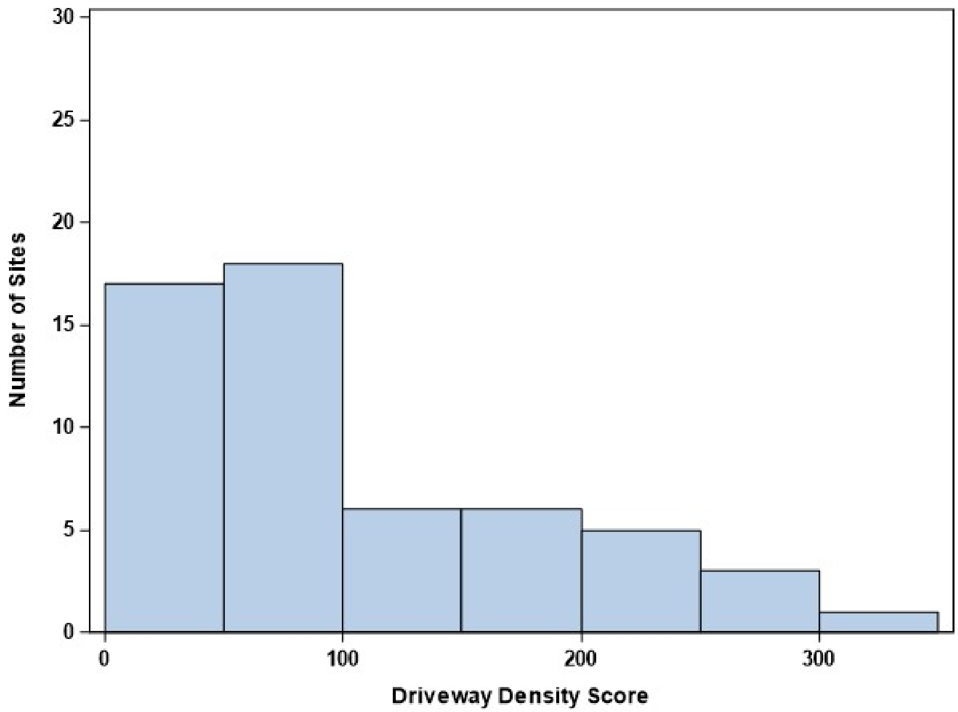
Source: FHWA.

Figure 11. Bar Chart. Distribution of 2U sites by development type.



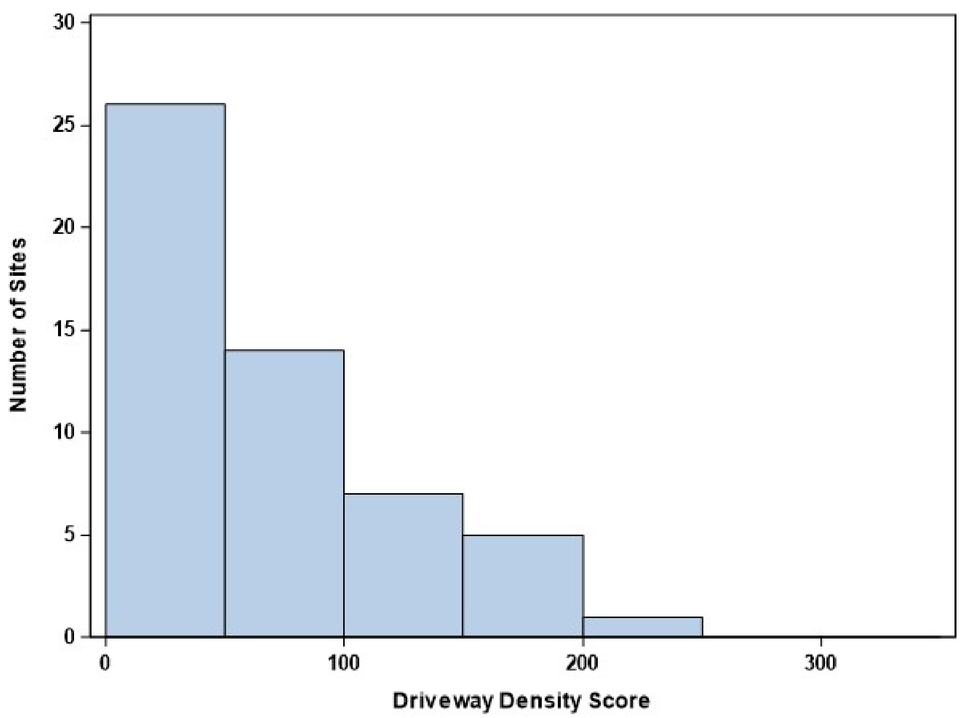
Source: FHWA.

Figure 12. Bar Chart. Distribution of 4D sites by development type.



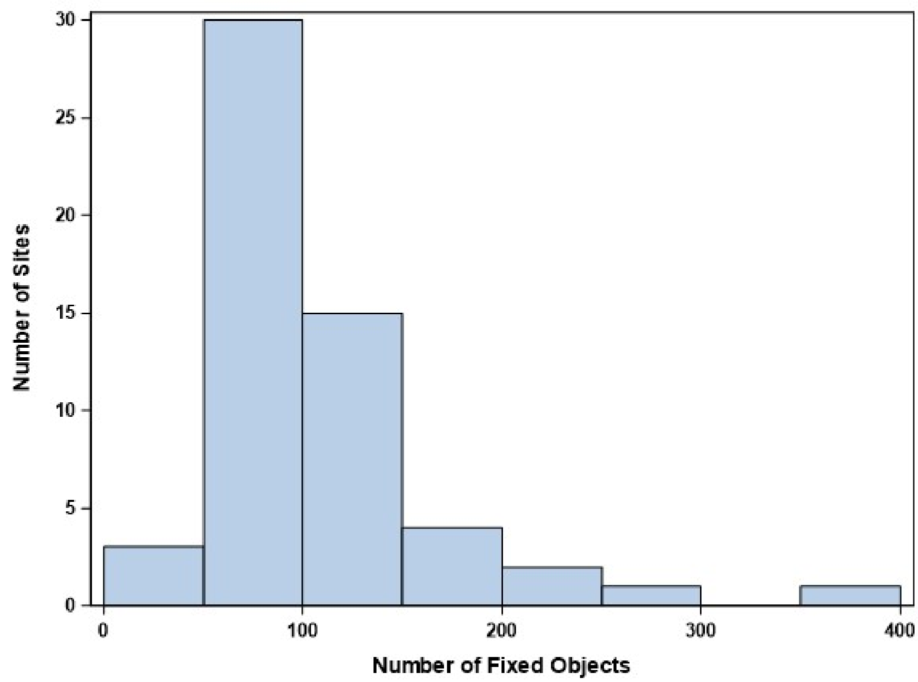
Source: FHWA.

Figure 13. Histogram. DDS for 2U arterial sites.



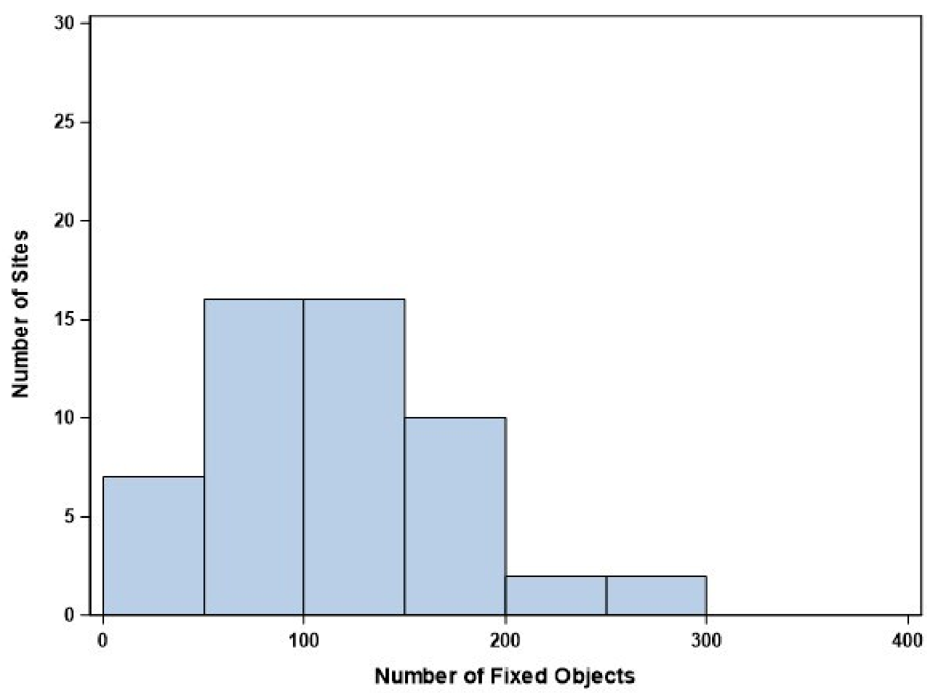
Source: FHWA.

Figure 14. Histogram. DDS for 4D arterial sites.



Source: FHWA.

Figure 15. Histogram. Distribution of the number of fixed objects along the roadside for 2U arterial sites.

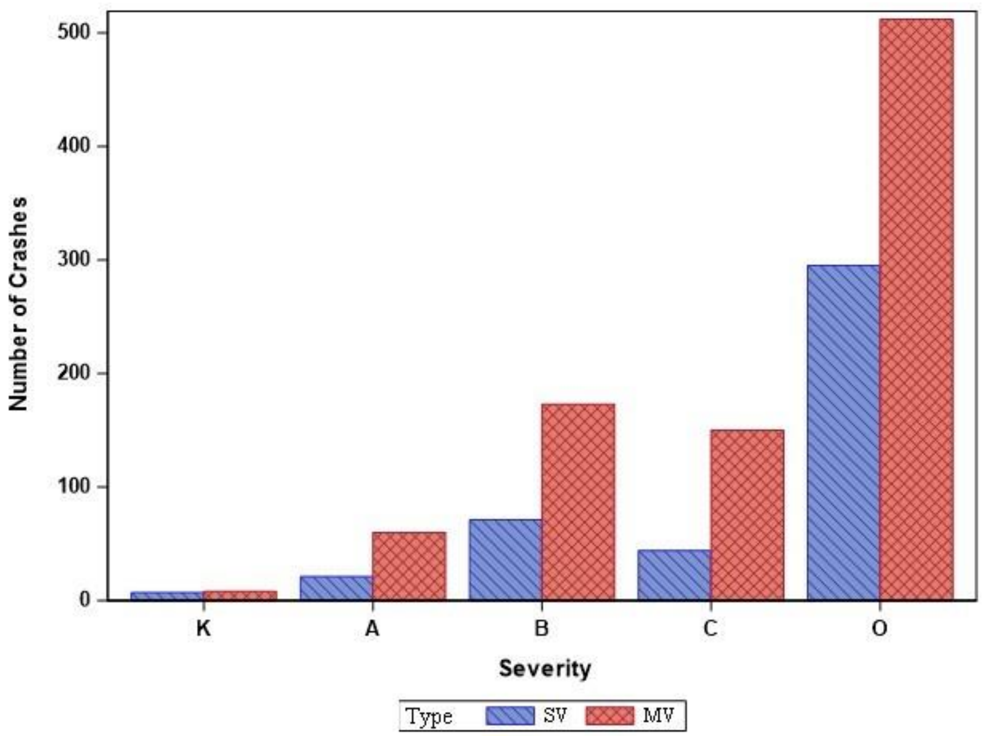


Source: FHWA.

Figure 16. Histogram. Distribution of the number of fixed objects along the roadside for 4D arterial sites.

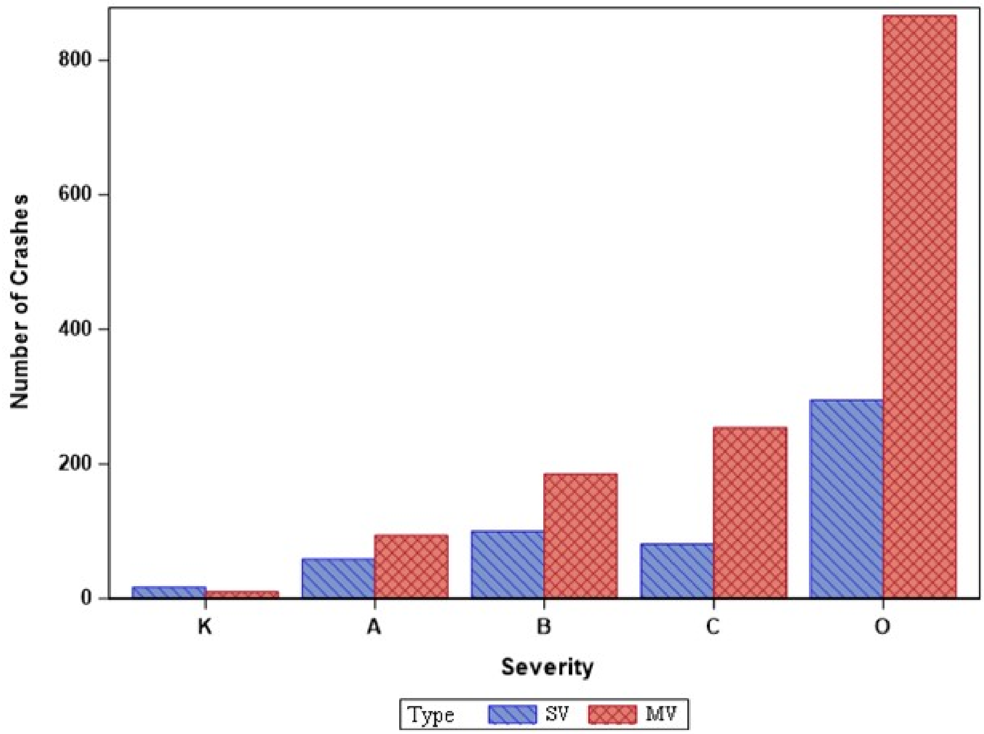
CRASH CHARACTERISTICS

There were a total of 1,341 non-intersection-related crashes on 2U sites, and 1,961 non-intersection-related crashes on 4D sites. Fatal and injury (FI) crashes made up 39.8 percent of total crashes on 2U and 40.8 percent of total crashes on 4D sites. Figure 17 and figure 18 show the crash frequencies by severity level and number of vehicles involved on the 2U and 4D analysis sites, respectively. Table 6 shows a summary of crash frequencies by State and severity level for 2U sites. Table 7 shows the same information for 4D sites. Table 8 and table 9 present the same data shown in table 6 and table 7, but as crash densities (crashes per mile per year). The values in these tables are not crash rates and do not consider AADT at each site. In addition, the number of sites in each State and the length of each site vary, so these values are not meant to be used to compare values across States. They simply provide a summary of the crash frequency and density data of the sites used in this research.



Source: FHWA.

Figure 17. Bar Chart. Nonintersection crash frequency by severity for 2U sites.



Source: FHWA.

Figure 18. Bar Chart. Nonintersection crash frequency by severity for 4D sites.

Table 6. Crash frequency by State and crash severity for 2U sites.

State	Number of Sites	Number of Years	Fatal (K)	Serious Injury (A)	Minor Injury (B)	Possible Injury (C)	Property Damage Only (PDO)	Total
Florida	13	8	11	62	79	106	217	475
Indiana	10	8	1	2	36	0	93	132
New York	13	8	1	12	104	0	198	315
North Carolina	11	5	1	2	11	50	165	229
Washington	9	8	1	3	14	38	134	190
Total	**56**	**N/A**	**15**	**81**	**244**	**194**	**807**	**1,341**

N/A = not applicable.

Table 7. Crash frequency by State and crash severity for 4D sites.

State	Number of Sites	Number of Years	Fatal (K)	Serious Injury (A)	Minor Injury (B)	Possible Injury (C)	Property Damage Only (PDO)	Total
Florida	28	8	22	144	202	218	546	1,132
Indiana	7	8	2	4	36	0	147	189
North Carolina	13	5	3	1	28	80	350	462
Washington	5	8	0	4	19	37	118	178
Total	**53**	**N/A**	**27**	**153**	**285**	**335**	**1,161**	**1,961**

N/A = not applicable.

Table 8. Summary of crash density (crash/mi/yr) by State and crash severity for 2U sites.

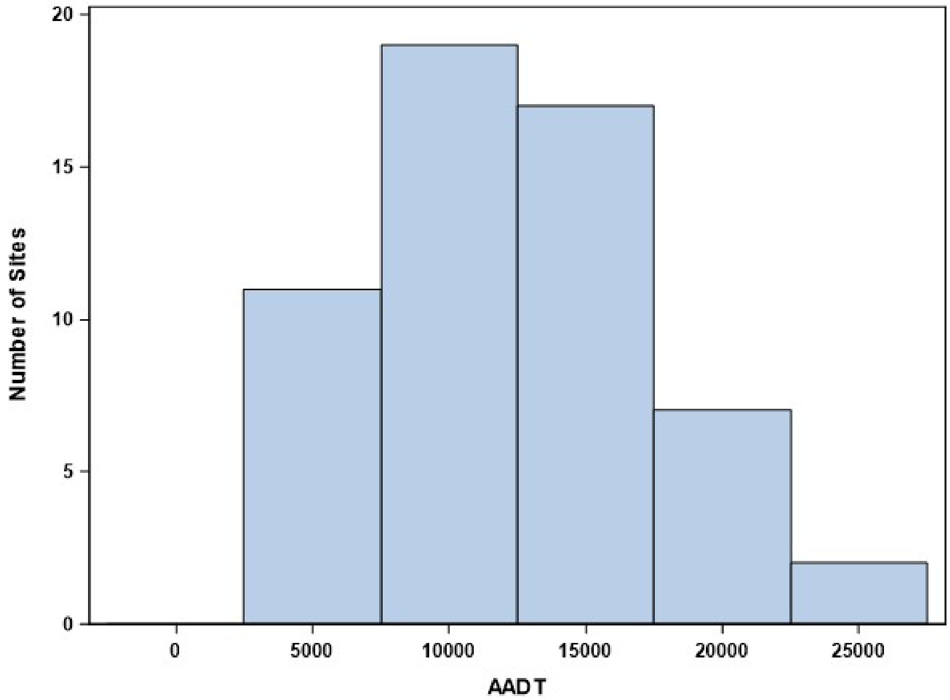
State	Fatal (K)	Serious Injury (A)	Minor Injury (B)	Possible Injury (C)	Property Damage Only (PDO)	Total
Florida	0.106	0.599	0.763	1.023	2.095	4.586
Indiana	0.020	0.040	0.722	0.000	1.865	2.647
New York	0.012	0.138	1.199	0.000	2.282	3.631
North Carolina	0.020	0.040	0.217	0.988	3.259	4.524
Washington	0.013	0.040	0.189	0.512	1.806	2.560

Table 9. Summary of crash density (crash/mi/yr) by State and crash severity for 4D sites.

State	Fatal (K)	Serious Injury (A)	Minor Injury (B)	Possible Injury (C)	Property Damage Only (PDO)	Total
Florida	0.096	0.627	0.880	0.950	2.378	4.931
Indiana	0.029	0.059	0.530	0.000	2.165	2.784
North Carolina	0.048	0.016	0.444	1.269	5.551	7.328
Washington	0.000	0.220	1.047	2.039	6.502	9.808

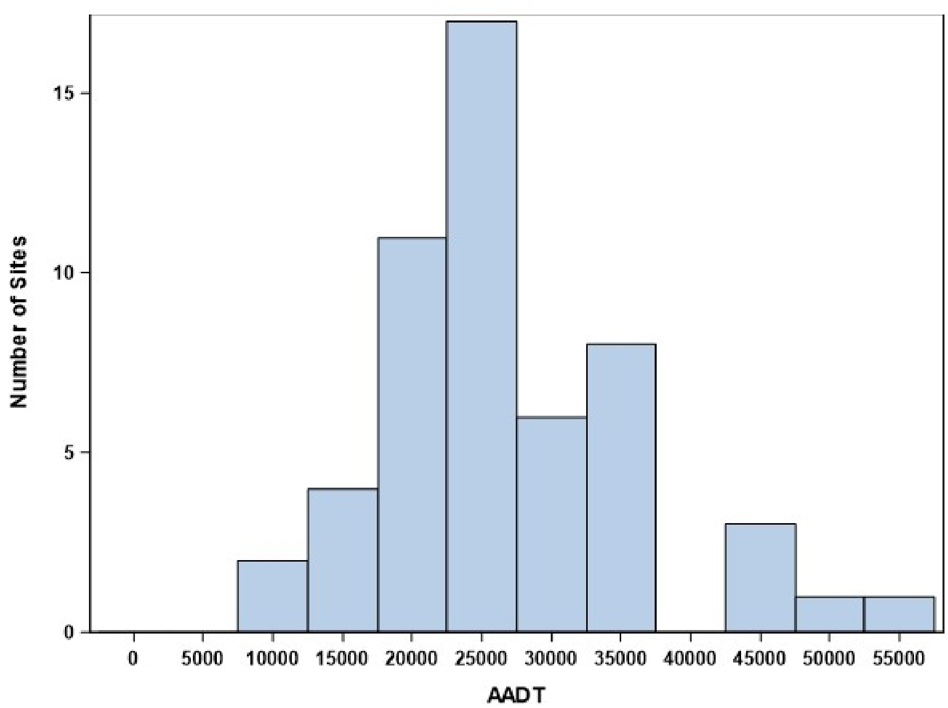
Crash frequencies by number of vehicles involved in the crash (single vehicle [SV] or MV) and severity level are shown for all analysis sites in appendix A. MV crashes accounted for 67.3 percent of 2U nonintersection crashes, while 71.8 percent of 4D nonintersection crashes were MV crashes.

The final AADT database is shown in appendix A. For 2U sites, AADT values ranged from 4,565 to 25,917, with an average of 12,225 (figure 19). For 4D sites, AADT values ranged from 9,300 to 54,167 with an average of 26,809 (figure 20).



Source: FHWA.

Figure 19. Histogram. Distribution of AADT for 2U sites.



Source: FHWA.

Figure 20. Histogram. Distribution of AADT for 4D sites.

SPEED MEASURES

The research team initially considered a broad range of speed measures during preliminary modeling. These nine speed measures include the following:

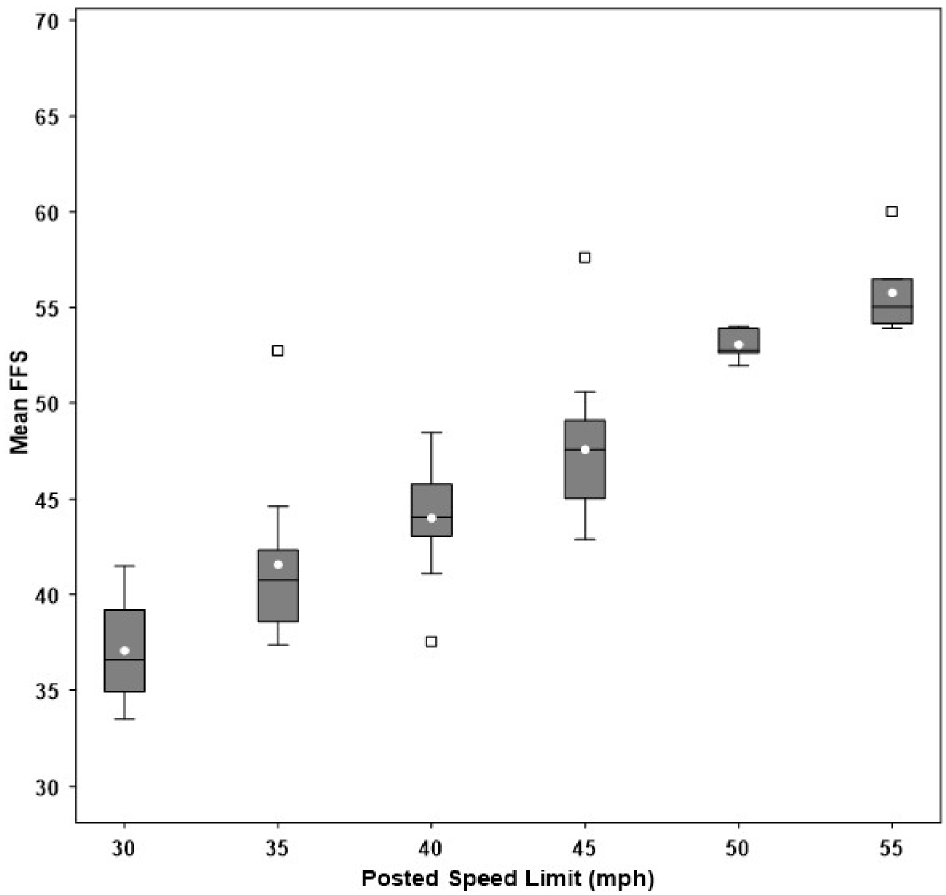
- Mean SMS: The average of all individual trip SMSs for each site.
- 85th percentile of trip SMSs: The 85th percentile of all individual trip SMSs for each site.
- Mean FFS: The average of all individual trip FFSs for each site. (This measure was similar to mean SMS.)
- Standard deviation (SD) of SMS: The SD of the distribution of all individual trip SMSs for each site. This measures speed variability between trips.
- SD of FFS: The SD of the distribution of individual trip's FFS for each site.
- 85th percentile of trip SMS minus 15th percentile of trip SMS: The 85th percentile of the distribution of individual trip SMS minus the 15th percentile of the SMS distribution for each site.
- Mean of difference between trip maximum and minimum speed: The average of all individual trips' arithmetic difference between the trip's maximum spot speed and minimum spot speed. Provides a measure of speed variability within trips.
- The SD of difference between trip maximum and minimum speed: The SD of the distribution of an individual trip's arithmetic difference between the trip's maximum speed and minimum speed.
- Difference between PSL and 85th percentile of trip SMS: The site's 85th percentile of trip SMS minus the site's PSL.

After an initial round of preliminary modeling, none of the nine speed measures were found to have a stronger relationship with crash measures than the others. Therefore, the field of speed measures was reduced to the five that seemed intuitively likely to have the strongest relationship with safety and that might be the simplest for highway agencies to collect. The five speed measures that were used in the final statistical modeling included mean SMS, SD of SMS, mean FFS, mean of difference between trip maximum and minimum speed, and difference between PSL and 85th percentile of trip SMS.

Figure 21 through figure 30 present box plots illustrating the distributions of the five speed measures by speed limit, separately for 2U and 4D segments. Each data point used to make these plots represents a specific speed measure for a particular study segment. For example, figure 21 presents data for the mean FFS for 2U segments. Each individual trip on a segment has a FFS; each data point used to make the figure represents the mean value of these individual trip values for a given study segment. Each grey box represents the middle 50 percent of values for that speed measure on segments at that speed limit. The horizontal black line represents the median value, while the white dot represents the mean value. The whiskers extending to the top and bottom of each box represent the extent of upper and lower data points within 1.5 times the height of the box. If any data points lie outside the extent of the whiskers, they are shown as hollow squares above or below the whiskers. Table 10 through table 19 present similar information to what is shown in the box plots, but in tabular form. For each box plot, the associated table shows the number of observations; the minimum, mean, and maximum values; and the SD of the distribution of values for each speed limit.

Figure 21 presents a box plot where mean FFS is reported for each 2U site. Figure 22 shows a similar box plot, but of 4D sites. The majority of all sites had mean FFS above the PSL. Figure 23 and figure 24 show similar box plots as figure 21 and figure 22, but mean SMS is used in the box plots. For 2U sites, the mean SMS tended to decrease relative to the PSL as the PSL increased. For example, the median of the mean SMS values for PSLs of 30, 35, and 40 mph were greater than the PSL. However, the median of the mean SMS values for PSLs greater than 40 mph were less than the PSL. This relationship was different for 4D sites. At all PSL levels, the median of the mean SMS values was at or slightly above the PSL for 4D sites.

Figure 25 presents a box plot of each 2U site's SD of SMS across all trips on the site. The majority of SD values were between 4.0 and 5.5 mph for 2U sites. Figure 26 presents the same data as figure 25, except for 4D sites. There appears to be a trend that SD of SMS decreases as PSL increases.



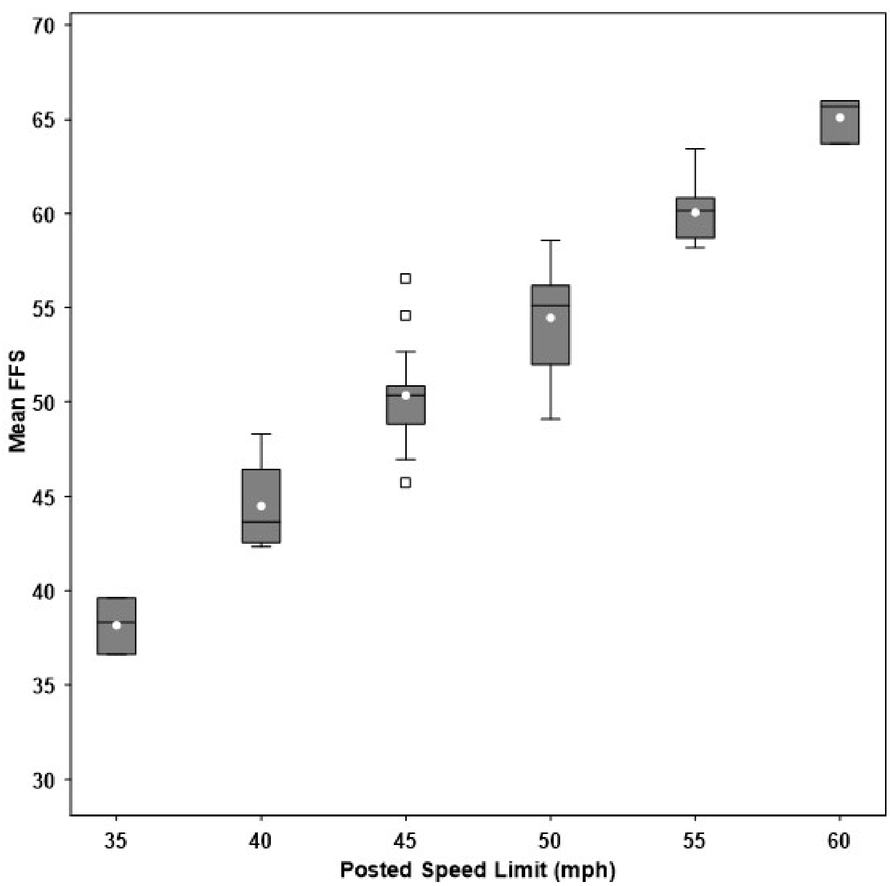
Source: FHWA.

Figure 21. Graph. Box plot of mean FFSs on 2U sites by PSL.

Table 10. Characteristics of FFS distribution on 2U sites by PSL.

Statistic	Speed Limit 30 mph	Speed Limit 35 mph	Speed Limit 40 mph	Speed Limit 45 mph	Speed Limit 50 mph	Speed Limit 55 mph
Number of sites	8	11	10	16	5	6
Minimum	33.5	37.4	37.6	42.9	52.0	53.9
Mean	37.1	41.6	44.0	47.6	53.0	55.8
Maximum	41.5	52.8	48.4	57.6	54.0	60.0
SD	2.90	4.22	3.05	3.61	0.88	2.28

Figure 27 shows a box plot of each 2U site's average value of individual trip's maximum point speed minus the minimum point speed. For all PSLs on 2U roadways, the average difference between the maximum and minimum point speed within a single trip was between 13 and 14 mph. The variance of this difference, however, was quite different between the PSL levels. Figure 28 shows the same data as figure 27, except for 4D sites. The average 4D site had a difference of between 11.5 and 15 mph between a vehicle's minimum and maximum speed on a single trip through the segment. The variance of this difference tended to increase as PSL increased.



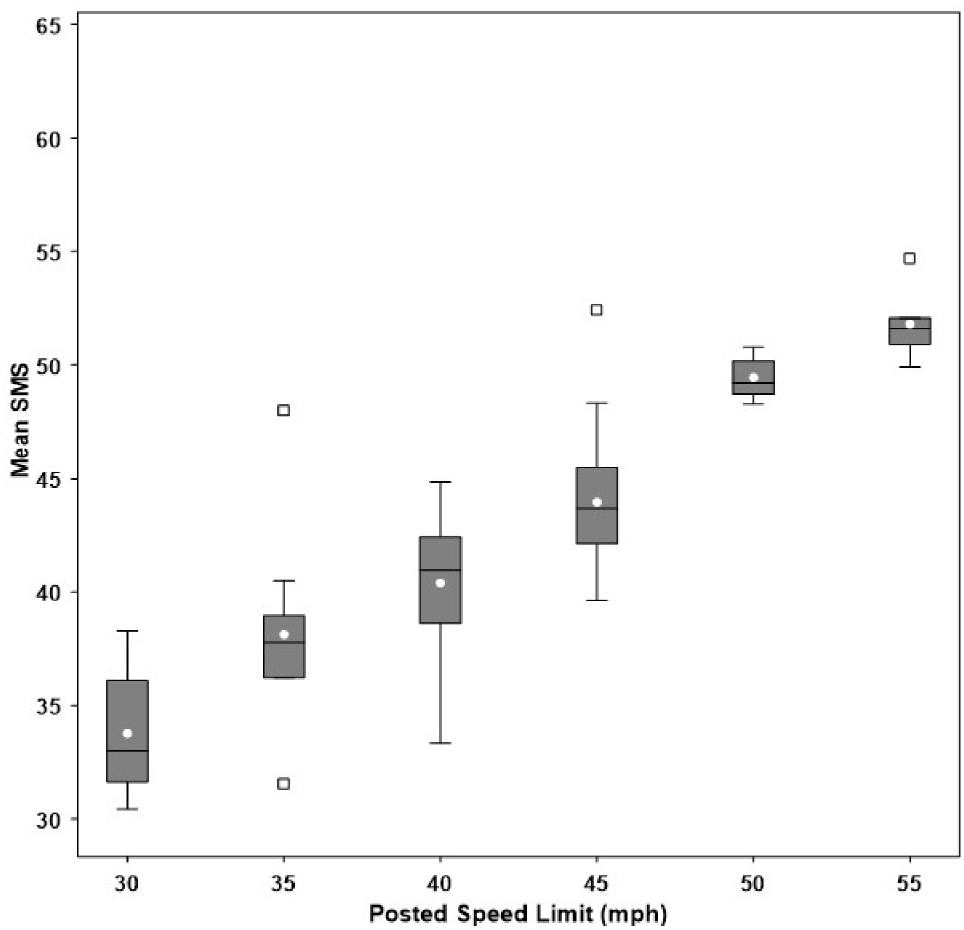
Source: FHWA.

Figure 22. Graph. Box plot of mean FFSs on 4D sites by PSL.

Table 11. Characteristics of FFS distribution on 4D sites by PSL.

Statistic	Speed Limit 35 mph	Speed Limit 40 mph	Speed Limit 45 mph	Speed Limit 50 mph	Speed Limit 55 mph	Speed Limit 60 mph
Number of sites	3	4	20	9	14	3
Minimum	36.6	42.3	45.8	49.1	58.2	63.7
Mean	38.2	44.5	50.4	54.5	60.1	65.1
Maximum	39.6	48.3	56.6	58.6	63.4	66.0
SD	1.51	2.72	2.47	2.97	1.52	1.25

Figure 29 presents a box plot of each 2U site's value of the 85th percentile of SMS minus the PSL. Figure 29 follows the same trend as discussed with figure 23; the difference between the 85th percentile SMS and PSL decreases as PSL increases. Figure 30 presents the same data as figure 29, except for 4D sites. The difference between the 85th percentile SMS and PSL was very similar across all PSL levels.

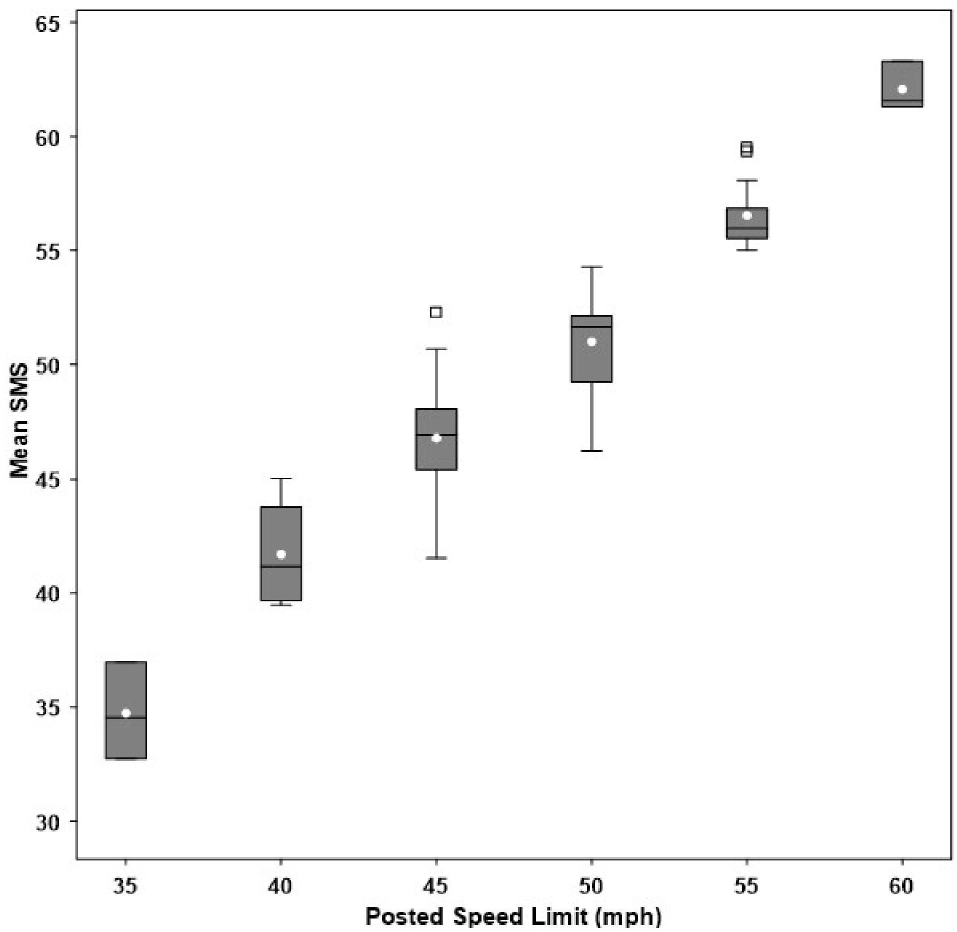


Source: FHWA.

Figure 23. Graph. Box plot of mean SMSs on 2U sites by PSL.

Table 12. Characteristics of SMS distribution on 2U sites by PSL.

Statistic	Speed Limit 30 mph	Speed Limit 35 mph	Speed Limit 40 mph	Speed Limit 45 mph	Speed Limit 50 mph	Speed Limit 55 mph
Number of sites	8	11	10	16	5	6
Minimum	30.4	31.6	33.3	39.6	48.3	49.9
Mean	33.8	38.1	40.4	44.0	49.4	51.8
Maximum	38.3	48.0	44.9	52.5	50.8	54.7
SD	2.95	3.97	3.21	3.30	1.03	1.61

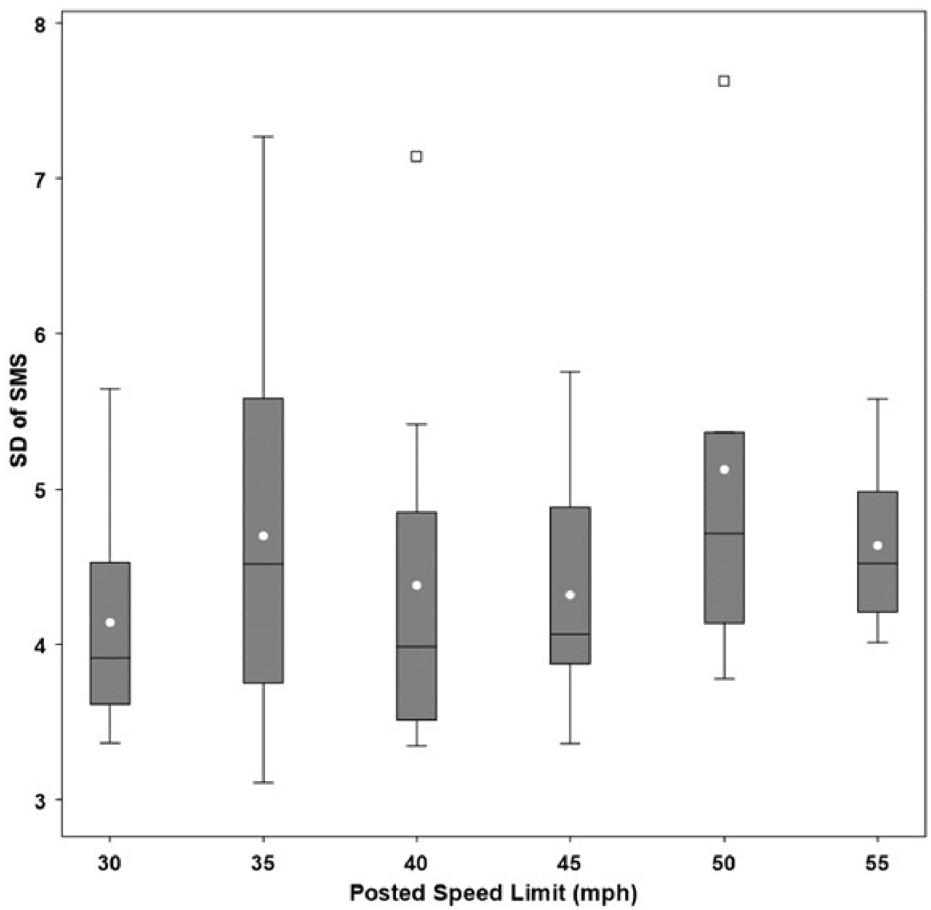


Source: FHWA.

Figure 24. Graph. Box plot of mean SMSs on 4D sites by PSL.

Table 13. Characteristics of SMS distribution on 4D sites by PSL.

Statistic	Speed Limit 35 mph	Speed Limit 40 mph	Speed Limit 45 mph	Speed Limit 50 mph	Speed Limit 55 mph	Speed Limit 60 mph
Number of sites	3	4	20	9	14	3
Minimum	32.7	39.5	41.5	46.2	55.0	61.3
Mean	34.7	41.7	46.8	51.0	56.6	62.1
Maximum	37.0	45.0	52.3	54.3	59.6	63.3
SD	2.13	2.59	2.63	2.63	1.47	1.09

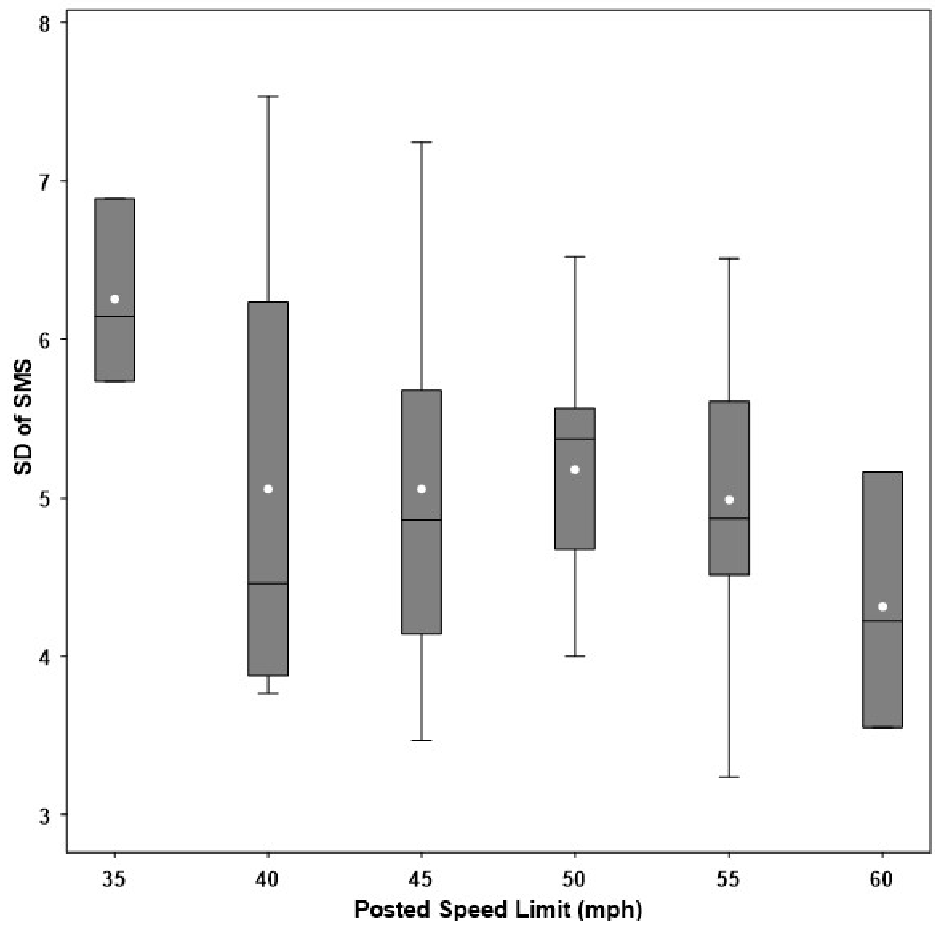


Source: FHWA.

Figure 25. Graph. Box plot of SD of SMSs on 2U sites by PSL.

Table 14. Characteristics of SD of SMS distribution on 2U sites by PSL.

Statistic	Speed Limit 30 mph	Speed Limit 35 mph	Speed Limit 40 mph	Speed Limit 45 mph	Speed Limit 50 mph	Speed Limit 55 mph
Number of sites	8	11	10	16	5	6
Minimum	3.4	3.1	3.3	3.4	3.8	4.0
Mean	4.1	4.7	4.4	4.3	5.1	4.6
Maximum	5.6	7.3	7.1	5.8	7.6	5.6
SD	0.77	1.22	1.16	0.71	1.52	0.57

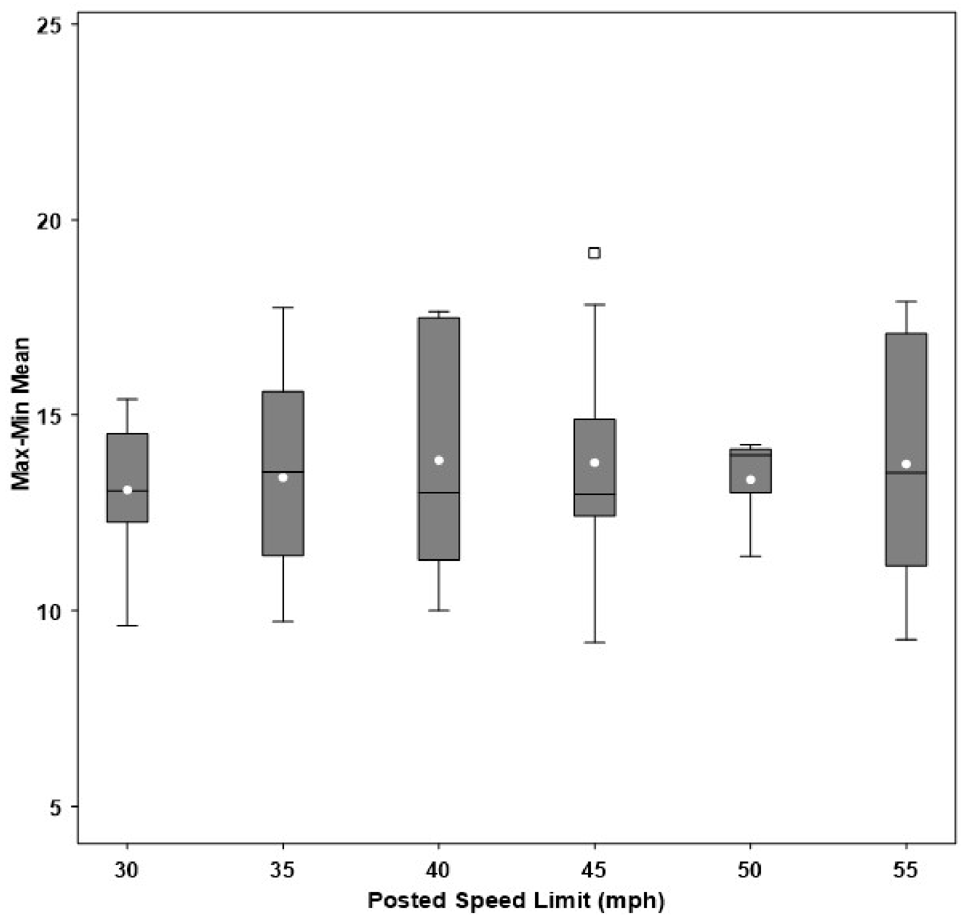


Source: FHWA.

Figure 26. Graph. Box plot of SD of SMSs on 4D sites by PSL.

Table 15. Characteristics of SD of SMS distribution on 4D sites by PSL.

Statistic	Speed Limit 35 mph	Speed Limit 40 mph	Speed Limit 45 mph	Speed Limit 50 mph	Speed Limit 55 mph	Speed Limit 60 mph
Number of sites	3	4	20	9	14	3
Minimum	5.7	3.8	3.5	4.0	3.2	3.6
Mean	6.3	5.1	5.1	5.2	5.0	4.3
Maximum	6.9	7.5	7.2	6.5	6.5	5.2
SD	0.58	1.73	1.20	0.83	0.91	0.81

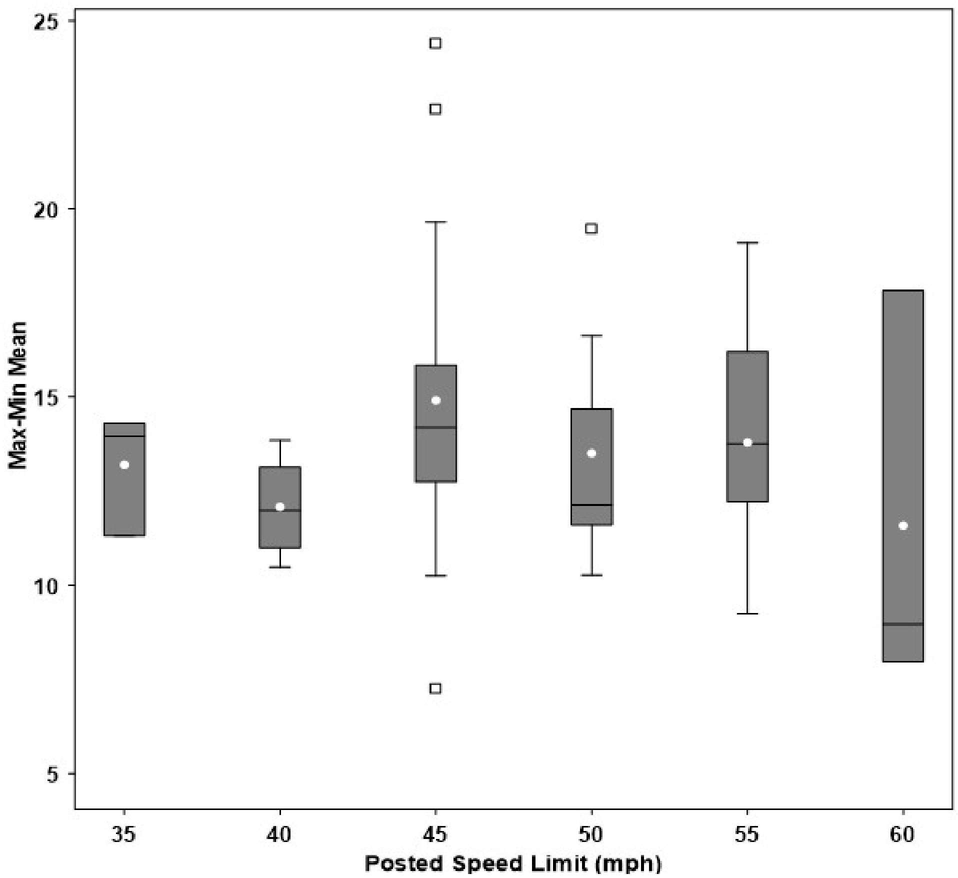


Source: FHWA.

Figure 27. Graph. Box plot of the mean individual-trip maximum minus minimum speed on 2U sites by PSL.

Table 16. Characteristics of distribution of mean individual-trip maximum minus minimum on 2U sites by PSL.

Statistic	Speed Limit 30 mph	Speed Limit 35 mph	Speed Limit 40 mph	Speed Limit 45 mph	Speed Limit 50 mph	Speed Limit 55 mph
Number of sites	8	11	10	16	5	6
Minimum	9.6	9.7	10.0	9.2	11.4	9.3
Mean	13.1	13.4	13.8	13.8	13.4	13.7
Maximum	15.4	17.8	17.7	19.2	14.3	17.9
SD	1.83	2.54	2.97	2.59	1.20	3.39

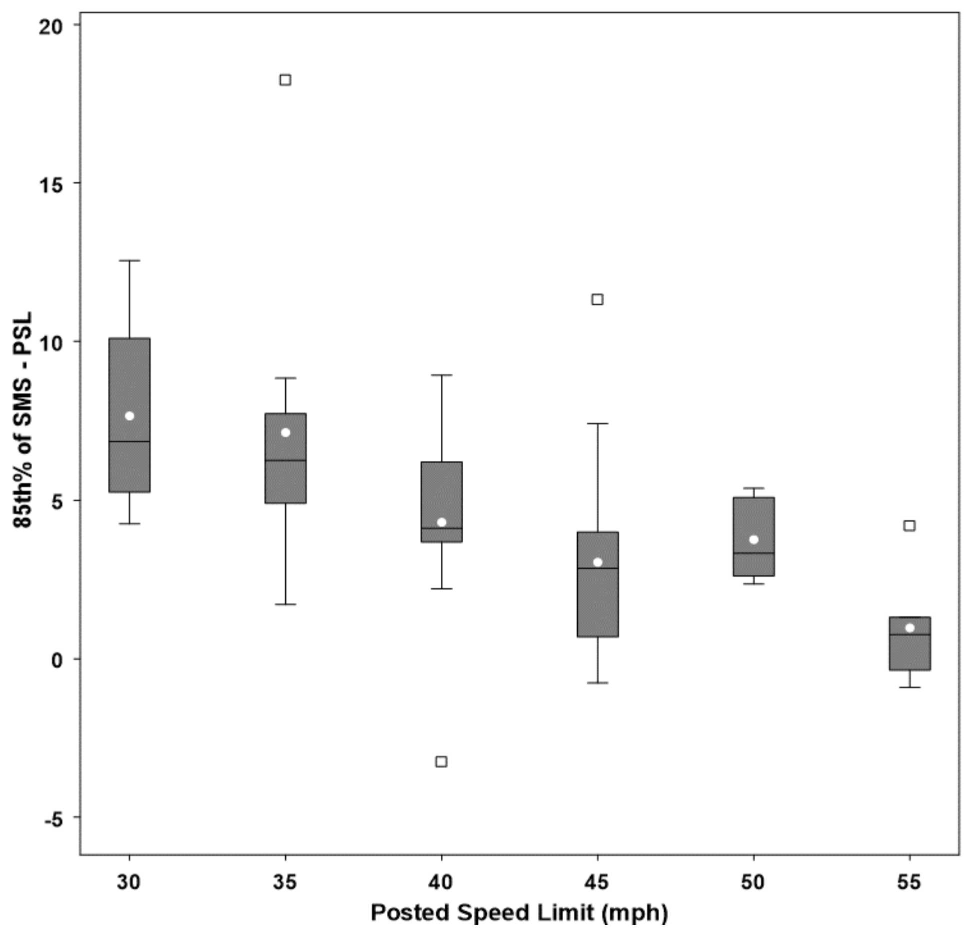


Source: FHWA.

Figure 28. Graph. Box plot of the mean individual-trip maximum minus minimum speed on 4D sites by PSL.

Table 17. Characteristics of distribution of mean individual-trip maximum minus minimum on 4D sites by PSL.

Statistic	Speed Limit 35 mph	Speed Limit 40 mph	Speed Limit 45 mph	Speed Limit 50 mph	Speed Limit 55 mph	Speed Limit 60 mph
Number of sites	3	4	20	9	14	3
Minimum	11.3	10.5	7.3	10.3	9.2	8.0
Mean	13.2	12.1	14.9	13.5	13.8	11.6
Maximum	14.3	13.9	24.4	19.5	19.1	17.8
SD	1.64	1.43	4.09	3.01	2.79	5.43

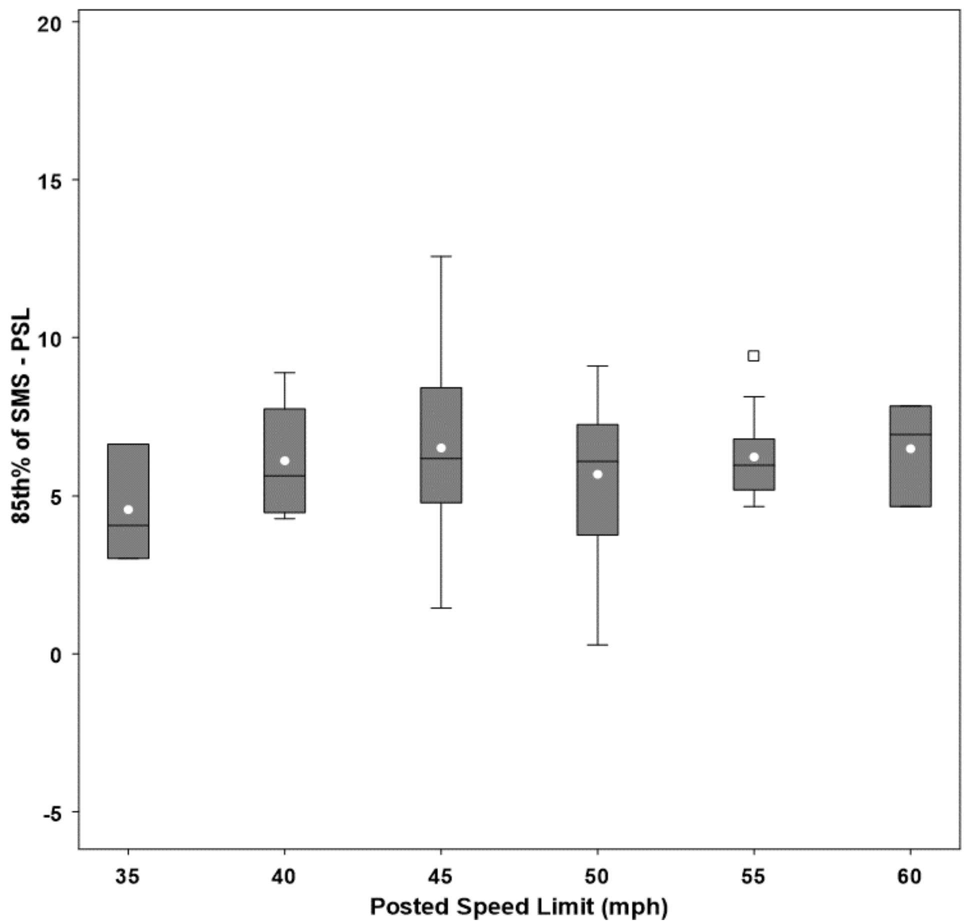


Source: FHWA.

Figure 29. Graph. Box plot of the 85th percentile of SMS minus PSL on 2U sites by PSL.

Table 18. Characteristics of distribution of the 85th percentile of SMS minus PSL on 2U sites by PSL.

Statistic	Speed Limit 30 mph	Speed Limit 35 mph	Speed Limit 40 mph	Speed Limit 45 mph	Speed Limit 50 mph	Speed Limit 55 mph
Number of sites	8	11	10	16	5	6
Minimum	4.3	1.7	−3.3	−0.8	2.3	−0.9
Mean	7.7	7.1	4.3	3.0	3.7	1.0
Maximum	12.6	18.3	8.9	11.3	5.4	4.2
SD	3.21	4.18	3.32	3.13	1.4	1.79



Source: FHWA.

Figure 30. Graph. Box plot of the 85th percentile of SMS minus PSL on 4D sites by PSL.

Table 19. Characteristics of distribution of the 85th percentile of SMS minus PSL on 4D sites by PSL.

Statistic	Speed Limit 35 mph	Speed Limit 40 mph	Speed Limit 45 mph	Speed Limit 50 mph	Speed Limit 55 mph	Speed Limit 60 mph
Number of sites	3	4	20	9	14	3
Minimum	3.0	4.3	1.5	0.3	4.6	4.7
Mean	4.6	6.1	6.5	5.7	6.2	6.5
Maximum	6.6	8.9	12.6	9.1	9.4	7.8
SD	1.86	2.12	2.66	2.76	1.43	1.64

CHAPTER 4. STATISTICAL ANALYSIS

In order to determine the safety impact of speed on crash rates, various cross-sectional analyses were performed on the data. Several preliminary analyses were conducted in parallel with data quality control reviews and updates. The results of these analyses are not reported, as the crash and AADT databases were not finalized at the time the models were developed.

Initially, the research team contemplated using a crash measure that considered the HSM's crash-prediction methodology. Specifically, the crash measure was the difference between observed crashes and predicted crashes using the chapter 12 safety performance functions and crash modification factors (CMFs)/functions (AASHTO 2010). The first preliminary analysis looked for correlation between this crash measure and each of the nine speed measures initially considered for inclusion in the analysis.

Originally, separate models were developed for each State; however, since some States have only a few segments all the States were grouped together to increase sample size. Pearson correlations were calculated between the crash variable and each speed measure, separately for each roadway type. With all States grouped, measures of correlation were fairly close to zero during this first round of modeling. There were no speed measures that stood out as better or worse than the others at predicting any of the crash measures. Researchers hypothesized that there were several possible reasons for this, including the following:

- Speed may have a much bigger impact on severity of crashes than on crash frequency. In addition, reporting practices for property-damage-only (PDO) crashes may vary by State, so using models for fatal-and-injury crashes only may be more appropriate.
- Grouping all the States together ignores the potential differences among States in such things as practices in how speed limits are set, highway design practices, enforcement practices, and driving culture.
- The roadway features known to impact safety accounted for by the CMFs may themselves be correlated with speed. For example, the number and type of driveway access points on a roadway segment may impact the speed at which drivers choose to travel.

In an attempt to address some of these issues, the research team identified several other crash variables to use in the models, including the following:

- Crash rate—The roadway features known to impact safety accounted for by the CMFs may themselves be correlated with speed. For example, the number and type of driveway access points on a roadway segment may impact the speed at which drivers choose to travel. For this reason, a measure of crash rate was selected as the dependent variable in the model, ignoring CMFs. The crash rate measure takes into account AADT and segment length.
- Observed KABC crashes minus predicted KABC crashes—Using the fatal-and-serious-injury model from chapter 12 of the HSM to predict crashes and comparing that to observed KABC crashes, the issue of PDO crash reporting practices being varied among States and the unreliability of PDO crash data in general can be eliminated.

- Proportion of total crashes that are severe—This measure is another way of looking at the impact of speed on severity, and whether certain speed measures are associated with a higher proportion of severe crashes.

However, because the HSM crash predictions were not calibrated to the individual States included in this study, and there were not a sufficient number of sites per State to model each State separately, crash measures based on the HSM prediction methodology were determined to be inappropriate for use across States. Finally, rather than modeling correlations between crash measures and speed measures, the research team chose to develop models using functional forms similar to those used to develop the safety performance functions in the HSM.

All models fit to the data were generalized linear mixed models with State and Site ID nested within state as random effects to correct for unobserved correlation among sites within a State and within a site across years. The natural log (ln) of the AADT [(ln(AADT)] was included as a covariate in the models to adjust for volume differences between sites, and for applicable response variables, the ln of site length (in miles) was included as an offset to adjust for differences in length between sites. The speed measures modeled throughout the process included the following:

- Mean SMS (SMS).
- SD of SMS (SD of SMS).
- Mean FFS (FFS).
- Mean of maximum speed minus minimum speed of each trip (MMM).
- 85th percentile of the SMS minus the PSL (85-SL).

These speed measures were chosen for final modeling from a longer original list of potential speed measures based on having the most promising results in early data exploration and preliminary modeling, and for engineering and practitioner-related concerns.

Four types of analyses were conducted, as described in table 20.

Table 20. Description of statistical analysis types.

Analysis Type	Dependent Variable	Independent Variables	Number of Models
1	Crashes per mile per year (total KABC, SV KABC, or MV KABC)	AADT, speed measure (SMS, SD of SMS, FFS, MMM, or 85-SL)	30
2	Crashes per mile per year (total KABC, SV KABC, or MV KABC)	AADT, sight characteristics, speed measure (SMS, SD of SMS, FFS, MMM, or 85-SL)	30
3	Crash severity (ratio of KA to KABC)	AADT, sight characteristics, speed measure (SMS, SD of SMS, FFS, MMM, or 85-SL)	10
4	Speed measure (SMS, SD of SMS, FFS, MMM, or 85-SL)	AADT, sight characteristics	10

All models were run separately for two-lane and four-lane sites. The models were fitted with the GLIMMIX procedure of SAS software version 9.4.

Crash severity was categorized according to the KABCO severity scale. PDO crashes (O on the KABCO scale) were not included in the analysis due to potential crash reporting differences for that crash severity across States. Intersection and intersection-related crashes were not included in the crash database. However, note that driveway and driveway-related crashes were included. Each model type is described and results are presented in the following sections of this chapter.

ANALYSIS TYPE 1: CRASH FREQUENCY VERSUS SPEED

The dependent variables modeled were total fatal-, serious-, minor-, and possible-injury segment-related crashes (total KABC); SV fatal-, serious-, minor-, and possible-injury segment-related crashes (SV KABC); and MV fatal-, serious-, minor-, and possible-injury segment-related crashes (MV KABC). Because crash data are discrete count data, overdispersed, and zero-inflated, the crash measures were fit with negative binomial regression, which is well-suited to analyses of crash data and is often implemented. A log link function was used. The only independent variables included in these models were ln(AADT) and the speed measures. Separate models were developed for each of the five speed measures listed in chapter 4. The models have the general functional form shown in figure 31.

$$N_{Crash} = \exp[b_0 + b_1 \ln(AADT) + b_2 Speed]$$

Figure 31. Equation. General functional form of crash frequency versus speed models.

Where:

N_{Crash} = crashes per mile per year.

$AADT$ = annual average daily traffic.

$Speed$ = speed measure.

b_0, b_1, b_2 = regression coefficients.

The summarized results of these models are found in table 21, table 22, and table 23 for MV, SV, and total KABC crashes respectively; *p*-values less than 0.05 are denoted with an asterisk. Models for which the AADT and the speed measure were significant at the 5-percent significance level, and for which the estimate is in the expected direction (that is, higher speeds or more variation in speed results in higher crash frequency), are denoted with a double asterisk in the speed measure column.

The speed measure and ln(AADT) were both significant effects at the 5-percent significance level in nine of the 30 models. More significance was generally found in 4D models than in 2U models, and four out of the six models involving the SD of the SMS were found to have significant effects. All of these effect sizes were in the positive direction, meaning sites with more variability in the SMS tend to have more crashes per mile per year than sites with lower speed variability. Otherwise, an inverse relationship between speed and crashes was observed in these model results. The exponent of the effect estimate represents a factor change in crashes; for example, for the total crash 4D model, an increase of 10 mph in mean SMS results in a 30-percent decrease in the number of crashes per mile per year ($\exp(-0.036 \times 10) = 0.698$), on average assuming constant AADT.

Table 21. Model results for MV KABC crashes versus speed measures and AADT.

Speed Measure	Roadway Type	ln(AADT) Estimate	ln(AADT) *p*-value	Speed Estimate	Speed *p*-value
Mean of SMS	2U	0.845	0.007*	−0.021	0.213
Mean of SMS	4D	1.022	<0.001*	−0.048	0.003*
SD of SMS**	2U	0.826	0.006*	0.306	0.018*
SD of SMS**	4D	0.660	0.031*	0.267	0.009*
Mean of FFS	2U	0.846	0.007*	−0.018	0.273
Mean of FFS	4D	1.016	<0.001*	−0.045	0.005*
Mean of (Max − Min)	2U	0.777	0.013*	0.006	0.890
Mean of (Max − Min)	4D	1.020	<0.001*	0.035	0.308
85% of SMS − PSL	2U	0.713	0.017*	−0.059	0.046*
85% of SMS − PSL	4D	0.940	0.002*	−0.043	0.395

**p*-value is significant at the 5-percent significance level.

**AADT and the speed measure are significant at the 5-percent significance level, and the estimates are in the expected direction.

Max = maximum; Min = minimum.

Table 22. Model results for SV KABC crashes versus speed measures and AADT.

Speed Measure	Roadway Type	ln(AADT) Estimate	ln(AADT) *p*-value	Speed Estimate	Speed *p*-value
Mean of SMS	2U	1.150	<0.001*	0.010	0.506
Mean of SMS	4D	0.734	0.012*	0.005	0.783
SD of SMS	2U	1.206	<0.001*	−0.034	0.749
SD of SMS	4D	0.710	0.024*	0.035	0.753
Mean of FFS	2U	1.134	<0.001*	0.012	0.450
Mean of FFS	4D	0.730	0.012*	0.007	0.684
Mean of (Max − Min)	2U	1.170	<0.001*	0.032	0.409
Mean of (Max − Min)	4D	0.802	0.008*	0.027	0.442
85% of SMS − PSL	2U	1.181	<0.001*	−0.013	0.607
85% of SMS − PSL	4D	0.748	0.010*	0.011	0.818

*p-value is significant at the 5-percent significance level.
Max = maximum; Min = minimum.

Table 23. Model results for all KABC crashes versus speed measures and AADT.

Speed Measure	Roadway Type	ln(AADT) Estimate	ln(AADT) *p*-value	Speed Estimate	Speed *p*-value
Mean of SMS	2U	0.884	<0.001*	−0.014	0.314
Mean of SMS	4D	1.004	<0.001*	−0.036	0.021*
SD of SMS**	2U	0.875	<0.001*	0.214	0.038*
SD of SMS**	4D	0.736	0.011*	0.200	0.043*
Mean of FFS	2U	0.883	<0.001*	−0.012	0.389
Mean of FFS	4D	1.000	<0.001*	−0.033	0.036*
Mean of (Max − Min)	2U	0.833	0.001*	0.012	0.735
Mean of (Max − Min)	4D	0.993	<0.001*	0.028	0.398
85% of SMS − PSL	2U	0.784	0.001*	−0.045	0.053
85% of SMS − PSL	4D	0.940	<0.001*	−0.032	0.487

*p-value is significant at the 5-percent significance level.
Max = maximum; Min = minimum.

ANALYSIS TYPE 2: CRASH FREQUENCY VERSUS SPEED AND SITE CHARACTERISTICS

This analysis was identical to Analysis Type 1 with site characteristic variables added into the models. This allowed the research team to further explore the speed versus crash relationship while accounting for site characteristics. The site characteristics included as independent variables in the models were lane width, horizontal alignment, driveway density, fixed objects, presence of lighting, presence of bike lanes, development type, and median width. How these variables were treated in the modeling is shown in table 24. These site characteristics were selected for inclusion in the model to ensure existing HSM chapter 12 CMF variables were accounted for and that additional information about the sites that might be relevant to speed choices was included. The functional forms of these models are the same as above, just with added parameters. The full results of these models are found in appendix B. There are effectively no significant effects in any of these models at the 5-percent significance level, outside of ln(AADT). This suggests that speed has no significant effect on crash rate after site characteristics are accounted for in the modeling.

Table 24. Site characteristic variable classification.

Independent Variable	Variable Type	Bins/Categories
Lane width	Categorical	Average lane width > 12.5 ft [1] 10.5 ft ≤ average lane width ≤ 12.5 ft [2] Average lane width < 10.5 ft [3]
Horizontal alignment	Binary	Gradual curve (GC) Tangent (T)
DDS	Categorical	DDS > 95 [1] 35 ≤ DDS ≤ 95 [2] DDS < 35 [3]
Fixed objects	Categorical	Fixed objects > 110 [1] 70 ≤ fixed objects ≤ 110 [2] Fixed objects < 70 [3]
Presence of lighting	Binary	Not present [0] Present [1]
Presence of bike lanes	Binary	Not present [0] Present [1]
Development type	Categorical	Commercial Industrial/institutional Residential Undeveloped
Median width	Continuous	N/A

N/A = not applicable.
Note: Model coding appears in brackets.

For each categorical or binary variable listed in table 24, the bottom category listed was considered the baseline during modeling.

ANALYSIS TYPE 3: CRASH SEVERITY VERSUS SPEED AND SITE CHARACTERISTICS

It was of interest to examine potential relationships of the speed measures to crash severity. The dependent variable chosen to represent relative severity was defined as the ratio of KA crashes to KABC crashes, giving a proportion ranging from zero to one for each site-year. This variable was modeled against the speed measures and the site characteristics. A beta distribution of the response variable was assumed, and a logit link was used. Results of these models are also found in appendix B. These severity models also showed no significance of model effects.

ANALYSIS TYPE 4: SITE CHARACTERISTICS VERSUS SPEED

Next, the speed measures were modeled against the site characteristics to explore if any road characteristics have a strong relationship with the speed measures. All speed measures were assumed to be normally distributed. Results of these models are found in appendix B. Many effects were found to be statistically significant at the 5-percent significance level, especially lane width and number of fixed objects, which were both found to be significant in all models across road type and speed measure; although the direction of the effects varied across the models and speed measures. Table 25 shows the site characteristics that were found to be significant at the 5-percent level in each model. The estimates associated with each of these roadway characteristics can be found in the full model result tables in appendix B. Since these are Gaussian models with an identity link, the effect parameter estimates are directly interpretable to the speed measures; for example, the SD of the SMS model for 4D roadways has a significant median width estimate of 0.01, meaning that on average for every foot increase in median width the SD of the SMS could be expected to increase by 0.01 mph when keeping other variables constant.

Table 25. Site characteristics significant at the 5-percent significance level when predicting speed measures.

Speed Measure	Roadway Type	LnAADT	Horizontal Alignment	Lane Width	Presence of Bike Lane	Presence of Lighting	Fixed-Object Density	Driveway Density	Area Development Type	Median Width
Mean of SMS	2U	N	N	Y	N	N	Y	Y	Y	N/A
Mean of SMS	4D	N	Y	Y	N	Y	Y	Y	Y	Y
SD of SMS	2U	N	N	Y	N	Y	Y	Y	Y	N/A
SD of SMS	4D	N	Y	Y	Y	Y	Y	Y	Y	Y
Mean FFS	2U	N	N	Y	N	N	Y	Y	Y	N/A
Mean FFS	4D	N	Y	Y	N	Y	Y	Y	Y	Y
Mean of (max–min) spot speeds	2U	N	Y	Y	N	N	Y	Y	Y	N/A
Mean of (max–min) spot speeds	4D	N	Y	Y	N	Y	Y	N	N	N
85th percentile SMS–PSL	2U	N	N	Y	N	N	Y	N	Y	N/A
85th percentile SMS–PSL	4D	N	Y	Y	Y	N	Y	Y	Y	Y

Y = significant; N = not significant; N/A = not applicable.

ALTERNATE MODEL FORMS

International research provides some guidance for evaluating relationships between speed and safety. The power model developed in Sweden by Nilsson (2004) found the following relationship representing a CMF for the effect of a change in speed (increase or decrease) on crash frequency by severity level shown in figure 32.

$$CMF = \frac{Crashes\ after}{Crashes\ before} = \left(\frac{V_{final}}{V_{initial}}\right)^{x}$$

Figure 32. Equation. Change in speed CMF.

Where:

Crashes after = number of crashes during the study period before a change in speed.
Crashes before = number of crashes in the study period after a change in speed.
V_{final} = mean speed of traffic after change.
$V_{initial}$ = mean speed of traffic before change.
$x = 4$ for fatal crashes.
$x = 3$ for fatal and serious injury crashes.
$x = 2$ for fatal and all injury crashes.

The change in speed modeled above can be either a natural occurrence (e.g., increase in speeds chosen by drivers over time) or the result of a specific intervention (e.g., change in speed limit, change in speed enforcement practices, or change in roadway geometrics). Nilsson (2004) proposed specific values for the exponent *x*, but values of *x* can also be fitted empirically with U.S. data.

The International Road Assessment Programme (iRAP) has used the Nilsson model as the basis for a speed effect on crashes. Since iRAP was predicting fatal and serious injury crashes, they chose to use a value of *x* equal to 3. iRAP assumed that, in addition to representing the effect of changes on speed on a given site, the Nilsson model can be applied to represent the effect of speed differences between otherwise similar roadways. The Nilsson model also provides an indication that mean speeds, rather than other speed measures, may be most suited to crash prediction.

Hauer and Bonneson (2009) proposed an exponential model in the form shown in figure 33 as an alternative to the Nilsson power model.

$$CMF = e^{a\left[V_{initial} - V_{final} + \left(b/2\right)\times\left(V_{initial}^2 - V_{final}^2\right)\right]}$$

Figure 33. Equation. Exponential model for speed change CMF.

Where *a* and *b* are empirically determined.

Hauer and Bonneson's testing of this exponential model used data from a Norwegian study by Elvik et al. (2004), not data from the United States or Canada.

Elvik (2009) catalogued 115 studies (or reviews of studies) that have addressed the effect of increases or decreases in vehicle speed on safety and found strong support for the Nilsson power model. However, Elvik (2013) also conducted research to refit the power model with greater speed dependence and to compare the power model to the exponential model and found that the exponential model produced a slightly better fit than the power model, particularly for injury crashes, but the differences appear to be small.

The research team was interested in finding a way to use the data to develop speed–safety relationships similar to those shown in the Nilsson power model or the exponential model. However, because the speed data used in this research did not change over time, it was not possible to do a before–after analysis. The research team considered approaches to translate these models into a cross-sectional analysis, potentially using a set of base conditions as the "before" sites and then all other conditions as "after" sites, but this approach did not work. Therefore, models with formats similar to those used in international speed–safety research could not be developed.

CHAPTER 5. INTERPRETATION OF RESULTS AND DISCUSSION

The overall study objective was to develop speed–safety relationships that can be used in the HSM and in other safety-management tools such as Safety Analyst and usRAP models. This objective presumed that a statistically significant relationship would be found between crash frequency and/or severity and the speeds drivers are choosing for their trips on those roadway segments. However, this research indicates that on 2U and 4D urban and suburban arterials, no clear predictive relationship can be identified. Therefore, incorporating a speed measure into crash-prediction models for these roadway types would not improve on existing crash-prediction models that rely only on segment AADT and various roadway segment characteristics.

SMS and FFS were the two speed measures that were designed to capture the concept of "travel speed" for the roadway segments. These measures ended up being very similar to each other, so their *p*-values and estimates were very similar in the models that were developed. In the initial model that evaluated the relationship between each of the speed measures and crash frequency, using only AADT in the models (excluding any site characteristics), both SMS and FFS were found to be significant predictors of total KABC crash and MV KABC crash frequency on 4D roadway segments. However, the estimates for these variables were negative, indicating that higher speeds resulted in a lower number of crashes. This result make sense in that often factors on or near a roadway that contribute to crashes (such as driveway density) also result in lower speed limits and slower driving speeds. Including these inverse speed–safety relationships in a predictive model, however, would seem to indicate that increasing speeds on a roadway will decrease crashes. This is certainly not guidance that should be presented to highway safety practitioners, nor guidance they would be likely to accept. When site characteristics were added to the models, these relationships were no longer present, indicating that there is some correlation between the speed measures and the site characteristics. Indeed, in the analysis of the relationship between site characteristics and speed measures on two-lane roads, several site characteristics were found to be significant predictors of both SMS and FFS for two-lane roads; these include lane width, fixed-object density, driveway density, and area type. For 4D roads, the significant site characteristics included the same as those for 2U roads with the addition of horizontal alignment, lighting, and median width.

The one speed measure that had a consistent relationship with crashes for both roadway types for MV crashes and total crashes (but not SV crashes) was the SD of the SMS. This speed measure looks at the variability between trips on the same roadway segment (as opposed to speed variability within the trip). Segments with higher SDs of SMS are those where the travel time across the study segment varied greatly from trip to trip. Low SDs of SMS indicate that most trips across the segment took about the same amount of time. Modeling results indicated that when the SD of SMS increases, MV and total crashes increase. This finding provides some support for a number of previous speed–safety relationship studies, which have found crash risk increases as speeds move away from the mean speed. It also makes sense that the effect would be on MV crashes more than SV crashes, since speed variances between vehicles in the same proximity can result in a crash between them.

When site characteristics were added into the model, even the relationship between the SD of SMS and crashes disappeared, indicating that the additional variables are likely correlated with the speed measure. That is, the site characteristics may influence the variance in trip times among drivers on the same segment. Indeed, in the later analysis that considered the relationship between site characteristics and speed measures, almost all the included site characteristics were found to be statistically significant in the models for the SD of SMS.

While the SD of SMS may be the most promising speed measure in terms of predicting crash frequencies on urban and suburban arterials, it is unlikely that developing safety performance functions using this variable will be beneficial to highway safety practitioners. First, as discussed previously, the effect of this speed measure on crashes seems to be well captured by other site characteristics that are currently accounted for in existing HSM CMFs, or that can be accounted for in such a way. Second, the SD of SMS is not likely to be a variable that can be easily obtained by highway agencies. The SD of spot speeds may be a good approximation for this variable, if the spot speed is recorded at a location where drivers are traveling at the average speed for the segment. Given that many factors along the roadway can influence speed, it may be difficult to identify this representative spot. But even using this approximation, it is likely highway agencies would need to collect speeds for many vehicles over a long period of time to develop a substantial distribution of data points from which to calculate the SD. More research would need to be undertaken to determine how many observations are needed and over what length of time they should be gathered to best approximate the SD of SMS measure used in this research.

In summary, the results of this research help validate very early speed–safety research that indicated speed variance may play more of a role in crash likelihood than speed does. It also indicated that the influence of speed on safety may already be substantially captured by the inclusion of site characteristics in the crash-prediction models.

CHAPTER 6. RECOMMENDATIONS FOR FUTURE RESEARCH

LIMITATIONS OF THIS RESEARCH

Using the NDS data to evaluate the relationship between speed and safety provided many advantages over traditional speed data collection, including the ability to evaluate continuous speed data on the vehicle level for many hundreds of trips. However, the use of the NDS data also presented some constraints and limitations on the research. These include the following:

- The dataset included several trips made by the same drivers on each segment. Because even trips made by the same drivers were presumably made under varying conditions (lighting, weather, traffic patterns, signal indications, turning drivers, driver urgency, etc.), they could not be considered true "repeated measures" in the statistical analysis. Yet it is likely that variability in driving speed within trips made by a single driver is less than the variability that exists between trips made by different drivers. It is unclear how these repeated trips by the same driver may influence the speed distributions gathered for the research.

- The NDS speed data were collected over an approximate 2-year period, while the crash data included in this research were generally for 7 or 8 years for each State. For most States, the years of crash data included the years when speed data were collected. However, the analysis assumes that the speed data available were representative of speeds traveled during all the years of crash data included in the analysis. It also assumes that the roadway characteristics were consistent throughout the years for which the crash data were obtained and analyzed. The research team believes these are reasonable assumptions to make, but they are assumptions.

- Travel speeds on a given segment were not found to change substantially over time at the study sites evaluated (although speed data were collected over only an approximately 2- to 3-year period). Sites where speed limit or some other speed-influencing factor changed during the observation period were not found. Therefore, a before–after study design was not possible. Such a design would have provided more insight about the safety impact of changing driving speeds on a given corridor.

- It is unclear how well the NDS speed data represent the true speed distribution of the roadway, given that the study drivers are not a representative sample of all drivers on the roadway. Because the NDS data are not available for most roadway segments around the country, any speed measures obtained from the NDS would need to have analogous speed measures that could be collected on any roadway segment with the resources available to highway agencies. The safety-prediction models presented in the HSM are only beneficial if highway agencies have the means to apply them. Speed measures that require detailed spot speed analysis, long observation periods, or a great deal of labor to collect will not be reliably available to analysts using the crash-prediction procedures. Because operating speeds can change from segment to segment based on local conditions, extrapolating speed measures to adjacent roadway segments may not be as reliable as extrapolating AADT values along adjacent segments. Additional research would be required to determine how closely such field-collected data could represent the NDS-collected speed measures used in the research.

In addition to the limitations inherent to using the NDS data for the research, there are other limitations associated with the assumptions made in the study design. Specifically, the objective of this research—to evaluate a relationship between speed measures and crash experience over time—assumes that speed measures can be thought of as characteristics of roadway segments and that they are somewhat static in nature, in order to be predictive of crash frequency over time. However operating speed is not a static characteristic of a roadway segment. The variables included in the existing CMFs in the HSM are generally physical characteristics of the roadway or roadway environment (AASHTO 2010). Characteristics such as the number of approaches of left-turn lanes, the lane and shoulder widths, and curve radius are experienced by every driver. Traffic flow changes throughout the day and may differ by day of week or time of year, but because it is a count, the values can be summed and averaged in a meaningful way to obtain the AADT. While PSLs are also static characteristics experienced by all drivers, operating speeds are not. Each driver experiences the operating speed they choose at the time, as well as the operating speeds chosen by surrounding drivers. In addition, drivers can make changes to their operating speed at any time based on the conditions they are experiencing. Because speeds are rates (distance per unit time), they do not sum the way traffic counts do, and averages over time are less meaningful because they may hide the very outlier conditions that may be the most influential on crash likelihood. In addition, average speed measures can change over time due to external factors not related to roadway characteristics such as increases or decreases in speed enforcement activities.

In addition, the relationship between speed and crash likelihood may be more strongly related to the individual speed of specific drivers rather than to speed measures averaged over the population of drivers on the segment. The severity of any crash is related to the speed of the individual driver or drivers involved in the crash. The travel speed of the drivers involved in crashes may or may not be represented by average speed measures. Drivers involved in crashes may be traveling at outlier speeds that are not well captured by an average speed measure, especially for certain crash types such as SV run-off-the-road crashes. If the crash severity and likelihood are more closely related to outlier speeds than average speeds, it is unclear if existing datasets will be sufficient to provide the needed information to find these relationships.

As this research demonstrated, crash experience, design speed, operating speed, and roadway characteristics are all correlated. In the research conducted as part of National Cooperative Highway Research Program (NCHRP) Project 17-26, "Methodology to Predict the Safety Performance of Urban and Suburban Arterials," leading to the development of the HSM chapter 12 crash-prediction models for urban and suburban arterials, an inverse relationship was found between speed limits and crash frequency (i.e., more crashes at lower speeds) (Harwood et al., 2007). A similar relationship was found for some of the speed measures in this research. The logical explanation of this counterintuitive finding is that lower speed arterials also have more dense development, more driveways, and more intersections, which are often more closely spaced. This correlation between speed limits and other independent variables in the model makes it difficult for conventional statistical techniques to develop crash-prediction models empirically.

FUTURE RESEARCH NEEDS

In this research effort, the relationship between speed measures and crash severity was considered, and one analysis was conducted in which the dependent variable was the ratio of KA crashes to KABC crashes. Given the known relationship between crash speed and crash severity, it may be desirable to explore this relationship further, using different dependent variables and different model formats.

In addition, this research focused only on segment crashes; intersection crashes and intersection-related crashes were removed from the database. This approach was selected because the number of intersections within a segment would likely substantially influence the frequency of crashes experienced on the segment. Since crashes were evaluated on a per-mile basis to account for varying segment length, it would be difficult to incorporate intersection crashes in a way that accounted for the number of intersections present on the segment. In addition, the frequency of intersection crashes is partly a function of the minor route AADT and other intersection characteristics (such as presence of turn lanes), which were not collected for this study. However, it is likely that travel speed does influence the likelihood and severity of intersection crashes, especially at two-way stop-controlled intersections, where the major route traffic does not have to slow or stop. Future research could focus on looking specifically at the relationship of speed measures and intersection crashes.

Because this research included only urban and suburban arterials, where roadways are generally busier with access points, roadside fixed objects, turning maneuvers, and presence of pedestrians and bicycles, the influence of speed on crashes appeared to be substantially less than the influence of these other roadway characteristics on crashes (although the relationship between roadway characteristics and crashes was not directly evaluated in the absence of speed measures). This may not be the case with other facility types; rural facilities with fewer influences on speed choice may show a stronger relationship between speed and safety. This should be investigated.

Finally, it would be beneficial for researchers to understand how well speed measures taken from the NDS resemble speed measures taken from the full population of drivers over various time periods. In addition, it would be helpful to understand how well spot speed studies represent SMS measures over longer segments. Such an evaluation might include various forms of site data collection (e.g., radar guns, traffic classifiers, side-fire radar data collectors, and data from real-time routing and travel time providers) to be compared to a sample of the NDS data.

APPENDIX A. SITE CHARACTERISTICS, AADT, AND CRASH DATA

Table 26 through table 31 present site characteristics for all 2U and 4D sites. Table 32 through table 36 show crash frequency data for all 2U and 4D sites. Table 37 gives AADT values for all 2U and 4D sites.

Table 26. Cross-section and alignment characteristics for 2U sites.

Site	Speed Limit (mph)	Bike Lane Present	Left Shoulder Type	Left Shoulder or Gutter Width (ft)	Lane Width, Left of Centerline (ft)	Lane Width, Right of Centerline (ft)	Right Shoulder or Gutter Width (ft)	Right Shoulder Type	Horizontal Alignment
FL_2U_01	35	N	N	0	11.48	10.61	0	N	T
FL_2U_02	30	N	N	0	10.56	10.88	0	N	GC
FL_2U_04	30	N	N	0	11.02	10.78	0	N	T
FL_2U_07	35	N	N	0	10.57	10.15	0	N	GC
FL_2U_10	45	Y	P	4.89	10.97	11.08	3.36	PC	T
FL_2U_11	45	N	P	1.97	10.43	10.57	1.77	P	GC
FL_2U_13	45	N	N	0	10.71	10.54	0	N	T
FL_2U_14	45	N	P	4.98	10.96	11.89	4.5	P	GC
FL_2U_15	55	N	P	5.17	11.49	11.24	5.2	P	T
FL_2U_16	55	N	P	3.58	10.83	11.04	3.83	P	GC
FL_2U_17	50	N	P	4.29	11.78	11.34	4.91	P	T
FL_2U_18	45	N	P	2.92	11.19	11.69	3.9	P	T
FL_2U_19	45	N	P	4.46	11.25	11.6	3.48	P	T
IN_2U_014	35	N	N	0	9.97	11.1	0	N	T
IN_2U_015	40	N	N	0	8.8	9.88	0	N	T
IN_2U_029	40	N	P	10.49	11.08	10.67	9.29	P	T
IN_2U_030	40	N	P	2.66	11.88	11.32	3.36	P	T
IN_2U_031	40	N	P	2.48	11.55	11.6	4.47	P	GC
IN_2U_032	35	N	N	0	10.66	10.28	0	N	T
IN_2U_033	30	N	N	0	9.93	10.44	0	N	T
IN_2U_036	30	N	N	0	11.2	10.55	0	N	T

Site	Speed Limit (mph)	Bike Lane Present	Left Shoulder Type	Left Shoulder or Gutter Width (ft)	Lane Width, Left of Centerline (ft)	Lane Width, Right of Centerline (ft)	Right Shoulder or Gutter Width (ft)	Right Shoulder Type	Horizontal Alignment
IN_2U_037	50	N	P	11.61	11.75	11	11.34	P	T
IN_2U_040	30	N	N	0	11.26	13.03	0	N	GC
NC_2U_04	40	N	N	0	10.38	10.83	0	N	GC
NC_2U_05	40	N	P	2.08	9.8	9.78	1.83	P	T
NC_2U_10	35	N	P	1.72	9.78	10	2.38	P	T
NC_2U_11	45	N	P	1.52	10.28	10.04	1.64	P	GC
NC_2U_17	45	N	P	2.19	10.67	10.26	1.32	P	GC
NC_2U_23	45	N	P	1.59	10.18	9.26	3.52	P	T
NC_2U_27	45	N	P	2.11	9.62	10.41	2.27	P	GC
NC_2U_30	55	N	P	1.91	9.54	9.7	1.91	P	T
NC_2U_34	45	N	P	2	9.59	9.6	1.81	P	T
NC_2U_36	45	N	P	2.16	9.7	10.58	2.12	P	GC
NC_2U_37	35	N	P	1.67	10.26	9.68	1.68	P	T
NY_2U_02	35	N	P	3.95	10.25	10.29	5.42	P	GC
NY_2U_03	50	N	P	9.2	10.72	10.99	10.51	P	GC
NY_2U_04	40	N	PC	10.58	10.51	10.33	10.26	PC	T
NY_2U_07	45	N	P	7.1	11.45	11.15	8.02	P	GC
NY_2U_10	30	N	CG	0	12.92	20.7	0	CG	T
NY_2U_11	35	N	CG	0	14.99	14.18	0	CG	T
NY_2U_12	35	N	P	16.05	10.06	10.41	7.98	PC	T
NY_2U_13	30	N	VC	0	16	16.11	0	VC	T
NY_2U_14	45	N	P	8.14	10.69	10.66	7.7	P	T
NY_2U_15	55	N	T	7.64	11.73	11.66	8.62	P	T
NY_2U_16	35	N	P	11.3	10.17	10.19	13.01	P	GC
NY_2U_19	50	N	P	6.27	11.67	11.47	5.01	P	T
NY_2U_20	55	N	P	9.2	11.33	11.34	7.47	P	T
WA_2U_001	50	N	P	8.75	11.33	10.91	8.13	P	GC

Site	Speed Limit (mph)	Bike Lane Present	Left Shoulder Type	Left Shoulder or Gutter Width (ft)	Lane Width, Left of Centerline (ft)	Lane Width, Right of Centerline (ft)	Right Shoulder or Gutter Width (ft)	Right Shoulder Type	Horizontal Alignment
WA_2U_002	40	N	P	7.05	10.36	10.22	7.57	P	GC
WA_2U_003	45	N	P	6.14	10.25	10.62	8.17	P	GC
WA_2U_007	35	N	P	7.78	11.19	12.28	7.63	P	GC
WA_2U_014	30	N	P	4.83	9.83	10.23	6.61	P	GC
WA_2U_019	40	N	P	5.06	10.45	10.3	5.12	P	GC
WA_2U_020	45	N	P	4.09	10.94	11.27	2.92	P	GC
WA_2U_021	40	N	P	6.59	10.72	10.46	7.17	P	T
WA_2U_023	55	N	P	3.24	10.82	10.65	2.89	P	GC

Note: Definitions for codes used in this table are presented in table 3.

Table 27. Cross-section and alignment characteristics for 4D sites.

Site	Speed Limit (mph)	Bike Lane Present	Left Shoulder Type	Left Shoulder or Gutter Width (ft)	Curb Lane Width, Left of Centerline (ft)	Inside Lane Width, Left of Centerline (ft)	Inside Lane Width, Right of Centerline (ft)	Curb Lane Width, Right of Centerline (ft)	Right Shoulder or Gutter Width (ft)	Right Shoulder Type	Horizontal Alignment
FL_4D_001	45	Y	PC	4.72	10.06	9.77	10.48	9.75	4.44	PC	GC
FL_4D_002a	45	N	P	4.04	11.32	11.3	11.24	11.53	5.01	P	GC
FL_4D_002b	55	N	P	4.04	11.32	11.3	11.24	11.53	5.01	P	GC
FL_4D_004	50	N	P	4.86	11.39	10.91	11.41	11.28	4.28	P	T
FL_4D_006	55	N	P	4.31	11.9	10.8	10.86	11.5	3.73	P	T
FL_4D_007	45	Y	PC	4.57	11.39	11.37	10.93	11.81	4.52	PC	T
FL_4D_008	45	Y	PC	4.4	10.14	9.89	9.16	10.4	4.64	PC	GC
FL_4D_010	45	N	PC	3.22	10.23	10.29	10.23	10.71	3.2	PC	T
FL_4D_011	45	N	P	6.43	10.75	10.07	10.83	10.85	5.26	P	T
FL_4D_013	45	N	CG	0	10.27	10.92	11.24	10.86	0	CG	GC
FL_4D_015	55	Y	P	3.28	11.78	10.73	11.2	10.97	3.85	P	T
FL_4D_016	55	N	P	5.15	12.12	11.12	10.83	11.31	5.31	P	GC
FL_4D_017	60	N	P	3.57	11.31	10.84	11.25	11.18	3.52	P	T
FL_4D_020	45	N	P	4.56	11.94	10.99	11.54	11.41	4.25	P	GC
FL_4D_022	55	N	P	4.37	11	11.17	11.58	11.07	4.1	P	T
FL_4D_025	45	N	VC	0	10.02	10.62	11.91	10.86	0	VC	T
FL_4D_026	55	Y	P	3.99	11.26	11.18	10.41	11.23	4.26	P	T
FL_4D_028	45	Y	PC	2.82	10.74	10.15	9.83	10.55	3.51	PC	GC
FL_4D_031	45	N	P	3.76	11.82	12.23	11.61	12.21	4.94	P	T
FL_4D_034	45	Y	PC	4.75	10.96	10.08	10.52	10.58	5.08	PC	T
FL_4D_035	40	Y	PC	4.25	11.84	11.69	11.97	11.95	3.75	PC	GC
FL_4D_037	50	Y	P	4.94	11.46	11.32	11.45	11.02	4.86	P	T
FL_4D_038	45	Y	P	4.43	11.14	9.98	9.97	11.13	5	P	T
FL_4D_040	50	N	P	4.11	10.91	11.14	11.31	11.24	4.11	P	GC
FL_4D_041	50	Y	PC	4.2	11.49	11.39	10.88	11.79	5.62	PC	GC

Site	Speed Limit (mph)	Bike Lane Present	Left Shoulder Type	Left Shoulder or Gutter Width (ft)	Curb Lane Width, Left of Centerline (ft)	Inside Lane Width, Left of Centerline (ft)	Inside Lane Width, Right of Centerline (ft)	Curb Lane Width, Right of Centerline (ft)	Right Shoulder or Gutter Width (ft)	Right Shoulder Type	Horizontal Alignment
FL_4D_042	50	N	P	6.13	11.86	11.76	12.24	11.76	5.48	P	T
FL_4D_045	45	Y	PC	5.97	11.19	10.3	10.73	11.56	4.5	PC	T
FL_4D_046	55	Y	P	4.19	11.4	11.04	11.05	11.95	4.63	P	GC
IN_4D_002	55	N	P	10.19	10.87	10.83	12.16	11.28	10.95	P	T
IN_4D_012	50	N	P	11.6	11.01	12.01	11.9	11.06	10.71	P	T
IN_4D_013	35	Y	PC	5.1	10.39	10.81	10.8	10.59	4.88	PC	T
IN_4D_019	60	N	P	10.08	11.37	11.8	12.88	10.83	9.41	P	T
IN_4D_021	55	N	P	10.87	10.43	11.07	10.89	10.61	9.35	P	GC
IN_4D_023	55	N	P	9.39	10.76	11	11.07	10.8	8.95	P	GC
IN_4D_024	60	N	PC	10.67	11.01	10.77	11.21	10.53	10.25	PC	T
NC_4D_03	50	N	P	12.45	13.72	11.95	11.69	13.03	6.13	P	T
NC_4D_08	55	N	P	7.28	11.45	12.13	11.61	11.95	1.91	P	GC
NC_4D_10	55	N	P	1.49	11.52	10.77	10.64	10.33	1.99	P	T
NC_4D_14	45	N	CG	0	12.51	12	12.54	12.96	0	CG	GC
NC_4D_17	45	N	CG	0	13.19	10.89	11.27	12.89	0	CG	GC
NC_4D_20	55	N	P	11.92	11.33	10.66	11.29	12.24	9.74	P	GC
NC_4D_21	55	N	P	10.01	11.03	11.61	11.38	11.72	10.2	P	GC
NC_4D_26	45	N	P	8.05	13.54	11.72	11.87	13.89	6.64	P	GC
NC_4D_31	45	N	CG	0	13.16	11.22	11.26	13.51	0	CG	GC
NC_4D_36	45	N	CG	0	13.59	10.23	10.42	14.02	0	CG	GC
NC_4D_37	50	N	P	4.13	10.6	10.98	10.98	10.57	3.51	P	GC
NC_4D_38	50	N	CG	0	13.81	12.2	11.84	14.01	0	CG	T
NC_4D_40	45	N	CG	0	12.9	10.41	11.01	13.8	0	CG	T
WA_4D_03	35	N	CG	0	10.12	11.6	10.39	9.7	0	CG	T
WA_4D_04	35	N	CG	0	10.43	10.31	10.33	10.51	0	CG	T
WA_4D_05	40	N	P	5.11	12.32	11.42	10.52	12.33	0	CG	GC

Site	Speed Limit (mph)	Bike Lane Present	Left Shoulder Type	Left Shoulder or Gutter Width (ft)	Curb Lane Width, Left of Centerline (ft)	Inside Lane Width, Left of Centerline (ft)	Inside Lane Width, Right of Centerline (ft)	Curb Lane Width, Right of Centerline (ft)	Right Shoulder or Gutter Width (ft)	Right Shoulder Type	Horizontal Alignment
WA_4D_07	40	Y	PC	3.97	10.4	9.26	10.05	10.88	5.24	PC	GC
WA_4D_08	40	Y	PC	5.93	11.44	10.91	10.96	10.71	5.56	PC	T

Note: Definitions for the codes used in this table are presented in table 3.

Table 28. Lighting and roadside characteristics of 2U sites.

Site	Roadway Lighting	Number of Fixed Objects	Fixed-Object Offset (ft)	On-Street Parking
FL_2U_01	No	100	10	No
FL_2U_02	No	72	10	No
FL_2U_04	No	140	6	No
FL_2U_07	No	124	12	No
FL_2U_10	Yes	75	20	No
FL_2U_11	No	66	10	No
FL_2U_13	No	150	12	No
FL_2U_14	No	230	25	No
FL_2U_15	No	90	25	No
FL_2U_16	No	356	35	No
FL_2U_17	No	150	30	No
FL_2U_18	No	250	18	No
FL_2U_19	No	130	20	No
IN_2U_014	No	50	15	No
IN_2U_015	No	140	12	No
IN_2U_029	No	140	20	No
IN_2U_030	No	90	10	No
IN_2U_031	Yes	68	8	No
IN_2U_032	No	106	8	No
IN_2U_033	Yes	65	12	No
IN_2U_036	No	106	7	No
IN_2U_037	Yes	50	4	No
IN_2U_040	No	78	8	No
IN_4D_002	No	52	32	No
IN_4D_012	No	40	25	No
IN_4D_013	Yes	52	10	No
IN_4D_019	No	260	30	No
IN_4D_021	No	200	12	No
IN_4D_023	No	24	14	No
IN_4D_024	No	250	30	No
NC_2U_04	Yes	100	20	No
NC_2U_05	No	90	10	No
NC_2U_10	No	102	8	No
NC_2U_11	Yes	75	15	No
NC_2U_17	Yes	100	22	No
NC_2U_23	No	80	25	No
NC_2U_27	No	96	14	No
NC_2U_30	No	200	11	No
NC_2U_34	No	180	10	No
NC_2U_36	No	90	10	No
NC_2U_37	No	70	9	No

Site	Roadway Lighting	Number of Fixed Objects	Fixed-Object Offset (ft)	On-Street Parking
NY_2U_02	No	110	7	No
NY_2U_03	No	80	13	No
NY_2U_04	No	70	15	No
NY_2U_07	No	50	12	No
NY_2U_10	No	50	25	No
NY_2U_11	No	90	8	No
NY_2U_12	No	35	5	No
NY_2U_13	No	90	12	No
NY_2U_14	No	40	12	No
NY_2U_15	No	50	8	No
NY_2U_16	Yes	160	10	No
NY_2U_19	No	60	8	No
NY_2U_20	No	60	10	No
WA_2U_001	No	24	10	No
WA_2U_002	Yes	54	12	No
WA_2U_003	No	70	10	No
WA_2U_007	No	50	20	No
WA_2U_014	Yes	89	11	No
WA_2U_019	No	110	8	No
WA_2U_020	No	100	12	No
WA_2U_021	No	120	12	No
WA_2U_023	No	60	7	No

Table 29. Lighting, median, and roadside characteristics of 4D sites.

Site	Roadway Lighting	Median Width (ft)	Median Type	Number of Fixed Objects	Fixed-Object Offset (ft)	On-Street Parking
FL_4D_001	Yes	45	R	180	10	No
FL_4D_002a	No	44	D	71	8	No
FL_4D_002b	No	44	D	40	22	No
FL_4D_004	Yes	49	D	60	9	No
FL_4D_006	No	45	D	100	40	No
FL_4D_007	Yes	24	R	160	12	No
FL_4D_008	Yes	45	R	80	12	No
FL_4D_010	No	45	R	140	14	No
FL_4D_011	No	20	R	40	16	No
FL_4D_013	No	19	N	60	30	No
FL_4D_015	No	56	D	110	35	No
FL_4D_016	No	70	D	160	45	No
FL_4D_017	No	40	N	90	32	No
FL_4D_020	Yes	40	D	60	14	No
FL_4D_022	No	41	D	100	16	No
FL_4D_025	Yes	15	R	25	6	No
FL_4D_026	No	40	D	100	30	No
FL_4D_028	No	24	R	90	20	No
FL_4D_031	Yes	45	D	180	10	No
FL_4D_034	Yes	45	R	160	20	No
FL_4D_035	Yes	18	R	110	14	No
FL_4D_037	No	40	D	100	25	No
FL_4D_038	Yes	40	R	90	18	No
FL_4D_040	Yes	30	D	160	15	No
FL_4D_041	No	35	R	80	30	No
FL_4D_042	No	40	D	160	30	No
FL_4D_045	Yes	20	R	110	12	No
FL_4D_046	No	41	D	200	20	No
IN_4D_002	No	50	D	52	32	No
IN_4D_012	No	20	F	40	25	No
IN_4D_013	Yes	15	R	52	10	No
IN_4D_019	No	50	D	260	30	No
IN_4D_021	No	60	D	200	12	No
IN_4D_023	No	50	D	24	14	No
IN_4D_024	No	50	D	250	30	No
NC_4D_03	No	18	R	60	12	No
NC_4D_08	No	30	R	140	15	No
NC_4D_10	No	30	D	160	22	No
NC_4D_14	Yes	20	R	65	12	No
NC_4D_17	Yes	31	R	112	12	No

Site	Roadway Lighting	Median Width (ft)	Median Type	Number of Fixed Objects	Fixed-Object Offset (ft)	On-Street Parking
NC_4D_20	No	42	D	180	30	No
NC_4D_21	No	43	D	140	30	No
NC_4D_26	No	15	N	80	22	No
NC_4D_31	Yes	30	R	110	15	No
NC_4D_36	No	20	R	120	22	No
NC_4D_37	Yes	30	D	160	15	No
NC_4D_38	Yes	15	R	136	15	No
NC_4D_40	Yes	30	R	118	15	No
WA_4D_03	Yes	20	R	30	20	No
WA_4D_04	Yes	18	R	74	5	No
WA_4D_05	No	180	R	46	12	No
WA_4D_07	Yes	12	R	106	6	No
WA_4D_08	Yes	13	R	50	15	No

Note: Definitions for the codes used in this table are presented in table 3.

Table 30. Area type and access characteristics of 2U sites.

Site	General Area Type	Number of Side Streets	Number of Major Commercial Driveways	Number of Minor Commercial Driveways	Number of Major Industrial Driveways	Number of Minor Industrial Driveways	Number of Major Residential Driveways	Number of Minor Residential Driveways	DDS
FL_2U_01	Residential	9	1	0	0	0	1	13	219.88
FL_2U_02	Residential	7	0	0	0	0	0	20	189.18
FL_2U_04	Residential	4	0	0	0	0	1	95	292.08
FL_2U_07	Commercial	16	0	34	0	0	0	2	350.00
FL_2U_10	Residential	0	0	2	0	0	2	0	19.97
FL_2U_11	Residential	0	0	0	0	0	0	1	1.32
FL_2U_13	Undeveloped	5	0	0	0	0	0	1	54.64
FL_2U_14	Residential	4	0	3	1	4	6	0	34.69
FL_2U_15	Undeveloped	4	0	1	0	0	1	1	70.18
FL_2U_16	Residential	4	0	15	0	1	2	4	42.43
FL_2U_17	Residential	4	0	3	0	0	0	7	57.18
FL_2U_18	Residential	4	0	4	0	0	0	54	208.37
FL_2U_19	Residential	7	0	2	0	0	0	41	127.91
IN_2U_014	Residential	0	0	5	0	0	0	0	34.44
IN_2U_015	Industrial/ institutional	6	0	0	0	0	0	39	227.28
IN_2U_029	Industrial/ institutional	3	0	0	0	0	0	125	287.39
IN_2U_030	Residential	3	0	2	0	1	1	38	114.05
IN_2U_031	Residential	4	0	3	0	0	0	62	102.08
IN_2U_032	Residential	3	0	1	0	0	0	21	76.20
IN_2U_033	Residential	4	0	0	0	0	0	64	247.08
IN_2U_036	Residential	5	0	0	0	0	3	6	87.55
IN_2U_037	Residential	2	0	13	0	0	6	41	228.48
IN_2U_040	Residential	2	0	0	0	0	3	6	78.82
NC_2U_04	Industrial/ institutional	1	0	3	0	0	0	60	119.28
NC_2U_05	Residential	4	0	0	0	0	0	19	98.38

Site	General Area Type	Number of Side Streets	Number of Major Commercial Driveways	Number of Minor Commercial Driveways	Number of Major Industrial Driveways	Number of Minor Industrial Driveways	Number of Major Residential Driveways	Number of Minor Residential Driveways	DDS
NC_2U_10	Residential	7	0	1	0	0	0	36	158.33
NC_2U_11	Undeveloped	4	0	0	0	0	0	25	95.41
NC_2U_17	Residential	2	0	0	0	0	0	29	64.34
NC_2U_23	Residential	3	0	0	0	0	0	14	57.63
NC_2U_27	Residential	1	0	0	0	0	0	20	29.35
NC_2U_30	Undeveloped	1	0	0	0	0	2	6	19.29
NC_2U_34	Residential	4	0	0	0	1	0	43	57.26
NC_2U_36	Residential	3	0	0	0	0	0	12	65.95
NC_2U_37	Residential	6	0	1	0	0	4	16	186.73
NY_2U_02	Residential	8	0	2	0	0	0	53	166.17
NY_2U_03	Residential	2	0	0	0	0	0	18	43.56
NY_2U_04	Residential	0	0	0	0	0	0	6	10.22
NY_2U_07	Residential	2	0	0	0	0	0	2	30.32
NY_2U_10	Residential	4	0	0	0	0	0	14	117.52
NY_2U_11	Residential	10	0	2	0	0	0	40	263.49
NY_2U_12	Residential	7	0	0	0	0	0	4	84.58
NY_2U_13	Residential	2	0	5	0	0	1	22	137.01
NY_2U_14	Residential	1	0	6	0	0	1	0	24.57
NY_2U_15	Residential	1	0	2	0	0	0	5	20.24
NY_2U_16	Residential	7	0	2	0	0	0	48	84.14
NY_2U_19	Industrial/ institutional	4	0	1	0	0	0	34	61.18
NY_2U_20	Undeveloped	2	0	3	0	0	0	13	19.68
WA_2U_001	Undeveloped	0	0	2	0	0	0	8	13.50
WA_2U_002	Residential	5	0	0	0	0	0	31	98.14
WA_2U_003	Residential	9	0	2	0	0	0	28	186.05
WA_2U_007	Undeveloped	1	0	0	0	0	0	8	16.66
WA_2U_014	Residential	12	0	3	0	0	2	101	166.52
WA_2U_019	Residential	4	0	5	0	0	0	12	56.36

Site	General Area Type	Number of Side Streets	Number of Major Commercial Driveways	Number of Minor Commercial Driveways	Number of Major Industrial Driveways	Number of Minor Industrial Driveways	Number of Major Residential Driveways	Number of Minor Residential Driveways	DDS
WA_2U_020	Industrial/ institutional	2	0	0	0	0	0	0	19.21
WA_2U_021	Residential	7	0	0	0	0	0	8	65.88
WA_2U_023	Undeveloped	1	0	0	0	0	0	11	25.82

Note: No data were sorted into the “other” category.

Table 31. Area type and access characteristics of 4D sites.

Site	General Area Type	Number of Side Streets	Number of Major Commercial Driveways	Number of Minor Commercial Driveways	Number of Major Industrial Driveways	Number of Minor Industrial Driveways	Number of Major Residential Driveways	Number of Minor Residential Driveways	DDS
FL_4D_001	Residential	1	0	0	0	0	1	0	12.66
FL_4D_002a	Undeveloped	0	0	0	0	0	0	0	0.00
FL_4D_002b	Residential	2	0	0	0	0	0	0	18.79
FL_4D_004	Residential	3	0	1	0	0	0	0	47.51
FL_4D_006	Undeveloped	0	0	0	0	0	0	0	0.00
FL_4D_007	Commercial	3	0	3	0	0	0	0	37.80
FL_4D_008	Residential	2	0	0	0	0	1	0	35.60
FL_4D_010	Residential	6	0	7	0	0	3	7	112.44
FL_4D_011	Residential	7	0	7	0	0	0	0	121.41
FL_4D_013	Commercial	2	0	6	0	0	0	0	73.36
FL_4D_015	Undeveloped	3	0	2	0	0	0	4	51.18
FL_4D_016	Residential	4	0	1	0	0	1	7	49.56
FL_4D_017	Residential	7	0	0	0	0	0	13	44.64
FL_4D_020	Residential	2	1	2	0	0	0	0	36.49
FL_4D_022	Residential	10	0	4	0	0	0	7	69.29
FL_4D_025	Residential	9	0	0	0	0	0	34	196.12
FL_4D_026	Undeveloped	2	0	0	0	0	0	0	9.39
FL_4D_028	Residential	4	0	0	0	0	1	1	67.40
FL_4D_031	Residential	6	0	5	0	0	2	1	80.31
FL_4D_034	Industrial/ institutional	4	0	8	0	0	6	0	168.91
FL_4D_035	Residential	7	0	0	0	0	2	14	108.76
FL_4D_037	Commercial	5	0	0	0	0	0	0	73.06
FL_4D_038	Residential	6	0	6	0	0	1	5	167.41
FL_4D_040	Industrial/ institutional	4	0	7	0	0	0	0	52.72
FL_4D_041	Industrial/ institutional	0	0	0	0	0	0	0	0.00

Site	General Area Type	Number of Side Streets	Number of Major Commercial Driveways	Number of Minor Commercial Driveways	Number of Major Industrial Driveways	Number of Minor Industrial Driveways	Number of Major Residential Driveways	Number of Minor Residential Driveways	DDS
FL_4D_042	Commercial	1	0	20	0	0	0	0	86.55
FL_4D_045	Commercial	11	0	15	0	5	2	1	231.87
FL_4D_046	Residential	11	1	14	0	1	4	14	123.33
IN_4D_002	Industrial/ institutional	1	0	0	0	0	0	0	15.41
IN_4D_012	Commercial	1	0	0	0	0	0	0	22.32
IN_4D_013	Commercial	2	0	7	0	0	1	1	158.55
IN_4D_019	Undeveloped	2	0	0	0	0	0	0	8.92
IN_4D_021	Undeveloped	0	0	0	0	0	0	0	0.00
IN_4D_023	Commercial	0	0	1	0	0	1	2	11.50
IN_4D_024	Residential	2	0	3	0	0	2	3	24.01
NC_4D_03	Industrial/ institutional	0	1	2	0	1	0	0	39.24
NC_4D_08	Industrial/ institutional	1	0	0	0	0	1	0	14.35
NC_4D_10	Commercial	3	1	12	0	1	0	0	69.89
NC_4D_14	Residential	2	0	0	0	0	2	1	64.85
NC_4D_17	Residential	3	0	0	0	0	0	0	39.98
NC_4D_20	Industrial/ institutional	2	0	3	0	0	1	0	38.30
NC_4D_21	Commercial	2	4	1	0	0	0	0	46.28
NC_4D_26	Industrial/ institutional	4	0	0	0	0	0	4	62.11
NC_4D_31	Residential	5	0	0	0	0	0	0	57.88
NC_4D_36	Residential	1	0	0	0	0	2	27	48.51
NC_4D_37	Residential	6	0	0	0	0	0	20	68.95
NC_4D_38	Undeveloped	1	0	0	1	0	0	0	23.25
NC_4D_40	Residential	4	0	0	0	0	1	0	129.37
WA_4D_03	Residential	3	0	1	0	0	1	3	135.73
WA_4D_04	Residential	7	0	0	0	0	2	3	170.30

Site	General Area Type	Number of Side Streets	Number of Major Commercial Driveways	Number of Minor Commercial Driveways	Number of Major Industrial Driveways	Number of Minor Industrial Driveways	Number of Major Residential Driveways	Number of Minor Residential Driveways	DDS
WA_4D_05	Undeveloped	0	0	0	0	0	0	0	0.00
WA_4D_07	Residential	3	0	0	0	0	2	0	58.99
WA_4D_08	Industrial/ institutional	1	0	8	0	0	0	0	125.42

Note: No data were sorted into the "other" category.

Table 32. Nonintersection crash frequency at Florida sites by number of vehicles involved and severity level (2005–2012).

Site	MV-K	MV-A	MV-B	MV-C	MV-PDO	SV-K	SV-A	SV-B	SV-C	SV-PDO	Total
FL_2U_01	0	1	5	4	10	0	0	0	1	4	25
FL_2U_02	0	1	3	1	8	0	0	2	0	9	24
FL_2U_04	0	0	6	6	12	0	0	0	0	0	24
FL_2U_07	0	10	19	17	39	0	0	6	2	9	102
FL_2U_10	0	2	0	1	5	0	0	1	0	1	10
FL_2U_11	1	4	2	5	12	2	1	2	2	5	36
FL_2U_13	0	0	1	0	1	0	2	0	1	4	9
FL_2U_14	1	4	8	12	20	1	2	4	5	8	65
FL_2U_15	3	5	3	5	3	0	2	1	1	4	27
FL_2U_16	1	16	4	17	35	2	6	4	6	8	99
FL_2U_17	0	3	1	4	3	0	1	1	2	0	15
FL_2U_18	0	0	2	7	10	0	0	0	0	0	19
FL_2U_19	0	1	4	7	5	0	1	0	0	2	20
FL_4D_001	0	3	6	10	12	0	5	4	2	4	46
FL_4D_002a	0	0	2	0	3	0	0	3	0	6	14
FL_4D_002b	0	1	0	3	1	0	1	1	0	9	16
FL_4D_004	0	1	7	18	38	1	2	3	3	11	84
FL_4D_006	0	4	2	7	10	0	2	5	4	2	36
FL_4D_007	0	2	3	1	9	0	0	1	0	2	18
FL_4D_008	0	2	7	6	34	0	0	3	0	0	52
FL_4D_010	1	10	12	11	21	0	1	1	1	0	58
FL_4D_011	0	5	6	13	11	0	3	2	3	1	44
FL_4D_013	0	4	1	6	14	2	6	4	0	0	37
FL_4D_015	0	1	1	3	11	0	0	0	0	6	22
FL_4D_016	0	4	4	2	15	2	0	4	6	12	49
FL_4D_017	0	7	6	10	28	1	7	5	7	19	90
FL_4D_020	0	0	5	4	4	0	1	3	1	0	18
FL_4D_022	0	3	7	6	8	0	3	8	4	4	43
FL_4D_025	0	0	3	2	3	0	1	0	2	4	15
FL_4D_026	2	6	8	14	36	2	6	5	8	17	104

Site	MV-K	MV-A	MV-B	MV-C	MV-PDO	SV-K	SV-A	SV-B	SV-C	SV-PDO	Total
FL_4D_028	0	0	4	1	5	0	2	2	3	3	20
FL_4D_031	0	2	10	8	18	2	4	2	1	4	51
FL_4D_034	0	9	7	9	23	1	3	0	3	3	58
FL_4D_035	1	1	7	4	11	1	0	2	2	2	31
FL_4D_037	0	0	3	3	8	0	0	3	1	1	19
FL_4D_038	0	1	3	0	1	0	0	0	0	3	8
FL_4D_040	0	3	3	5	29	1	4	1	2	8	56
FL_4D_041	0	1	1	1	5	0	2	1	1	1	13
FL_4D_042	1	3	4	8	10	2	2	1	1	1	33
FL_4D_045	0	0	4	1	15	0	0	1	0	0	21
FL_4D_046	1	12	8	4	25	1	4	3	3	15	76

Table 33. Nonintersection crash frequency at Indiana sites by number of vehicles involved and severity level (2006–2013).

Site	MV-K	MV-A	MV-B	MV-C	MV-PDO	SV-K	SV-A	SV-B	SV-C	SV-PDO	Total
IN_2U_014	0	0	4	0	11	0	0	1	0	7	23
IN_2U_015	0	0	0	0	2	0	0	1	0	6	9
IN_2U_029	0	0	4	0	7	0	0	0	0	1	12
IN_2U_030	0	1	4	0	8	0	0	1	0	2	16
IN_2U_031	0	0	1	0	1	0	0	1	0	2	5
IN_2U_032	0	1	3	0	9	1	0	2	0	5	21
IN_2U_033	0	0	6	0	7	0	0	0	0	3	16
IN_2U_036	0	0	0	0	3	0	0	1	0	1	5
IN_2U_037	0	0	0	0	0	0	0	1	0	2	3
IN_2U_040	0	0	1	0	10	0	0	5	0	6	22
IN_4D_002	0	1	2	0	12	0	0	1	0	2	18
IN_4D_012	0	0	4	0	10	0	0	2	0	9	25
IN_4D_013	0	0	6	0	22	0	0	2	0	4	34
IN_4D_019	0	0	5	0	9	0	0	5	0	35	54
IN_4D_021	1	0	0	0	12	0	0	1	0	10	24
IN_4D_023	0	2	2	0	7	1	0	0	0	7	19
IN_4D_024	0	1	2	0	2	0	0	4	0	6	15

Table 34. Nonintersection crash frequency at New York sites by number of vehicles involved and severity level (2006–2013).

Site	MV-K	MV-A	MV-B	MV-C	MV-PDO	SV-K	SV-A	SV-B	SV-C	SV-PDO	Total
NY_2U_02	0	0	3	0	7	0	0	3	0	4	17
NY_2U_03	0	1	2	0	4	0	0	1	0	31	39
NY_2U_04	0	1	3	0	14	0	0	1	0	11	30
NY_2U_07	0	0	2	0	2	0	0	1	0	2	7
NY_2U_10	0	0	3	0	7	0	0	0	0	4	14
NY_2U_11	0	0	4	0	2	0	0	1	0	2	9
NY_2U_12	0	1	3	0	3	0	0	2	0	0	9
NY_2U_13	0	1	3	0	6	0	0	1	0	1	12
NY_2U_14	1	0	2	0	9	0	0	2	0	3	17
NY_2U_15	0	1	8	0	5	0	0	5	0	8	27
NY_2U_16	0	0	2	0	2	0	1	0	0	5	10
NY_2U_19	0	3	4	0	10	0	0	0	0	7	24
NY_2U_20	0	1	39	0	25	0	2	9	0	24	100

Table 35. Nonintersection crash frequency at North Carolina sites by number of vehicles involved and severity level (2013–2017).

Site	MV-K	MV-A	MV-B	MV-C	MV-PDO	SV-K	SV-A	SV-B	SV-C	SV-PDO	Total
NC_2U_04	0	1	3	5	10	0	0	0	1	3	23
NC_2U_05	0	0	0	1	5	0	0	1	1	2	10
NC_2U_10	0	0	0	1	4	0	0	0	0	1	6
NC_2U_11	0	0	0	4	10	1	0	0	1	4	20
NC_2U_17	0	0	0	2	8	0	0	0	2	3	15
NC_2U_23	0	0	1	4	18	0	0	0	2	5	30
NC_2U_27	0	0	1	0	2	0	0	1	0	6	10
NC_2U_30	0	0	1	6	24	0	1	0	3	15	50
NC_2U_34	0	0	2	7	19	0	0	1	4	6	39
NC_2U_36	0	0	0	5	9	0	0	0	0	4	18
NC_2U_37	0	0	0	1	6	0	0	0	0	1	8
NC_4D_03	0	0	0	1	8	0	0	0	0	5	14
NC_4D_08	1	0	0	4	14	0	0	1	1	6	27
NC_4D_10	0	1	4	4	20	0	0	0	1	12	42
NC_4D_14	0	0	1	3	7	0	0	0	0	2	13
NC_4D_17	0	0	0	4	9	0	0	0	0	3	16
NC_4D_20	1	0	6	26	117	0	0	0	4	11	165
NC_4D_21	0	0	3	7	17	0	0	2	3	8	40
NC_4D_26	0	0	1	0	3	0	0	0	0	1	5
NC_4D_31	0	0	1	5	15	0	0	0	0	2	23
NC_4D_36	0	0	0	1	9	0	0	0	0	3	13
NC_4D_37	1	0	0	1	21	0	0	0	1	3	27
NC_4D_38	0	0	6	6	40	0	0	1	3	3	59
NC_4D_40	0	0	2	4	9	0	0	0	1	2	18

Table 36. Nonintersection crash frequency at Washington sites by number of vehicles involved and severity level (2006–2013).

Site	MV-K	MV-A	MV-B	MV-C	MV-PDO	SV-K	SV-A	SV-B	SV-C	SV-PDO	Total
WA_2U_001	0	0	1	5	8	0	0	0	1	7	22
WA_2U_002	0	0	0	5	7	0	0	0	0	2	14
WA_2U_003	0	0	0	1	3	0	1	2	1	2	10
WA_2U_007	0	0	2	3	10	0	0	2	1	9	27
WA_2U_014	0	0	0	1	4	0	0	1	2	6	14
WA_2U_019	0	1	0	1	16	0	0	1	1	3	23
WA_2U_020	0	0	2	9	24	0	0	2	1	14	52
WA_2U_021	0	0	1	1	7	0	0	0	1	0	10
WA_2U_023	1	0	0	2	1	0	1	0	2	11	18
WA_4D_03	0	1	1	3	7	0	0	1	0	1	14
WA_4D_04	0	0	2	6	11	0	0	0	2	0	21
WA_4D_05	0	0	0	0	1	0	0	1	0	0	2
WA_4D_07	0	3	0	14	62	0	0	8	7	20	114
WA_4D_08	0	0	3	5	14	0	0	3	0	2	27

Table 37. AADT by year.

Site	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
FL_2U_01	15,000	15,000	15,000	15,000	15,000	15,000	15,000	15,000	15,000	15,000	15,000	15,000
FL_2U_02	15,000	15,000	15,000	15,000	15,000	15,000	15,000	15,000	15,000	15,000	15,000	15,000
FL_2U_04	15,000	15,000	15,000	15,000	15,000	15,000	15,000	15,000	15,000	15,000	15,000	15,000
FL_2U_07	19,400	19,400	19,400	19,400	19,400	19,400	19,400	19,400	19,400	19,400	19,400	19,400
FL_2U_10	13,600	13,600	13,600	13,600	13,600	18,800	18,800	18,800	18,800	18,800	18,800	18,800
FL_2U_11	17,500	17,500	17,500	17,500	17,500	17,500	17,500	17,500	17,500	17,500	17,500	17,500
FL_2U_13	13,400	13,400	13,400	13,400	13,400	14,700	14,700	14,700	14,700	14,700	14,700	14,700
FL_2U_14	20,000	20,000	20,000	20,000	20,000	20,000	21,000	22,000	22,000	22,000	22,000	22,000
FL_2U_15	25,500	25,500	25,500	25,500	25,500	23,500	27,500	26,500	26,500	26,500	26,500	26,500
FL_2U_16	18,000	18,000	18,000	18,000	18,000	18,200	17,300	17,600	17,600	17,600	17,600	17,600
FL_2U_17	15,600	15,600	15,600	15,600	15,600	15,300	15,200	14,000	14,000	14,000	14,000	14,000
FL_2U_18	5,600	5,600	5,600	5,600	5,600	5,600	5,600	5,600	5,600	5,600	5,600	5,600
FL_2U_19	5,600	5,600	5,600	5,600	5,600	5,600	5,600	5,600	5,600	5,600	5,600	5,600
FL_4D_001	18,800	18,800	18,800	18,800	18,800	18,800	18,800	18,800	18,800	18,800	18,800	18,800
FL_4D_002a	16,100	16,100	16,100	16,100	16,100	16,100	16,100	16,100	16,100	16,100	16,100	16,100
FL_4D_002b	16,200	16,200	16,200	16,200	16,200	16,200	16,800	17,200	17,200	17,200	17,200	17,200
FL_4D_004	51,000	51,000	51,000	51,000	51,000	51,000	51,000	51,000	51,000	51,000	51,000	51,000
FL_4D_006	33,000	33,000	33,000	33,000	33,000	33,000	34,000	35,000	35,000	35,000	35,000	35,000
FL_4D_007	17,300	17,300	17,300	17,300	17,300	17,300	17,300	22,500	22,500	22,500	22,500	22,500
FL_4D_008	18,800	18,800	18,800	18,800	18,800	18,800	18,800	18,800	18,800	18,800	18,800	18,800
FL_4D_010	27,500	27,500	27,500	27,500	27,500	27,500	27,500	27,500	27,500	27,500	27,500	27,500
FL_4D_011	22,500	22,500	22,500	22,500	22,500	22,500	22,500	22,500	22,500	22,500	22,500	22,500
FL_4D_013	42,500	42,500	42,500	42,500	42,500	42,500	42,500	42,500	42,500	42,500	42,500	42,500
FL_4D_015	34,000	34,000	34,000	34,000	34,000	34,500	37,000	37,000	37,000	37,000	37,000	37,000
FL_4D_016	45,000	45,000	45,000	45,000	45,000	48,000	47,000	47,000	47,000	47,000	47,000	47,000
FL_4D_017	29,000	29,000	29,000	29,000	29,000	28,000	27,500	28,500	28,500	28,500	28,500	28,500
FL_4D_020	26,500	26,500	26,500	26,500	26,500	26,500	26,500	26,500	26,500	26,500	26,500	26,500
FL_4D_022	22,500	22,500	22,500	22,500	22,500	22,000	23,000	22,000	22,000	22,000	22,000	22,000
FL_4D_025	28,500	28,500	28,500	28,500	28,500	29,000	29,000	30,500	30,500	30,500	30,500	30,500
FL_4D_026	24,500	24,500	24,500	24,500	24,500	25,000	25,000	25,000	25,000	25,000	25,000	25,000

Site	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
FL_4D_028	21,500	21,500	21,500	21,500	21,500	21,500	21,500	21,500	21,500	21,500	21,500	21,500
FL_4D_031	9,300	9,300	9,300	9,300	9,300	9,300	9,300	9,300	9,300	9,300	9,300	9,300
FL_4D_034	26,500	26,500	26,500	26,500	26,500	27,000	24,000	25,000	25,000	25,000	25,000	25,000
FL_4D_035	19,400	19,400	19,400	19,400	19,400	19,400	19,400	19,400	19,400	19,400	19,400	19,400
FL_4D_037	24,500	24,500	24,500	24,500	24,500	24,500	24,500	24,500	24,500	24,500	24,500	24,500
FL_4D_038	24,500	24,500	24,500	24,500	24,500	24,500	24,500	23,500	23,500	23,500	23,500	23,500
FL_4D_040	35,500	35,500	35,500	35,500	35,500	34,500	37,500	37,000	37,000	37,000	37,000	37,000
FL_4D_041	31,500	31,500	31,500	31,500	31,500	31,000	33,500	34,000	34,000	34,000	34,000	34,000
FL_4D_042	32,975	32,975	32,975	32,975	32,975	32,728	31,506	30,929	30,929	30,929	30,929	30,929
FL_4D_045	16,300	16,30	16,30	16,30	16,30	19,700	20,500	23,500	23,500	23,500	23,500	23,500
FL_4D_046	21,000	21,000	21,000	21,000	21,000	21,000	21,500	22,500	22,500	22,500	22,500	22,500
IN_2U_014	6,848	6,848	6,848	6,848	6,848	6,848	6,475	6,475	6,475	6,475	6,475	6,475
IN_2U_015	6,848	6,848	6,848	6,848	6,848	6,848	6,475	6,475	6,475	6,475	6,475	6,475
IN_2U_029	6,766	6,766	6,766	6,766	6,766	10,379	11,614	11,614	11,614	11,614	11,614	11,614
IN_2U_030	10,473	10,473	10,473	10,473	10,473	10,473	11,650	11,650	11,650	11,650	11,650	11,650
IN_2U_031	7,147	7,147	7,147	7,147	7,147	10,473	11,650	11,650	11,650	11,650	11,650	11,650
IN_2U_032	6,848	6,848	6,848	6,848	6,848	6,848	6,475	6,475	6,475	6,475	6,475	6,475
IN_2U_033	6,848	6,848	6,848	6,848	6,848	6,848	6,475	6,475	6,475	6,475	6,475	6,475
IN_2U_036	6,848	6,848	6,848	6,848	6,848	6,848	6,475	6,475	6,475	6,475	6,475	6,475
IN_2U_037	4,520	4,520	4,520	4,520	4,520	4,601	4,596	4,596	4,596	4,596	4,596	4,596
IN_2U_040	8,506	8,506	8,506	8,506	8,506	8,659	8,650	8,650	8,650	8,650	8,650	8,650
IN_4D_002	34,841	34,841	34,841	34,841	34,841	34,333	35,346	35,346	35,346	35,346	35,346	35,346
IN_4D_012	26,573	26,573	26,573	26,573	26,573	27,052	27,024	27,024	27,024	27,024	27,024	27,024
IN_4D_013	23,515	23,515	23,515	23,515	23,515	23,938	23,914	23,914	23,914	23,914	23,914	23,914
IN_4D_019	19,345	19,345	19,345	19,345	19,345	19,693	19,673	19,673	19,673	19,673	19,673	19,673
IN_4D_021	17,752	17,752	17,752	17,752	17,752	19,262	19,435	19,435	19,435	19,435	19,435	19,435
IN_4D_023	22,979	22,979	22,979	22,979	22,979	18,745	18,914	18,914	18,914	18,914	18,914	18,914
IN_4D_024	9,776	9,776	9,776	9,776	9,776	15,596	15,705	15,705	15,705	15,705	15,705	15,705
NY_2U_02	8,355	8,355	8,355	8,355	8,355	8,844	8,625	8,625	8,625	8,625	8,625	8,625
NY_2U_03	7,660	7,660	7,660	7,660	7,660	7,409	7,239	7,239	7,239	7,239	7,239	7,239
NY_2U_04	7,660	7,660	7,660	7,660	7,660	7,409	7,239	7,239	7,239	7,239	7,239	7,239

Site	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
NY_2U_07	6,141	6,141	6,141	6,141	6,141	5,904	5,853	5,853	5,853	5,853	5,853	5,853
NY_2U_10	16,068	16,068	16,068	16,068	16,068	16,052	15,951	15,951	15,951	15,951	15,951	15,951
NY_2U_11	10,421	10,421	10,421	10,421	10,421	10,334	7,807	7,807	7,807	7,807	7,807	7,807
NY_2U_12	10,762	10,762	10,762	10,762	10,762	7,855	7,955	7,955	7,955	7,955	7,955	7,955
NY_2U_13	7,817	7,817	7,817	7,817	7,817	6,749	6,749	6,749	6,749	6,749	6,749	6,749
NY_2U_14	10,188	10,188	10,188	10,188	10,188	11,481	11,006	11,006	11,006	11,006	11,006	11,006
NY_2U_15	12,710	12,710	12,710	12,710	12,710	11,573	11,200	11,200	11,200	11,200	11,200	11,200
NY_2U_16	9,911	9,911	9,911	9,911	9,911	9,843	9,231	9,231	9,231	9,231	9,231	9,231
NY_2U_19	9,533	9,533	9,533	9,533	9,533	9,468	9,275	9,275	9,275	9,275	9,275	9,275
NY_2U_20	15,222	15,222	15,222	15,222	15,222	16,285	16,488	16,488	16,488	16,488	16,488	16,488
NC_2U_04	17,000	17,000	17,000	17,000	17,000	16,000	16,000	16,000	16,000	16,000	16,000	16,000
NC_2U_05	16,000	16,000	16,000	16,000	16,000	19,000	18,000	19,000	19,000	19,000	19,000	19,000
NC_2U_10	9,700	9,700	9,700	9,700	9,700	9,500	9,500	9,700	9,700	9,700	9,700	9,700
NC_2U_11	22,000	22,000	22,000	22,000	22,000	23,000	23,000	24,000	24,000	24,000	24,000	24,000
NC_2U_17	14,000	14,000	14,000	14,000	14,000	14,000	14,000	18,000	18,000	18,000	18,000	18,000
NC_2U_23	14,000	14,000	14,000	14,000	14,000	15,000	15,000	13,000	13,000	13,000	13,000	13,000
NC_2U_27	8,800	8,800	8,800	8,800	8,800	11,000	12,000	12,000	12,000	12,000	12,000	12,000
NC_2U_30	12,000	12,000	12,000	12,000	12,000	13,000	13,000	13,000	13,000	13,000	13,000	13,000
NC_2U_34	20,000	20,000	20,000	20,000	20,000	21,000	21,000	21,000	21,000	21,000	21,000	21,000
NC_2U_36	12,000	12,000	12,000	12,000	12,000	13,000	13,000	16,000	16,000	16,000	16,000	16,000
NC_2U_37	12,000	12,000	12,000	12,000	12,000	12,000	12,000	13,000	13,000	13,000	13,000	13,000
NC_4D_03	29,000	29,000	29,000	29,000	29,000	31,000	31,000	26,000	26,000	26,000	26,000	26,000
NC_4D_08	23,000	23,000	23,000	23,000	23,000	23,000	23,000	22,000	22,000	22,000	22,000	22,000
NC_4D_10	31,000	31,000	31,000	31,000	31,000	31,000	31,000	37,000	37,000	37,000	37,000	37,000
NC_4D_14	27,000	27,000	27,000	27,000	27,000	29,000	29,000	28,000	28,000	28,000	28,000	28,000
NC_4D_17	24,000	24,000	24,000	24,000	24,000	24,000	24,000	23,000	23,000	23,000	23,000	23,000
NC_4D_20	52,000	52,000	52,000	52,000	52,000	55,000	55,000	56,000	56,000	56,000	56,000	56,000
NC_4D_21	46,000	46,000	46,000	46,000	46,000	47,000	47,000	46,000	46,000	46,000	46,000	46,000
NC_4D_26	23,000	23,000	23,000	23,000	23,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000
NC_4D_31	22,000	22,000	22,000	22,000	22,000	22,000	22,000	25,000	25,000	25,000	25,000	25,000
NC_4D_36	22,000	22,000	22,000	22,000	22,000	22,000	22,000	25,000	25,000	25,000	25,000	25,000

Site	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
NC_4D_37	17,000	17,000	17,000	17,000	17,000	19,000	19,000	19,000	19,000	19,000	19,000	19,000
NC_4D_38	21,000	21,000	21,000	21,000	21,000	24,000	24,000	25,000	25,000	25,000	25,000	25,000
NC_4D_40	16,000	16,000	16,000	16,000	16,000	17,000	17,000	18,000	18,000	18,000	18,000	18,000
WA_2U_001	12,000	12,000	12,000	12,000	12,000	12,000	12,000	12,000	12,000	12,000	12,000	12,000
WA_2U_002	10,187	10,187	10,187	10,187	10,187	10,187	10,187	10,187	10,187	10,187	10,187	10,187
WA_2U_003	10,760	10,760	10,760	10,760	10,760	10,760	10,760	10,760	10,760	10,760	10,760	10,760
WA_2U_007	12,000	12,000	12,000	12,000	12,000	12,000	12,000	11,000	11,000	11,000	11,000	11,000
WA_2U_014	9,000	9,000	9,000	9,000	9,000	9,000	9,000	9,000	9,000	9,000	9,000	9,000
WA_2U_019	16,899	16,899	16,899	16,899	16,899	16,899	16,899	16,899	16,899	16,899	16,899	16,899
WA_2U_020	16,000	16,000	16,000	16,000	16,000	16,000	16,000	16,000	16,000	16,000	16,000	16,000
WA_2U_021	10,955	10,955	10,955	10,955	10,955	10,955	10,740	10,525	10,525	10,525	10,525	10,525
WA_2U_023	13,000	13,000	13,000	13,000	13,000	13,000	13,000	13,000	13,000	13,000	13,000	13,000
WA_4D_03	37,020	37,020	37,020	37,020	37,020	37,020	37,020	37,020	37,020	37,020	37,020	37,020
WA_4D_04	31,374	31,374	31,374	31,374	31,374	31,374	31,374	31,374	31,374	31,374	31,374	31,374
WA_4D_05	21,657	21,657	21,657	21,657	21,657	21,657	21,657	21,657	21,657	21,657	21,657	21,657
WA_4D_07	27,000	27,000	27,000	27,000	27,000	27,000	26,000	26,000	26,000	26,000	26,000	26,000
WA_4D_08	34,000	34,000	34,000	34,000	34,000	34,000	35,000	35,000	35,000	35,000	35,000	35,000

APPENDIX B. STATISTICAL MODEL RESULTS

Appendix B presents the statistical model results in table 38 through table 51.

Table 38. Type III test results of significant MV KABC crash frequency versus speed-measure models.

Effect	Site Type	Num DF	Den DF	*F*-Value	*Pr* > *F*	Significant at 5% Level?
lnAADT	2U	1	357	7.57	0.006	Yes
SD of SMS	2U	1	357	5.68	0.018	Yes
lnAADT	2U	1	358	5.78	0.017	Yes
85-SL	2U	1	358	4.02	0.046	Yes
lnAADT	4D	1	330	13.14	<0.001	Yes
SMS	4D	1	330	9.18	0.003	Yes
lnAADT	4D	1	331	4.71	0.031	Yes
SD of SMS	4D	1	331	6.83	0.009	Yes
lnAADT	4D	1	331	12.69	<0.001	Yes
FFS	4D	1	331	7.81	0.005	Yes

Num DF = numerator degrees of freedom; Den DF = denominator degrees of freedom.

Table 39. Type III test results of significant total KABC crash frequency versus speed-measure models.

Effect	Site Type	Num DF	Den DF	*F*-Value	*Pr* > *F*	Significant at 5% Level?
lnAADT	2U	1	357	12.53	<0.001	Yes
SD of SMS	2U	1	357	4.32	0.038	Yes
lnAADT	2U	1	358	10.38	0.001	Yes
85-SL	2U	1	358	3.78	0.053	Yes
lnAADT	4D	1	330	13.81	<0.001	Yes
SMS	4D	1	330	5.37	0.021	Yes
lnAADT	4D	1	331	6.49	0.011	Yes
SD of SMS	4D	1	331	4.11	0.043	Yes
lnAADT	4D	1	331	13.47	<0.001	Yes
FFS	4D	1	331	4.44	0.036	Yes

Num DF = numerator degrees of freedom; Den DF = denominator degrees of freedom.

Table 40. Type III test results of significant 85th percentile SMS minus PSL versus site-characteristics models.

Effect	Site Type	Num DF	Den DF	*F*-Value	*Pr* > *F*	Significant at 5% Level?
lnAADT	2U	1	358	0.00	1.000	No
Horizontal alignment	2U	1	358	0.56	0.454	No
Lane width	2U	2	358	9.68	<0.001	Yes
Bike lane	2U	1	358	0.83	0.363	No
Lighting	2U	1	358	2.36	0.126	No
Fixed objects	2U	2	358	3.46	0.033	Yes
Driveway density	2U	2	358	0.83	0.438	No
Area type	2U	3	358	23.89	<0.001	Yes
lnAADT	4D	1	331	0.00	1.000	No
Horizontal alignment	4D	1	331	27.57	<0.001	Yes
Lane width	4D	2	331	18.48	<0.001	Yes
Bike lane	4D	1	331	4.57	0.033	Yes
Lighting	4D	1	331	0.08	0.776	No
Fixed objects	4D	2	331	15.13	<0.001	Yes
Driveway density	4D	2	331	7.51	<0.001	Yes
Area type	4D	3	331	16.38	<0.001	Yes
Median width	4D	1	331	26.58	<0.001	Yes

Num DF = numerator degrees of freedom; Den DF = denominator degrees of freedom.

Table 41. Type III test results of significant mean FFS versus site-characteristics models.

Effect	Site Type	Num DF	Den DF	*F*-Value	*Pr* > *F*	Significant at 5% Level?
lnAADT	2U	1	358	0.00	1.000	No
Horizontal alignment	2U	1	358	1.88	0.171	No
Lane width	2U	2	358	35.05	<0.001	Yes
Bike lane	2U	1	358	0.10	0.757	No
Lighting	2U	1	358	1.39	0.239	No
Fixed objects	2U	2	358	17.05	<0.001	Yes
Driveway density	2U	2	358	29.09	<0.001	Yes
Area type	2U	3	358	27.70	<0.001	Yes
lnAADT	4D	1	331	0.00	1.000	No
Horizontal alignment	4D	1	331	10.31	0.001	Yes
Lane width	4D	2	331	61.65	<0.001	Yes
Bike lane	4D	1	331	0.43	0.510	No
Lighting	4D	1	331	151.18	<0.001	Yes
Fixed objects	4D	2	331	64.84	<0.001	Yes
Driveway density	4D	2	331	55.49	<0.001	Yes
Area type	4D	3	331	16.80	<0.001	Yes
Median width	4D	1	331	23.75	<0.001	Yes

Num DF = numerator degrees of freedom; Den DF = denominator degrees of freedom.

Table 42. Type III test results of significant mean of difference between trip maximum and minimum speed versus site-characteristics models.

Effect	Site Type	Num DF	Den DF	*F*-Value	*Pr* > *F*	Significant at 5% Level?
lnAADT	2U	1	358	0.00	1.000	No
Horizontal alignment	2U	1	358	6.29	0.013	Yes
Lane width	2U	2	358	22.24	<0.001	Yes
Bike lane	2U	1	358	0.01	0.930	No
Lighting	2U	1	358	0.92	0.338	No
Fixed objects	2U	2	358	30.89	<0.001	Yes
Driveway density	2U	2	358	7.92	<0.001	Yes
Area type	2U	3	358	11.24	<0.001	Yes
lnAADT	4D	1	331	0.00	1.000	No
Horizontal alignment	4D	1	331	12.83	<0.001	Yes
Lane width	4D	2	331	9.17	<0.001	Yes
Bike lane	4D	1	331	0.05	0.828	No
Lighting	4D	1	331	9.44	0.002	Yes
Fixed objects	4D	2	331	10.76	<0.001	Yes
Driveway density	4D	2	331	0.53	0.587	No
Area type	4D	3	331	0.47	0.706	No
Median width	4D	1	331	0.00	0.962	No

Num DF = numerator degrees of freedom; Den DF = denominator degrees of freedom.

Table 43. Type III test results of significant mean SMS versus site-characteristics models.

Effect	Site Type	Num DF	Den DF	*F*-Value	*Pr* > *F*	Significant at 5% Level?
lnAADT	2U	1	358	0.00	1.000	No
Horizontal alignment	2U	1	358	0.19	0.666	No
Lane width	2U	2	358	39.05	<0.001	Yes
Bike lane	2U	1	358	0.02	0.883	No
Lighting	2U	1	358	2.74	0.099	No
Fixed objects	2U	2	358	10.08	<0.001	Yes
Driveway density	2U	2	358	27.87	<0.001	Yes
Area type	2U	3	358	31.26	<0.001	Yes
lnAADT	4D	1	331	0.00	1.000	No
Horizontal alignment	4D	1	331	12.48	<0.001	Yes
Lane width	4D	2	331	76.39	<0.001	Yes
Bike lane	4D	1	331	0.05	0.824	No
Lighting	4D	1	331	178.70	<0.001	Yes
Fixed objects	4D	2	331	57.65	<0.001	Yes
Driveway density	4D	2	331	60.21	<0.001	Yes
Area type	4D	3	331	20.07	<0.001	Yes
Median width	4D	1	331	27.76	<0.001	Yes

Num DF = numerator degrees of freedom; Den DF = denominator degrees of freedom.

Table 44. Type III test results of significant SD of SMS versus site-characteristics models.

Effect	Site Type	Num DF	Den DF	*F*-Value	*Pr* > *F*	Significant at 5% Level?
lnAADT	2U	1	358	0.00	1.000	No
Horizontal alignment	2U	1	358	0.00	0.965	No
Lane width	2U	2	358	10.70	<0.001	Yes
Bike lane	2U	1	358	1.27	0.260	No
Lighting	2U	1	358	8.41	0.004	Yes
Fixed objects	2U	2	358	11.07	<0.001	Yes
Driveway density	2U	2	358	13.71	<0.001	Yes
Area type	2U	3	358	13.61	<0.001	Yes
lnAADT	4D	1	331	0.00	0.999	No
Horizontal alignment	4D	1	331	22.48	<0.001	Yes
Lane width	4D	2	331	12.26	<0.001	Yes
Bike lane	4D	1	331	5.71	0.017	Yes
Lighting	4D	1	331	17.94	<0.001	Yes
Fixed objects	4D	2	331	12.75	<0.001	Yes
Driveway density	4D	2	331	24.56	<0.001	Yes
Area type	4D	3	331	67.85	<0.001	Yes
Median width	4D	1	331	14.08	<0.001	Yes

Num DF = numerator degrees of freedom; Den DF = denominator degrees of freedom.

Table 45. Full-model estimates of significant MV KABC crash frequency versus speed-measure models.

Effect	Site Type	Estimate	SE	DF	*t*-Value	*Pr* > |*t*|	Significant at 5% Level?
Intercept	2U	−9.39	2.96	4	−3.17	0.034	Yes
lnAADT	2U	0.83	0.30	357	2.75	0.006	Yes
SD of SMS	2U	0.31	0.13	357	2.38	0.018	Yes
Intercept	2U	−6.67	2.80	4	−2.38	0.076	No
lnAADT	2U	0.71	0.30	358	2.40	0.017	Yes
85-SL	2U	−0.06	0.03	358	−2.01	0.046	Yes
Intercept	4D	−7.86	2.90	3	−2.71	0.073	No
lnAADT	4D	1.02	0.28	330	3.63	<0.001	Yes
SMS	4D	−0.05	0.02	330	−3.03	0.003	Yes
Intercept	4D	−7.89	2.94	3	−2.68	0.075	No
lnAADT	4D	0.66	0.30	331	2.17	0.031	Yes
SD of SMS	4D	0.27	0.10	331	2.61	0.009	Yes
Intercept	4D	−7.81	2.94	3	−2.66	0.077	No
lnAADT	4D	1.02	0.29	331	3.56	<0.001	Yes
FFS	4D	−0.04	0.02	331	−2.80	0.005	Yes

SE = standard error; DF = degrees of freedom.

Table 46. Full-model estimates of significant total KABC crash frequency versus speed-measure models.

Effect	Site Type	Estimate	SE	DF	*t*-Value	*Pr* > |*t*|	Significant at 5% Level?
Intercept	2U	−9.05	2.43	4	−3.73	0.020	Yes
lnAADT	2U	0.87	0.25	357	3.54	<0.001	Yes
SD of SMS	2U	0.21	0.10	357	2.08	0.038	Yes
Intercept	2U	−7.02	2.30	4	−3.05	0.038	Yes
lnAADT	2U	0.78	0.24	358	3.22	0.001	Yes
85-SL	2U	−0.04	0.02	358	−1.94	0.053	Yes
Intercept	4D	−7.95	2.79	3	−2.85	0.065	No
lnAADT	4D	1.00	0.27	330	3.72	<0.001	Yes
SMS	4D	−0.04	0.02	330	−2.32	0.021	Yes
Intercept	4D	−7.99	2.80	3	−2.86	0.065	No
lnAADT	4D	0.74	0.29	331	2.55	0.011	Yes
SD of SMS	4D	0.20	0.10	331	2.03	0.043	Yes
Intercept	4D	−7.94	2.82	3	−2.81	0.067	No
lnAADT	4D	1.00	0.27	331	3.67	<0.001	Yes
FFS	4D	−0.03	0.02	331	−2.11	0.036	Yes

SE = standard error; DF = degrees of freedom.

Table 47. Full-model estimates of significant 85th percentile SMS minus PSL versus site-characteristics models.

Effect	Site Type	HA	Lane Width	Bike Lane	Lighting	Fixed Objects	DD	Area Type	Estimate	SE	DF	*t*-Value	*Pr* > |*t*|	Signif. at 5% Level?
Intercept	2U	—	—	—	—	—	—	—	1.21	1.58	4	0.77	0.485	No
lnAADT	2U	—	—	—	—	—	—	—	0.00	0.00	358	0.00	1.000	No
HA	2U	GC	—	—	—	—	—	—	0.33	0.44	358	0.75	0.454	No
HA	2U	T	—	—	—	—	—	—	0.00	—	—	—	—	Yes
Lane width	2U	—	1	—	—	—	—	—	2.08	0.90	358	2.31	0.022	Yes
Lane width	2U	—	2	—	—	—	—	—	1.98	0.48	358	4.15	<0.001	Yes
Lane width	2U	—	3	—	—	—	—	—	0.00	—	—	—	—	Yes
Bike lane	2U	—	—	0	—	—	—	—	1.53	1.68	358	0.91	0.363	No
Bike lane	2U	—	—	1	—	—	—	—	0.00	—	—	—	—	Yes
Lighting	2U	—	—	—	0	—	—	—	−0.93	0.61	358	−1.53	0.126	No
Lighting	2U	—	—	—	1	—	—	—	0.00	—	—	—	—	Yes
Fixed objects	2U	—	—	—	—	1	—	—	1.39	0.59	358	2.34	0.020	Yes
Fixed objects	2U	—	—	—	—	2	—	—	1.28	0.53	358	2.40	0.017	Yes
Fixed objects	2U	—	—	—	—	3	—	—	0.00	—	—	—	—	Yes
DD	2U	—	—	—	—	—	1	—	0.53	0.61	358	0.87	0.385	No
DD	2U	—	—	—	—	—	2	—	0.70	0.55	358	1.28	0.200	No
DD	2U	—	—	—	—	—	3	—	0.00	—	—	—	—	Yes
Area type	2U	—	—	—	—	—	—	Comm.	−1.21	1.53	358	−0.79	0.431	No
Area type	2U	—	—	—	—	—	—	I/I	−4.73	0.78	358	−6.07	<0.001	Yes
Area type	2U	—	—	—	—	—	—	Res.	0.59	0.53	358	1.10	0.272	No
Area type	2U	—	—	—	—	—	—	Undev.	0.00	—	—	—	—	Yes
Intercept	4D	—	—	—	—	—	—	—	5.28	0.63	3	8.39	0.004	Yes
lnAADT	4D	—	—	—	—	—	—	—	−0.00	0.00	331	−0.00	1.000	No
HA	4D	GC	—	—	—	—	—	—	1.13	0.22	331	5.25	<0.001	Yes
HA	4D	T	—	—	—	—	—	—	0.00	—	—	—	—	Yes

Effect	Site Type	HA	Lane Width	Bike Lane	Lighting	Fixed Objects	DD	Area Type	Estimate	SE	DF	*t*-Value	*Pr* > |*t*|	Signif. at 5% Level?
Lane width	4D	—	1	—	—	—	—	—	2.64	0.54	331	4.90	<0.001	Yes
Lane width	4D	—	2	—	—	—	—	—	1.88	0.32	331	5.83	<0.001	Yes
Lane width	4D	—	3	—	—	—	—	—	0.00	—	—	—	—	Yes
Bike lane	4D	—	—	0	—	—	—	—	0.58	0.27	331	2.14	0.033	Yes
Bike lane	4D	—	—	1	—	—	—	—	0.00	—	—	—	—	Yes
Lighting	4D	—	—	—	0	—	—	—	0.07	0.23	331	0.28	0.776	No
Lighting	4D	—	—	—	1	—	—	—	0.00	—	—	—	—	Yes
Fixed objects	4D	—	—	—	—	1	—	—	1.08	0.25	331	4.35	<0.001	Yes
Fixed objects	4D	—	—	—	—	2	—	—	1.62	0.31	331	5.28	<0.001	Yes
Fixed objects	4D	—	—	—	—	3	—	—	0.00	—	—	—	—	Yes
DD	4D	—	—	—	—	—	1	—	1.16	0.36	331	3.23	0.001	Yes
DD	4D	—	—	—	—	—	2	—	0.10	0.29	331	0.35	0.727	No
DD	4D	—	—	—	—	—	3	—	0.00	—	—	—	—	Yes
Area type	4D	—	—	—	—	—	—	Comm.	−2.74	0.43	331	−6.30	<0.001	Yes
Area type	4D	—	—	—	—	—	—	I/I	−2.60	0.40	331	−6.48	<0.001	Yes
Area type	4D	—	—	—	—	—	—	Res.	−2.37	0.40	331	−5.96	<0.001	Yes
Area type	4D	—	—	—	—	—	—	Undev.	0.00	—	—	—	—	Yes
Median width	4D	—	—	—	—	—	—	—	−0.03	0.00	331	−5.16	<0.001	Yes

—Not applicable.
HA = horizontal alignment; DD = driveway density; SE = standard error; DF = degrees of freedom; Signif. = significant; Comm. = commercial; I/I = industrial/institutional; Res. = residential; Undev. = undeveloped.

Table 48. Full-model estimates of significant mean FFS versus site-characteristics models.

Effect	Site Type	HA	Lane Width	Bike Lane	Lighting	Fixed Objects	DD	Area Type	Estimate	SE	DF	*t*-Value	*Pr* > |*t*|	Signif. at 5% Level?
Intercept	2U	—	—	—	—	—	—	—	51.28	1.98	4	25.95	<0.001	Yes
lnAADT	2U	—	—	—	—	—	—	—	0.00	0.00	358	0.00	1.000	No
HA	2U	GC	—	—	—	—	—	—	0.75	0.55	358	1.37	0.171	No
HA	2U	T	—	—	—	—	—	—	0.00	—	—	—	—	Yes
Lane width	2U	—	1	—	—	—	—	—	−4.21	1.12	358	−3.75	<0.001	Yes
Lane width	2U	—	2	—	—	—	—	—	3.96	0.60	358	6.56	<0.001	Yes
Lane width	2U	—	3	—	—	—	—	—	0.00	—	—	—	—	Yes
Bike lane	2U	—	—	0	—	—	—	—	−0.65	2.10	358	−0.31	0.757	No
Bike lane	2U	—	—	1	—	—	—	—	0.00	—	—	—	—	Yes
Lighting	2U	—	—	—	0	—	—	—	−0.89	0.75	358	−1.18	0.239	No
Lighting	2U	—	—	—	1	—	—	—	0.00	—	—	—	—	Yes
Fixed objects	2U	—	—	—	—	1	—	—	2.60	0.74	358	3.49	<0.001	Yes
Fixed objects	2U	—	—	—	—	2	—	—	−0.96	0.66	358	−1.45	0.149	No
Fixed objects	2U	—	—	—	—	3	—	—	0.00	—	—	—	—	Yes
DD	2U	—	—	—	—	—	1	—	−4.49	0.76	358	−5.93	<0.001	Yes
DD	2U	—	—	—	—	—	2	—	−0.56	0.68	358	−0.82	0.411	No
DD	2U	—	—	—	—	—	3	—	0.00	—	—	—	—	Yes
Area type	2U	—	—	—	—	—	—	Comm.	−10.09	1.91	358	−5.29	<0.001	Yes
Area type	2U	—	—	—	—	—	—	I/I	−7.58	0.97	358	−7.81	<0.001	Yes
Area type	2U	—	—	—	—	—	—	Res.	−5.12	0.66	358	−7.71	<0.001	Yes
Area type	2U	—	—	—	—	—	—	Undev.	0.00	—	—	—	—	Yes
Intercept	4D	—	—	—	—	—	—	—	45.25	1.28	3	35.46	<0.001	Yes
lnAADT	4D	—	—	—	—	—	—	—	0.00	0.00	331	0.00	1.000	No
HA	4D	GC	—	—	—	—	—	—	−1.33	0.41	331	−3.21	0.001	Yes
HA	4D	T	—	—	—	—	—	—	0.00	—	—	—	—	Yes

Effect	Site Type	HA	Lane Width	Bike Lane	Lighting	Fixed Objects	DD	Area Type	Estimate	SE	DF	*t*-Value	*Pr* > |*t*|	Signif. at 5% Level?
Lane width	4D	—	1	—	—	—	—	—	6.27	1.11	331	5.65	<0.001	Yes
Lane width	4D	—	2	—	—	—	—	—	7.13	0.65	331	10.95	<0.001	Yes
Lane width	4D	—	3	—	—	—	—	—	0.00	—	—	—	—	Yes
Bike lane	4D	—	—	0	—	—	—	—	0.35	0.53	331	0.66	0.510	No
Bike lane	4D	—	—	1	—	—	—	—	0.00	—	—	—	—	Yes
Lighting	4D	—	—	—	0	—	—	—	5.50	0.45	331	12.30	<0.001	Yes
Lighting	4D	—	—	—	1	—	—	—	0.00	—	—	—	—	Yes
Fixed objects	4D	—	—	—	—	1	—	—	5.65	0.50	331	11.27	<0.001	Yes
Fixed objects	4D	—	—	—	—	2	—	—	3.23	0.59	331	5.45	<0.001	Yes
Fixed objects	4D	—	—	—	—	3	—	—	0.00	—	—	—	—	Yes
DD	4D	—	—	—	—	—	1	—	−6.70	0.70	331	−9.56	<0.001	Yes
DD	4D	—	—	—	—	—	2	—	−1.66	0.57	331	−2.89	0.004	Yes
DD	4D	—	—	—	—	—	3	—	0.00	—	—	—	—	Yes
Area type	4D	—	—	—	—	—	—	Comm.	−3.16	0.83	331	−3.83	<0.001	Yes
Area type	4D	—	—	—	—	—	—	I/I	−0.62	0.76	331	−0.81	0.417	No
Area type	4D	—	—	—	—	—	—	Res.	0.90	0.76	331	1.19	0.237	No
Area type	4D	—	—	—	—	—	—	Undev.	0.00	—	—	—	—	Yes
Median width	4D	—	—	—	—	—	—	—	−0.05	0.01	331	−4.87	<0.001	Yes

—Not applicable.
HA = horizontal alignment; DD = driveway density; SE = standard error; DF = degrees of freedom; Signif. = significant; Comm. = commercial; I/I = industrial/institutional; Res. = residential; Undev. = undeveloped.

Table 49. Full-model estimates of significant mean of difference between trip maximum and minimum speed versus site-characteristics models.

Effect	Site Type	HA	Lane Width	Bike Lane	Lighting	Fixed Objects	DD	Area Type	Estimate	SE	DF	*t*-Value	*Pr* > |*t*|	Signif. at 5% Level?
Intercept	2U	—	—	—	—	—	—	—	13.52	0.92	4	14.75	<0.001	Yes
lnAADT	2U	—	—	—	—	—	—	—	0.00	0.00	358	0.00	1.000	No
HA	2U	GC	—	—	—	—	—	—	0.64	0.25	358	2.51	0.013	Yes
HA	2U	T	—	—	—	—	—	—	0.00	—	—	—	—	Yes
Lane width	2U	—	1	—	—	—	—	—	−1.28	0.52	358	−2.46	0.015	Yes
Lane width	2U	—	2	—	—	—	—	—	−1.77	0.27	358	−6.59	<0.001	Yes
Lane width	2U	—	3	—	—	—	—	—	0.00	—	—	—	—	Yes
Bike lane	2U	—	—	0	—	—	—	—	−0.09	0.98	358	−0.09	0.930	No
Bike lane	2U	—	—	1	—	—	—	—	0.00	—	—	—	—	Yes
Lighting	2U	—	—	—	0	—	—	—	0.34	0.36	358	0.96	0.338	No
Lighting	2U	—	—	—	1	—	—	—	0.00	—	—	—	—	Yes
Fixed objects	2U	—	—	—	—	1	—	—	1.47	0.34	358	4.31	<0.001	Yes
Fixed objects	2U	—	—	—	—	2	—	—	−0.75	0.31	358	−2.44	0.015	Yes
Fixed objects	2U	—	—	—	—	3	—	—	0.00	—	—	—	—	Yes
DD	2U	—	—	—	—	—	1	—	−1.35	0.35	358	−3.82	<0.001	Yes
DD	2U	—	—	—	—	—	2	—	−0.61	0.32	358	−1.91	0.058	No
DD	2U	—	—	—	—	—	3	—	0.00	—	—	—	—	Yes
Area type	2U	—	—	—	—	—	—	Comm.	3.48	0.89	358	3.89	<0.001	Yes
Area type	2U	—	—	—	—	—	—	I/I	1.74	0.45	358	3.85	<0.001	Yes
Area type	2U	—	—	—	—	—	—	Res.	1.66	0.31	358	5.35	<0.001	Yes
Area type	2U	—	—	—	—	—	—	Undev.	0.00	—	—	—	—	Yes
Intercept	4D	—	—	—	—	—	—	—	14.35	1.01	3	14.16	<0.001	Yes
lnAADT	4D	—	—	—	—	—	—	—	0.00	0.00	331	0.00	1.000	No
HA	4D	GC	—	—	—	—	—	—	1.23	0.34	331	3.58	<0.001	Yes

Effect	Site Type	HA	Lane Width	Bike Lane	Lighting	Fixed Objects	DD	Area Type	Estimate	SE	DF	*t*-Value	*Pr* > |*t*|	Signif. at 5% Level?
HA	4D	T	—	—	—	—	—	—	0.00	—	—	—	—	Yes
Lane width	4D	—	1	—	—	—	—	—	−1.17	0.87	331	−1.34	0.182	No
Lane width	4D	—	2	—	—	—	—	—	−2.09	0.52	331	−4.04	<0.001	Yes
Lane width	4D	—	3	—	—	—	—	—	0.00	—	—	—	—	Yes
Bike lane	4D	—	—	0	—	—	—	—	0.10	0.44	331	0.22	0.828	No
Bike lane	4D	—	—	1	—	—	—	—	0.00	—	—	—	—	Yes
Lighting	4D	—	—	—	0	—	—	—	−1.15	0.37	331	−3.07	0.002	Yes
Lighting	4D	—	—	—	1	—	—	—	0.00	—	—	—	—	Yes
Fixed objects	4D	—	—	—	—	1	—	—	1.68	0.40	331	4.19	<0.001	Yes
Fixed objects	4D	—	—	—	—	2	—	—	2.01	0.49	331	4.07	<0.001	Yes
Fixed objects	4D	—	—	—	—	3	—	—	0.00	—	—	—	—	Yes
DD	4D	—	—	—	—	—	1	—	0.02	0.58	331	0.04	0.966	No
DD	4D	—	—	—	—	—	2	—	−0.36	0.46	331	−0.77	0.440	No
DD	4D	—	—	—	—	—	3	—	0.00	—	—	—	—	Yes
Area type	4D	—	—	—	—	—	—	Comm.	−0.29	0.69	331	−0.42	0.672	No
Area type	4D	—	—	—	—	—	—	I/I	−0.18	0.64	331	−0.28	0.781	No
Area type	4D	—	—	—	—	—	—	Res.	−0.63	0.64	331	−0.99	0.325	No
Area type	4D	—	—	—	—	—	—	Undev.	0.00	—	—	—	—	Yes
Median width	4D	—	—	—	—	—	—	—	0.00	0.01	331	−0.05	0.962	No

—Not applicable.
HA = horizontal alignment; DD = driveway density; SE = standard error; DF = degrees of freedom; Signif. = significant; Comm. = commercial; I/I = industrial/institutional; Res. = residential; Undev. = undeveloped.

Table 50. Full-model estimates of significant mean SMS versus site-characteristics models.

Effect	Site Type	HA	Lane Width	Bike Lane	Lighting	Fixed Objects	DD	Area Type	Estimate	SE	DF	*t*-Value	*Pr* > |*t*|	Signif. at 5% Level?
Intercept	2U	—	—	—	—	—	—	—	47.52	1.93	4	24.63	<0.001	Yes
lnAADT	2U	—	—	—	—	—	—	—	0.00	0.00	358	0.00	1.000	No
HA	2U	GC	—	—	—	—	—	—	0.23	0.53	358	0.43	0.666	No
HA	2U	T	—	—	—	—	—	—	0.00	—	—	—	—	Yes
Lane width	2U	—	1	—	—	—	—	—	−3.67	1.09	358	−3.35	<0.001	Yes
Lane width	2U	—	2	—	—	—	—	—	4.32	0.59	358	7.33	<0.001	Yes
Lane width	2U	—	3	—	—	—	—	—	0.00	—	—	—	—	Yes
Bike lane	2U	—	—	0	—	—	—	—	−0.30	2.04	358	−0.15	0.883	No
Bike lane	2U	—	—	1	—	—	—	—	0.00	—	—	—	—	Yes
Lighting	2U	—	—	—	0	—	—	—	−1.21	0.73	358	−1.65	0.099	No
Lighting	2U	—	—	—	1	—	—	—	0.00	—	—	—	—	Yes
Fixed objects	2U	—	—	—	—	1	—	—	1.98	0.73	358	2.73	0.007	Yes
Fixed objects	2U	—	—	—	—	2	—	—	−0.68	0.64	358	−1.06	0.291	No
Fixed objects	2U	—	—	—	—	3	—	—	0.00	—	—	—	—	Yes
DD	2U	—	—	—	—	—	1	—	−4.17	0.74	358	−5.66	<0.001	Yes
DD	2U	—	—	—	—	—	2	—	−0.38	0.66	358	−0.58	0.562	No
DD	2U	—	—	—	—	—	3	—	0.00	—	—	—	—	Yes
Area type	2U	—	—	—	—	—	—	Comm.	−11.35	1.85	358	−6.12	<0.001	Yes
Area type	2U	—	—	—	—	—	—	I/I	−7.60	0.94	358	−8.05	<0.001	Yes
Area type	2U	—	—	—	—	—	—	Res.	−5.22	0.65	358	−8.08	<0.001	Yes
Area type	2U	—	—	—	—	—	—	Undev.	0.00	—	—	—	—	Yes
Intercept	4D	—	—	—	—	—	—	—	42.38	1.24	3	34.23	<0.001	Yes
lnAADT	4D	—	—	—	—	—	—	—	0.00	0.00	331	0.00	1.000	No
HA	4D	GC	—	—	—	—	—	—	−1.42	0.40	331	−3.53	<0.001	Yes
HA	4D	T	—	—	—	—	—	—	0.00	—	—	—	—	Yes
Lane width	4D	—	1	—	—	—	—	—	6.79	1.08	331	6.31	<0.001	Yes
Lane width	4D	—	2	—	—	—	—	—	7.69	0.63	331	12.19	<0.001	Yes
Lane width	4D	—	3	—	—	—	—	—	0.00	—	—	—	—	Yes

Effect	Site Type	HA	Lane Width	Bike Lane	Lighting	Fixed Objects	DD	Area Type	Estimate	SE	DF	*t*-Value	*Pr* > |*t*|	Signif. at 5% Level?
Bike lane	4D	—	—	0	—	—	—	—	−0.11	0.51	331	−0.22	0.824	No
Bike lane	4D	—	—	1	—	—	—	—	0.00	—	—	—	—	Yes
Lighting	4D	—	—	—	0	—	—	—	5.79	0.43	331	13.37	<0.001	Yes
Lighting	4D	—	—	—	1	—	—	—	0.00	—	—	—	—	Yes
Fixed objects	4D	—	—	—	—	1	—	—	5.13	0.49	331	10.56	<0.001	Yes
Fixed objects	4D	—	—	—	—	2	—	—	2.74	0.57	331	4.79	<0.001	Yes
Fixed objects	4D	—	—	—	—	3	—	—	0.00	—	—	—	—	Yes
DD	4D	—	—	—	—	—	1	—	−6.88	0.68	331	−10.13	<0.001	Yes
DD	4D	—	—	—	—	—	2	—	−1.90	0.55	331	−3.42	<0.001	Yes
DD	4D	—	—	—	—	—	3	—	0.00	—	—	—	—	Yes
Area type	4D	—	—	—	—	—	—	Comm.	−3.23	0.80	331	−4.04	<0.001	Yes
Area type	4D	—	—	—	—	—	—	I/I	−1.17	0.73	331	−1.60	0.111	No
Area type	4D	—	—	—	—	—	—	Res.	1.03	0.74	331	1.40	0.163	No
Area type	4D	—	—	—	—	—	—	Undev.	0.00	—	—	—	—	Yes
Median width	4D	—	—	—	—	—	—	—	−0.05	0.01	331	−5.27	<0.001	Yes

—Not applicable.

HA = horizontal alignment; DD = driveway density; SE = standard error; DF = degrees of freedom; Signif. = significant; Comm. = commercial; I/I = industrial/institutional; Res. = residential; Undev. = undeveloped.

Table 51. Full-model estimates of significant SD of SMS versus site-characteristics models.

Effect	Site Type	HA	Lane Width	Bike Lane	Lighting	Fixed Objects	DD	Area Type	Estimate	SE	DF	*t*-Value	*Pr* > |*t*|	Signif. at 5% Level?
Intercept	2U	—	—	—	—	—	—	—	4.62	0.34	4	13.45	<0.001	Yes
lnAADT	2U	—	—	—	—	—	—	—	0.00	0.00	358	0.00	1.000	No
HA	2U	GC	—	—	—	—	—	—	0.00	0.09	358	−0.04	0.965	No
HA	2U	T	—	—	—	—	—	—	0.00	—	—	—	—	Yes
Lane width	2U	—	1	—	—	—	—	—	0.01	0.19	358	0.07	0.941	No
Lane width	2U	—	2	—	—	—	—	—	0.48	0.10	358	4.55	<0.001	Yes
Lane width	2U	—	3	—	—	—	—	—	0.00	—	—	—	—	Yes
Bike lane	2U	—	—	0	—	—	—	—	−0.41	0.36	358	−1.13	0.260	No
Bike lane	2U	—	—	1	—	—	—	—	0.00	—	—	—	—	Yes
Lighting	2U	—	—	—	0	—	—	—	0.37	0.13	358	2.90	0.004	Yes
Lighting	2U	—	—	—	1	—	—	—	0.00	—	—	—	—	Yes
Fixed objects	2U	—	—	—	—	1	—	—	−0.40	0.13	358	−3.14	0.002	Yes
Fixed objects	2U	—	—	—	—	2	—	—	−0.53	0.11	358	−4.70	<0.001	Yes
Fixed objects	2U	—	—	—	—	3	—	—	0.00	—	—	—	—	Yes
DD	2U	—	—	—	—	—	1	—	0.68	0.13	358	5.24	<0.001	Yes
DD	2U	—	—	—	—	—	2	—	0.44	0.12	358	3.76	<0.001	Yes
DD	2U	—	—	—	—	—	3	—	0.00	—	—	—	—	Yes
Area type	2U	—	—	—	—	—	—	Comm.	0.87	0.33	358	2.66	0.008	Yes
Area type	2U	—	—	—	—	—	—	I/I	−0.82	0.17	358	−4.94	<0.001	Yes
Area type	2U	—	—	—	—	—	—	Res.	−0.35	0.11	358	−3.09	0.002	Yes
Area type	2U	—	—	—	—	—	—	Undev.	0.00	—	—	—	—	Yes
Intercept	4D	—	—	—	—	—	—	—	5.63	0.30	3	18.57	<0.001	Yes
lnAADT	4D	—	—	—	—	—	—	—	0.00	0.00	331	0.00	0.999	No
HA	4D	GC	—	—	—	—	—	—	−0.44	0.09	331	−4.74	<0.001	Yes
HA	4D	T	—	—	—	—	—	—	0.00	—	—	—	—	Yes

Effect	Site Type	HA	Lane Width	Bike Lane	Lighting	Fixed Objects	DD	Area Type	Estimate	SE	DF	*t*-Value	*Pr* > |*t*|	Signif. at 5% Level?
Lane width	4D	—	1	—	—	—	—	—	−0.82	0.26	331	−3.19	0.002	Yes
Lane width	4D	—	2	—	—	—	—	—	−0.74	0.15	331	−4.95	<0.001	Yes
Lane width	4D	—	3	—	—	—	—	—	0.00	—	—	—	—	Yes
Bike lane	4D	—	—	0	—	—	—	—	0.28	0.12	331	2.39	0.017	Yes
Bike lane	4D	—	—	1	—	—	—	—	0.00	—	—	—	—	Yes
Lighting	4D	—	—	—	0	—	—	—	−0.42	0.10	331	−4.24	<0.001	Yes
Lighting	4D	—	—	—	1	—	—	—	0.00	—	—	—	—	Yes
Fixed objects	4D	—	—	—	—	1	—	—	−0.45	0.11	331	−3.94	<0.001	Yes
Fixed objects	4D	—	—	—	—	2	—	—	0.02	0.13	331	0.13	0.898	No
Fixed objects	4D	—	—	—	—	3	—	—	0.00	—	—	—	—	Yes
DD	4D	—	—	—	—	—	1	—	1.08	0.16	331	6.84	<0.001	Yes
DD	4D	—	—	—	—	—	2	—	0.44	0.13	331	3.40	<0.001	Yes
DD	4D	—	—	—	—	—	3	—	0.00	—	—	—	—	Yes
Area type	4D	—	—	—	—	—	—	Comm.	−0.54	0.18	331	−2.95	0.003	Yes
Area type	4D	—	—	—	—	—	—	I/I	0.95	0.17	331	5.66	<0.001	Yes
Area type	4D	—	—	—	—	—	—	Res.	−0.87	0.17	331	−5.16	<0.001	Yes
Area type	4D	—	—	—	—	—	—	Undev.	0.00	—	—	—	—	Yes
Median width	4D	—	—	—	—	—	—	—	0.01	0.00	331	3.75	<0.001	Yes

—Not applicable.
HA = horizontal alignment; DD = driveway density; SE = standard error; DF = degrees of freedom; Signif. = significant; Comm. = commercial; I/I = industrial/institutional; Res. = residential; Undev. = undeveloped.

REFERENCES

American Association of State Highway and Transportation Officials. (2010). *Highway Safety Manual* (including 2014 supplement), Washington, DC.

American Association of State Highway and Transportation Officials. (2019). "Safety Analyst: Software Tools for Safety Management of Specific Highway Sites." (website) Washington, DC. Available online: www.safetyanalyst.org, last accessed July 25, 2019.

Elvik, R. (2013). "A Re-Parameterisation of the Power Model of the Relationship Between the Speed of Traffic and the Number of Accidents and Accident Victims." *Accident Analysis and Prevention*, *50*, pp. 854–860, Elsevier, Amsterdam, Netherlands.

Elvik R., Christensen, P., and Amundsen, A.H. (2004). *Speed and Road Accidents: An Evaluation of the Power Model*, Report 740, Institute of Transport Economics, Oslo, Norway.

Elvik, R. (2009). *The Power Model and the Relationship Between Speed and Road Safety*, Institute of Transport Economics, Oslo, Norway.

Harwood, D.W., Bauer, K.M., Richard, K.R., Gilmore, D.K., Graham, J.L., Potts, I.B., Torbic, D.J., and Hauer, E. (2007). NCHRP Project 17-26, "Methodology to Predict the Safety Performance of Urban and Suburban Arterials," NCHRP Web Document No. 129: Phases I and II, Transportation Research Board, Washington, DC.

Hauer, E., and Bonneson, J. (2009). "An Empirical Examination of the Relationship Between Speed and Safety," *Transportation Research Record* 2103, pp. 10–17, Transportation Research Board, Washington, DC.

Nilsson, G. (2004). *Traffic Safety and the Power Model to Describe the Risk of Crash Involvement*, Bulletin 221, Lund Institute of Technology, Lund University, Sweden.

Solomon, D. (1964). *Accidents on Main Rural Highways Related to Speed, Driver, and Vehicle*, U.S. Department of Commerce, Bureau of Public Roads, United States Government Printing Office, Washington, DC.

Transportation Research Board of the National Academy of Sciences. (2013a). The Second Strategic Highway Research Program Naturalistic Driving Study Dataset, Washington, DC.

Transportation Research Board of the National Academy of Sciences. (2013b). The Second Strategic Highway Research Program Roadway Inventory Dataset, Washington, DC.

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