Development of a Posted Speed Limit Setting Procedure and Tool (2021)

DETAILS

190 pages | 8.5 x 11 | PAPERBACK
ISBN 978-0-309-67982-4 | DOI 10.17226/26200

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SUGGESTED CITATION

National Academies of Sciences, Engineering, and Medicine 2021. *Development of a Posted Speed Limit Setting Procedure and Tool*. Washington, DC: The National Academies Press. https://doi.org/10.17226/26200.

NCHRP

Web-Only Document 291:

Development of a Posted Speed Limit Setting Procedure and Tool

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Contractor's Final Report for NCHRP Project 17-76
Submitted March 2021

NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

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Author Acknowledgments

The research reported herein was performed under National Cooperative Highway Research Program Project 17-76 by the Texas A&M Transportation Institute (TTI), which is a member of The Texas A&M University System, and Michigan State University (MSU).

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The work was performed under the general supervision of Dr. Fitzpatrick. The research reported here was supported by several staff members at TTI (Colleen Dau, Matthew Foley, Joene Gieguy Konan, Marc Laplante, Tomas Lindheimer, Christopher Lira, Chaolun Ma, Mohammada Moghadasi, Sadia Najneen, Marcelina Perez, Maria Rodriguez, Aaron Trevizo, and Umme Zakiraand) and MSU.

The authors wish to acknowledge the many experts who contributed to this research by participating in discussions on posted speed limits and providing comments during presentations and early drafts. The authors appreciate the time and effort of these individuals.

CONTENTS

Note: The contractor's report published herein is associated with *NCHRP Research Report 966: Posted Speed Limit Setting Procedure and Tool: User Guide*. Readers can read or purchase *NCHRP Research Report 966* at www.trb.org.

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SUMMARY

Several factors are considered within engineering studies when determining the posted speed limit for a speed zone. National Cooperative Highway Research Program (NCHRP) Project 17-76 investigated the factors that influence operating speed as well as safety and used that knowledge to develop the Speed Limit Setting Procedure (SLS-Procedure) so engineers can make informed decisions about the setting of speed limits. The SLS-Procedure was automated with the Speed Limit Setting Tool (SLS-Tool). The SLS-Tool is spreadsheet based and is included with the *NCHRP Research Report 966: Posted Speed Limit Setting Procedure and Tool: User Guide* (*1*).

Currently, the predominant method for setting speed limits uses the 85th percentile speed. It is viewed as being a fair way to set speed limits based on the driving behavior of most drivers (85 percent), who represent reasonable and prudent drivers since the fastest 15 percent of drivers are excluded. The 85th percentile speed is also believed to represent a safe speed that would minimize crashes. Criticisms of the 85th percentile speed method include a concern that drivers may not see or be aware of all the conditions present within the corridor, and such an approach may not adequately consider vulnerable roadway users such as pedestrians and bicyclists. Other concerns are that drivers are not always reasonable and prudent, or they only consider what is reasonable and prudent for themselves and not for all users of the system; and the use of measured operating speeds to set speed limits could cause increased speed over time (i.e., speed creep). Drivers frequently select speeds a certain increment above the posted speed limit, anticipating that they will not receive a ticket if they are not above that assumed enforcement speed tolerance. Also, most of the early research justifying the use of the 85th percentile speed was conducted on rural roads; therefore, the 85th percentile speed may not be appropriate for urban roads.

The research team considered the breadth of approaches available for the setting of speed limits and the need to develop a methodology that could be used for any roadway type. The research team selected a decision-rule-based procedure for the SLS-Procedure. Given the increased emphasis on designing for the context of the roadway, the research team decided that the SLS-Procedure should be sensitive to context and use the expanded functional classification scheme available in *NCHRP Research Report 841: Development of Crash Modification Factors for Uncontrolled Pedestrian Crossing Treatments*. The roadway types and roadway contexts available within the expended functional classification scheme were collapsed into four Speed Limit Setting Groups (SLSGs): Limited Access, Undeveloped, Developed, and Full Access. Unique decision rules were developed for each SLSG.

For the SLS-Procedure, the research team recommended consideration of the measured operating speed as the starting point for selecting a posted speed limit but that the measured operating speed be adjusted based on roadway conditions and consideration of the crash experience on the segment.

The guiding principles developed by the research team for the SLS-Procedure included that the procedure:

- Use a data-driven approach with research-based decision rules.
- Produce consistent results for a given set of conditions.
- Incorporate contemporary policies, guidelines, and practices.
- Consider drivers’ speed choice and roadway safety.
- Provide transparency in the decision process.

- Consider all roadway types and roadway contexts.
- Vary the decision rules to account for the diverse characteristics of each speed limit setting group.
- Consider agency data and human resource constraints.
- Include inputs and outputs on the same screen to demonstrate the relationship between each roadway characteristic and selection of the suggested speed limit.
- Allow for future modifications to accommodate new knowledge.
- Create efficiencies in the decision process, where possible.

The SLS-Procedure starts with identifying the roadway segment context and type, which determine the appropriate SLSG. For that SLSG, the roadway characteristics and crash potential for the segment are used to identify the speed distribution that should be considered and whether the closest 5-mph increment value or a rounded-down 5-mph increment value should be used. Based on the previous steps, a potential suggested speed limit is identified. Figure 1 illustrates the procedure.

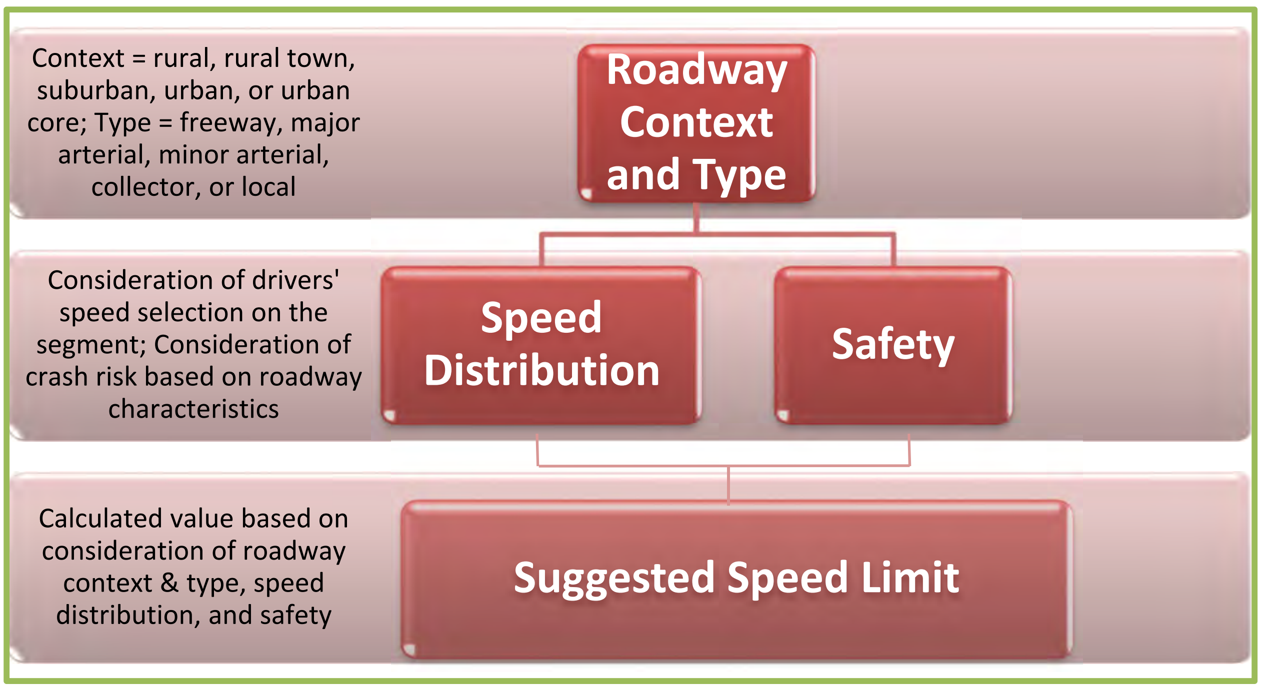


Figure 1. Overview of SLS-Procedure to calculate the suggested speed limit.

In NCHRP Project 17-76, the research team focused a portion of the Phase II efforts on collecting data for suburban and urban roads to fill the known research gap for city streets. The developed databases for Austin, Texas, and Washtenaw, Michigan, were used to investigate the relationships among crashes, roadway characteristics, and posted speed limits. The team found that crashes on city streets were lowest when the operating speed was within 5 mph of the average operating speed. Therefore, the research team recommended that the 50th percentile speed be a consideration within the SLS-Procedure, especially for the SLSGs of Developed and Full Access. The evaluation of the Austin, Texas, and Washtenaw, Michigan, data supported including the following variables within the decision rules: signal density, access density, and undivided median on four-lane (or more) streets. Findings from the literature were also used to develop the decision rules.

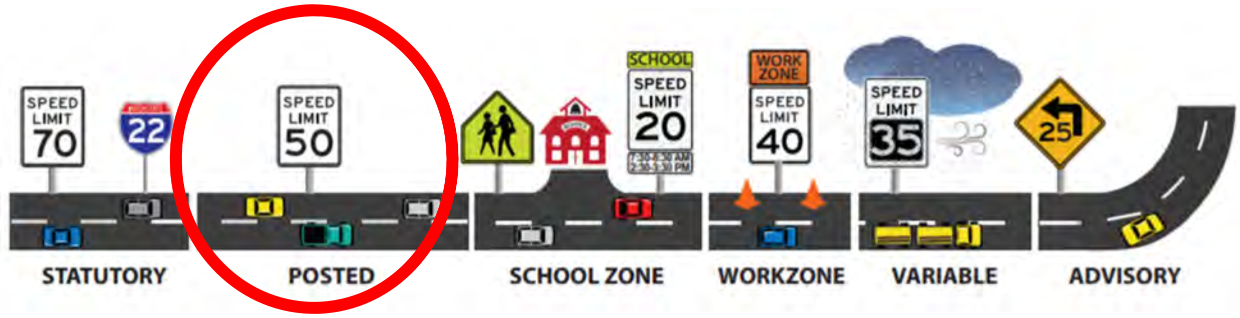
Presenting a workshop was a requirement of the research. Members of the research team conducted several workshops and presentations during the development of the SLS-Procedure, and these presentations provided opportunities to obtain feedback on the potential format of the procedure. The presentations with the panel were especially influential in setting the direction for the SLS-Procedure and SLS-Tool.

NCHRP Project 17-76 concluded with the development of two publications:

- *NCHRP Research Report 966: Posted Speed Limit Setting Procedure and Tool: User Guide*.
- *NCHRP Web-Only Document 291: Development of a Posted Speed Limit Setting Procedure and Tool* (this document).

CHAPTER 1. BACKGROUND

Speed limit is the maximum speed a driver is legally permitted for a given roadway segment. Several types of speed limits exist, including statutory speed limit, posted speed limit (PSL), school zone speed limit, work zone speed limit, variable speed limit, and advisory speed (Figure 2 illustrates these different types of speed limits).



Source: Federal Highway Administration *Speed Limit Basics*, page 1 (*2*).

Figure 2. Examples of speed limits.

A posted speed limit could be the same as the statutory speed set by the state legislature or could be an adjustment to the statutory speed limit determined using an engineering speed study. States establish statutory speed limits for specific types of roads—such as freeways, rural highways, or urban streets—which are applicable even if the speed limit sign is not posted.

OBJECTIVE AND SCOPE

National Cooperative Highway Research Program (NCHRP) Project 17-76 was tasked with identifying factors that influence a driver's operating speed and then developing a Speed Limit Setting Procedure (SLS-Procedure) and automating that procedure with a spreadsheet-based Speed Limit Setting Tool (SLS-Tool). The SLS-Procedure and SLS-Tool are used to calculate the suggested speed limit for a segment. The goal of the SLS-Procedure and SLS-Tool is to produce an unbiased and objective suggested speed limit value. Traffic engineers can use the SLS-Procedure and the suggested speed limit generated by the SLS-Tool to communicate with the public or government officials to explain the methodology behind setting speed limits.

Two publications were generated as part of NCHRP Project 17-76:

- *NCHRP Research Report 966: Posted Speed Limit Setting Procedure and Tool: User Guide* (*1*).
- *NCHRP Web-Only Document 291: Development of a Posted Speed Limit Setting Procedure and Tool* (this document).

ORGANIZATION OF WEB-ONLY DOCUMENT

This report documents the research efforts and findings from NCHRP Project 17-76 in the following chapters and appendices:

- **Chapter 1. Background:** This chapter introduces the objective of the research along with the chapters and appendices contained in this web-only final report.
- **Chapter 2. Research Approach:** This chapter provides details on how the project was conducted.

- **Chapter 3. Findings:** The findings are summarized in this chapter for each major effort within NCHRP Project 17-76.
- **Chapter 4. Conclusions, Recommendations, and Suggested Research:** This chapter provides the conclusions generated from the research along with a list of suggested research needs and improvements to the SLS-Tool.
- **Appendix A. Relationship among Roadway Characteristics, Speed, and Safety for Urban/Suburban Streets:** This appendix presents the findings reported in the research literature on the relationships among traffic crashes, operating speed, and roadway factors, including posted speed limit, for urban and suburban streets.
- **Appendix B. Relationship among Roadway Characteristics, Speed, and Safety for High-Speed Highways:** This appendix discusses the findings reported in the research literature for rural highways and limited-access highways regarding the relationships among crashes, operating speed, and roadway characteristics including posted speed limit.
- **Appendix C. Speed Limit Setting Approaches:** This appendix presents information on current approaches to setting speed limits including a summary of key publications calling for changes to how speed limits are set. It also provides an overview of various methods being used in the United States and in other countries including introducing recent trends to employ citywide or default speed limits. Existing material and proposed changes to the *Manual on Uniform Traffic Control Devices* (MUTCD) are summarized. To aid in understanding the relationships between operating speed and posted speed limit, this appendix includes plots showing average speed by posted speed limits.
- **Appendix D. Relationship among Urban/Suburban Roadway Characteristics, Operating Speed, and Crashes in Austin, Texas:** This appendix identifies the relationships among operating speed, crashes, and roadway characteristics including posted speed limit and vehicle volume for a database of Austin, Texas, sites.
- **Appendix E. Relationship among Urban/Suburban Roadway Characteristics, Posted Speed Limit, and Crashes in Washtenaw County, Michigan:** This appendix identifies the relationships among crashes, roadway characteristics, posted speed limit, and vehicle volume for a database of Washtenaw County, Michigan, sites.
- **Appendix F. Decision Rule Development:** This appendix provides an overview of the decision rules selected for the four Speed Limit Setting Groups (SLSGs), which are Limited Access, Undeveloped, Developed, and Full Access.
- **Appendix G. Workshop Slides:** This appendix includes the slides and presenter notes used in one of the workshops presented during the project.
- **Abbreviations:** This section provides the list of abbreviations used in the report.

CHAPTER 2. RESEARCH APPROACH

RESEARCH METHODOLOGY FOR NCHRP PROJECT 17-76

The research was originally proposed to be conducted within seven tasks. Each task listed is followed by the objectives of that task:

- **Task 1. Identify Current Knowledge and Practices:** The objective of this task was to review the literature related to speed and associated relationships. In addition, the factors or variables used in current speed setting practices were identified.
- **Task 2. Identify Sources for Data:** The objectives of this task were to identify sources for the following data: speed, traffic, roadway, enforcement practices, crash data, and any other additional critical data as identified in Task 1. Because of concerns with the amount of effort that could be needed with respect to obtaining data, during the kickoff meeting, the panel expressed their support for the research team not collecting new data with respect to enforcement. The panel also expressed a preference that the research team consider traffic mode split (e.g., between vehicles and bicyclists) in the analyses while also recognizing the challenges with obtaining such data.
- **Task 3. Develop Research Study Approach:** The objective of this task was to develop the research study approach proposed for use in Phase II. In Task 3, the development was accompanied by a beta test of the approach to identify where refinements were needed.
- **Task 4. Develop Interim Report and Phase II Work Plan:** The objectives of this task were to develop the work plan to be carried out in Phase II of the research project; develop the interim report that would summarize the results of Tasks 1 through 3; submit the Phase I interim report and the Phase II work plan; and participate in a panel meeting.
- **Task 5. Conduct Phase II Studies:** The objective of this task was to conduct the approved work plan regarding the identification of variables that influence operating speed and safety on a road or street with a focus on the effects of speed term differences.
- **Task 6. Develop and Test Guidance Materials:** The objective of this task was to develop the guidelines and then test the materials at a workshop.
- **Task 7. Prepare Final Documents:** The objective of this task was to prepare the final documents.

PHASE I EFFORTS

During the kickoff meeting for NCHRP Project 17-76, the panel identified three conditions where scientific-based methods/guides for setting speed limits were desired:

- Rural high-speed highways, where there is political pressure to increase the posted speed limit.
- Rural-to-city transition zones, where there is pressure to lower speed.
- Urban/suburban city streets, where there is pressure to adopt a uniform low speed (such as 25 mph).

The National Association of City Transportation Officials (NACTO) and Vision Zero are contributing to this discussion and using speed-related pedestrian/bike crash survivability to justify uniformly low posted speeds.

In accordance with the direction set by the panel, the research team focused the Phase I literature review efforts on these three areas. Other Phase I efforts were grouped into the following broad areas:

- Conduct project management.
- Identify existing procedures for setting the posted speed limit.
- Review literature with an emphasis on identifying known relationships among operating speed, safety, and roadway characteristics.
- Identify potential operating speed datasets.
- Obtain samples of speed data and review the quality and quantity of the speed datasets with respect to their usability for NCHRP Project 17-76.
- Review other techniques for selecting posted speed limits.

The research team met with the panel at the end of Phase I. In addition to approving the research team's proposed Phase II activities, the panel set the following directions during the Phase I panel meeting:

- The SLS-Tool should include the proposed expanded functional classification scheme as discussed in *NCHRP Research Report 855* (*3*).
- Two studies were recently completed regarding rural-to-city transition zones (*NCHRP Synthesis 412* [*4*] in 2011 and *NCHRP Report 737* [*5*] in 2012). With the recent studies on transition zones, NCHRP Project 17-76 should focus on corridors that are not transitioning to another functional classification.
- The decision support tool needs to be transparent (no black box).

PHASE II EFFORTS

Following the Phase I panel meeting, the following research efforts were conducted in Phase II:

- Build and analyze a roadway characteristic, posted speed limit, operating speed, and crash database for Austin, Texas.
- Build and analyze a roadway characteristic, posted speed limit, and crash database for Washtenaw County, Michigan.
- Develop an SLS-Procedure that will result in an unbiased and objective method for identifying a suggested speed limit value. Identify appropriate decision rules for use in the procedure.
- Automate the SLS-Procedure into an SLS-Tool using a spreadsheet as the base format.
- Conduct selected technology transfer activities.
- Document the efforts within the project.

CHAPTER 3. FINDINGS

Following are key findings by each of the major efforts within each phase.

PHASE I EFFORTS

Within Phase I, the research team grouped its efforts within six major activities. The findings from Phase I influenced the direction proposed and set for Phase II.

Phase I. Conduct Project Management

The direction set during the kickoff meeting was that the research team would consider the following roadway classes:

- High-speed rural.
- Rural-to-city transition zones.
- Urban/suburban streets.

The literature review findings were organized to reflect these three conditions. Occurring concurrently as NCHRP Project 17-76, the parallel NCHRP 17-79 project focused on examining the safety relationship between speed limit, roadway characteristics, and crashes on roads with speed limits of 75 mph or greater. The goal was for NCHRP Project 17-76 to use the findings from NCHRP 17-79 rather than duplicating efforts on higher-speed roads. Because of the recent reports on speeds in transition zones (*4, 5*), the focus of Phase II research was on city streets.

Trends/recent activity that could affect the direction of this project include the following:

- NACTO 2017 policy (*6*) that includes the following statement: “State rules or laws that set speed limits at the 85th percentile speed should be repealed.”
- The National Transportation Safety Board’s (NTSB’s) publication of a safety study on *Reducing Speeding-Related Crashes Involving Passenger Vehicles* (*7*). NTSB provides specific recommendations in its report, such as removing the guidance in the MUTCD (*8*) that speed limits should be within 5 mph of the 85th percentile speed.

Phase I. Identify Existing Procedures for Setting Posted Speed Limit

Most, if not all, of the procedures currently used in the United States are based on the 85th percentile speed. Several procedures provide consideration for adjusting the recommended posted speed based on existing conditions, such as existing crashes, roadside development/land use, sight distance, shoulder presence, traffic volume, and so forth. Other countries are using procedures that are based on factors other than the 85th percentile speed to set the posted speed limit. For example, both New Zealand and Canada consider the presence of a pedestrian facility.

There is currently an experiment being conducted in Portland, Oregon, for collector streets that is considering roadway conditions specifically associated with pedestrians and bicyclists in addition to conditions for motorists to identify the suggested posted speed limit.

Phase I. Review Literature

The review of the literature had an emphasis on identifying known relationships among operating speed, safety, and roadway characteristics. Consensus is that higher operating speeds are associated with more severe crashes, as supported by the basic physics of the situation. Few studies are available that examine the relationship between the magnitude of operating speed and the number of crashes, probably primarily due to the difficulties in obtaining actual operating speed for significant lengths of time and for a significant number of sites. A 2017 study on rural two-lane highways in Israel (*9*) and a 2016 study on two-lane urban roads in the city of Edmonton, Canada (*10*), are notable exceptions. The studies found that as operating speed increases, the number of crashes also increase.

The roadways, traffic control devices, and traffic variables that have been found to affect speed or crashes were identified and summarized in the interim report and are in Appendices A and B of this document. This knowledge was used to develop a list of variables that should be considered in Phase II.

Phase I. Identify Potential Operating Speed Datasets

The research team searched for potential sources of speed data. Having a large database of speed data, along with roadway characteristics and crashes, is critical to understanding the complex relationships among speed, roadway design, and safety. Higher quality and quantity of data are available for freeways; however, the focus for NCHRP Project 17-76 was urban/suburban streets. Several sources of speed data were identified; however, each had significant limitations with respect to NCHRP Project 17-76. Samples of the datasets with the most promise were obtained for the effort summarized in the next section.

Phase I. Obtain Samples of Speed Data

Samples of speed data from several sources were obtained. The review considered the quality and quantity of the speed data with respect to their usability for NCHRP Project 17-76. The traditional data collection technique of using on-road sensors or video cameras could produce usable data but would result in a smaller sample than preferred because of the cost to collect speed data in that manner. Therefore, Phase I efforts were focused on exploring emerging big datasets to see if they could serve the needs of NCHRP Project 17-76.

Vendor speed data by way of the National Performance Management Research Data Set (NPMRDS) is available to states and metropolitan planning organizations (MPOs); however, NCHRP would have had to pay to access the data for use in this research project. A review of a sample of the NPMRDS data, however, revealed several limitations with respect to arterial streets including lack of roadway vehicle volume, long segments that include several signalized intersections, and gaps in the speed data for a large portion of the 5-minute time bins.

Bluetooth data are available for several roadway segments in Austin, Texas. While the dataset is open source (i.e., the 17-76 project did not have to pay for the data), similar limitations as with other vendor data are present. The Bluetooth® data do not include roadway volume, represent long segments with signalized intersections in many cases, and are missing speed data for several 15-minute time bins.

The Texas A&M Transportation Institute (TTI) recently explored a dataset of binned speed data available for streets in Austin, Texas. This dataset formed the core of the Texas data used in the related analysis in Phase II. Shapefiles of the existing street network within the City of Ann Arbor and the surrounding suburban townships were available to the research team and formed the core of the Michigan data used in the related analysis in Phase II.

Phase I. Review Other Techniques for Selecting Posted Speed Limits

The review of USLIMITS2 (*11*), Portland (*12*), New Zealand (*13*), and Canada’s procedures showed that several of the variables identified in the literature review are also being considered in their procedures. In some cases, the consideration is specific; for example, in

USLIMITS2, a precise value for signal or access density (e.g., 4 signals per mile) would change the recommendation. In other cases, the value for the variable is based on engineering judgment (e.g., is parking activity high or not). The values and criteria being used in these other procedures could help guide the recommendations for a revised or newly developed procedure.

PHASE II EFFORTS

Based upon the Phase I key findings and with due consideration of the available funds, the research team conducted activities within six major areas. The following describes the findings by research effort.

Phase II. Build and Analyze Austin, Texas, Database

The findings from the database built using data for Austin, Texas, are in Appendix D. The database was used to analyze the relationships among roadway characteristics, posted speed limit, operating speed, and crash data. The analysis was conducted within three rounds using different approaches or subsets of the database.

Key findings from the evaluations supported the following decision rules for the SLS-Tool:

- Inclusion of the following variables:
  - Number of signals or signal density.
  - On-street parking.
- Addition of the following variable:
  - Median type. Raised medians were associated with fewer fatal and injury (KABC) crashes compared to no median or two-way left-turn lane (TWLTL), while TWLTLs were associated with more KABC crashes compared to no median.

The findings from the path analysis support the consideration of the 50th percentile speed in identifying a suggested speed limit.

Phase II. Build and Analyze Washtenaw County, Michigan, Database

The Washtenaw County, Michigan, database was used to analyze the relationships among roadway characteristics, posted speed limit, and crash data. The findings from this effort supported the following decision rules for the SLS-Tool:

- Inclusion of the following variables:
  - Signal density.
  - Access density, along with the break points at 40 and 60 access points per mile.
- Addition of the following variable:
  - Median type (raised medians were associated with fewer KABCO crashes compared to none or TWLTL, while TWLTLs were associated with fewer KABCO crashes compared to no median).

Phase II. Develop SLS-Procedure

Selecting the Base Format for SLS-Procedure

Currently, the predominant method for setting speed limits is with the use of the 85th percentile speed. It is viewed as being representative of a safe speed that will minimize crashes, and the 1964 Solomon study (*14*) is frequently quoted as being the source to justify the use of the 85th percentile speed. The use of the 85th percentile speed has been supported with the following:

- Represents a safe speed that minimizes crashes.
- Promotes uniform traffic flow along a corridor.
- Is a fair way to set the speed limit based on the driving behavior of most drivers (i.e., 85 percent).
- Represents reasonable and prudent drivers since the fastest 15 percent of drivers are excluded.
- Is enforceable in that it is fair to ticket the small percentage (15 percent) of drivers that are exceeding the posted speed limit.

Criticisms of the 85th percentile speed method have included the following:

- Setting the posted speed limit based on existing driver behavior may create unsafe road conditions because drivers may not see or be aware of all the conditions present within the corridor.
- Setting the posted speed limit on existing driver behavior rather than the roadway context may not adequately consider vulnerable roadway users such as pedestrians and bicyclists.
- Drivers are not always reasonable and prudent, or they only consider what is reasonable and prudent for themselves and not for all users of the system.
- Using measured operating speeds could cause operating speeds to increase over time (i.e., speed creep). Drivers frequently select speeds a certain increment above the posted speed limit, anticipating that they will not receive a ticket if they are not above that assume enforcement speed tolerance. In this case, the resulting operating speed would be above the posted speed limit. Using the 85th percentile speed approach in this situation would result in recommending a posted speed limit that is higher than the existing posted speed limit. Posting that higher speed limit would set up the cycle that the next spot speed study may again find a higher operating speed because of drivers using the assumed speed enforcement tolerance to select their speed.
- Most of the early research justifying the use of the 85th percentile speed was conducted on rural roads, so it may not be appropriate for urban roads.

As documented in Appendix C, a National Committee on Uniform Traffic Control Devices (NCUTCD) task force conducted a survey on speed limits. One of the questions from the NCUTCD task force survey was “How would you set speed limits if given the choice?” The provided responses included rounding to the nearest 5 mph of the 85th percentile, or rounding up or down, and so forth. Half of the survey participants selected “other” and typed a response, with the word “context” being used more than any other word. Within the design community, there is greater emphasis on designing roadways to fit the context of the site.

Given the increased emphasis on context within the profession, the research team decided that the SLS-Procedure should also be sensitive to context. The Expanded Functional Classification System available in *NCHRP Research Report 855* (*3*) was used to develop SLSGs that reflect logical groups with respect to setting speed limits. For example, freeways, which have very specific geometric design criteria, are present within several roadway type and roadway context combinations. Those roadway type and context combinations were grouped into a Limited-Access SLSG. The other SLSGs identified were Undeveloped, Developed, and Full Access.

Within each of these SLSGs, a unique set of decision rules was developed. For the Limited-Access and Undeveloped SLSGs with their higher operating speed and greater emphasis on mobility, retaining a connection to measured operating speed was deemed appropriate. After much debate among the research team, panel, and other subject matter experts, the research team also decided to retain the connection with measured operating speed for the Developed SLSG—with the knowledge that which measured operating speed would serve as the starting point (e.g., 85th percentile or 50th percentile), along with whether to use the closest speed or rounded down to nearest 5-mph increment, would be influenced by consideration of safety through the use of decision rules. Extensive debate was then engaged in about how to set the decision rules for the Full-Access SLSG, which included local streets and the urban core. The research team initially considered having set speed limits (e.g., 25 mph) for a set of conditions (e.g., specific combinations of roadway characteristics such as the number of lanes, average lane width, median presence, sidewalk presence, etc.). After additional extensive discussion among the team, panel, and subject matter experts, the final decision by the research team was to also have the Full-Access SLSG use measured operating speed; however, the measured operating speed would only consider the 50th percentile rather than the 85th percentile to provide greater consideration for the anticipated other users of the street within these settings.

In summary, for the SLS-Procedure, the research team recommended considering the measured operating speed as the starting point for selecting a posted speed limit, but also recommended adjusting the measured operating speed based on roadway conditions and crash experience on the segment. The NCHRP Project 17-76 SLS-Procedure was developed based on this key decision.

Guiding Principles

The guiding principles developed by the research team for the SLS-Procedure included the following:

- Use a data-driven approach with research-based decision rules.
- Produce consistent results for a given set of conditions.
- Incorporate contemporary policies, guidelines, and practices.
- Consider drivers' speed choice and roadway safety.
- Provide transparency in the decision process.
- Consider all roadway types and roadway contexts.
- Vary the decision rules to account for the diverse characteristics of each speed limit setting group.
- Consider agency data and human resource constraints.
- Include inputs and outputs on the same screen to demonstrate the relationship between each roadway characteristic and selection of the suggested speed limit.
- Allow for future modifications to accommodate new knowledge.
- Create efficiencies in the decision process, where possible.

Overview of SLS-Procedure

With consideration of the issues identified along with research into the relationships among roadway characteristics including posted speed limit, operating speed, and safety, the NCHRP Project 17-76 team developed a procedure to calculate a suggested speed limit (SSL). The SLS-Procedure starts with identifying the roadway segment context and type. Next, the speed distribution of drivers on that segment is used to identify a potential SSL that is then adjusted with consideration of the crash potential for the segment. Figure 1 illustrates the steps for the procedure. Additional details are provided in the user guide (*1*).

The SLS-Procedure was designed to result in an unbiased and objective method for identifying an SSL value. The following reference documents were directly considered during the research effort: MUTCD (*8*), USLIMITS2 original study (*11*), USLIMTS2 revised user guide (*15*), and *Highway Safety Manual* (HSM) (*16*). Several other references were also considered, as documented in Appendix F.

Previous knowledge and engineering judgment along with feedback from the panel were used to develop the decision rule recommendations on setting of posted speed limits with respect to freeways and rural highways. The team also explored the applicability of other speed limit guidance tools for establishing speed limits on rural freeways and other highways. This included knowledge-based expert systems like USLIMITS2, which uses detailed site-specific characteristics to determine appropriate speed limits.

The findings from the analyses conducted within NCHRP Project 17-76, in addition to previous knowledge, engineering judgment, and subject matter experts' suggestions, were used to develop decision rule recommendations on the setting of the posted speed limit for urban/suburban streets.

Within NCHRP Project 17-76, the research team focused Phase II on collecting data for suburban and urban roads to be able to investigate the relationships among crashes, roadway characteristics, and posted speed limit to fill the known research gap for city streets. The team found that crashes were lowest when the operating speed was within 5 mph of the average operating speed (see Appendix D). Therefore, the research team recommended that the 50th percentile speed also be a consideration within the SLS-Procedure.

Phase II. Develop SLS-Tool

The SLS-Procedure was automated into an SLS-Tool using a spreadsheet as the base format. Along with the SLS-Tool is a stand-alone document, *NCHRP Research Report 966: Posted Speed Limit Setting Procedure and Tool: User Guide* (*1*), that provides information regarding the variables used in the spreadsheet tool along with general information about the setting of speed limits. Information on the SLS-Procedure and a copy of the SLS-Tool are available in *NCHRP Research Report 966* (*1*).

The research team established the following guiding principles for the SLS-Tool development:

- Most or all data should be on one screen.
- Colors should indicate what the user should enter, what is being calculated, and warning/advisory notes.
- Data input should be organized by type (e.g., site description, speed data, site characteristics, and crashes).
- Only needed site characteristics for the particular SLSG should be shown by hiding rows using spreadsheet macros.

Phase II. Conduct Technology Transfer Activities

Presenting a workshop was a requirement of the research. Members of the research team conducted several workshops and presentations during the development of the SLS-Procedure, and these presentations provided opportunities to obtain feedback on the potential format of the procedure. The presentations with the panel were especially influential in setting the direction for the SLS-Procedure and SLS-Tool. A copy of the slides used at one of the workshops is provided in Appendix G.

Phase II. Document Research

The final effort within the project was to document the methodology and findings from the research.

CHAPTER 4. CONCLUSIONS, OPTIONS, AND SUGGESTED RESEARCH

CONCLUSIONS

The process of selecting a posted speed limit value for a roadway segment can be influenced by many factors, including engineering concerns, roadway characteristics, human factors such as the way drivers react to the roadway environment in terms of the speed they select, and policies including established agency laws or protocols along with political pressures.

The operating speed (engineering) approach is the most common method used in the United States. It relies on the 85th percentile speed with adjustments used to account for existing roadway geometry or crash experience. Many states/local agencies have their own laws/criteria for setting speed limits (many are very detailed). Professionals who perform posted speed limit studies rarely use *only* the 85th percentile speed (i.e., they use several other factors).

Using techniques other than the 85th percentile speed to select the posted speed limit is gaining in popularity in other counties. Several cities—such as Portland, Oregon; Boston, Massachusetts; New York City, New York; Seattle, Washington; and others—are also experimenting with alternative speed limit setting approaches for city streets.

NCHRP Project 17-76 collected insights into how the roadway environment influences operating speed and safety (crashes) through the review of the literature and the collection and analysis of data from two states. Using those insights along with an understanding of different methods being used and currently being considered for the setting of posted speed limits, the research team developed the SLS-Procedure and then automated that procedure with the SLS-Tool and explained that procedure with a user guide (*1*).

The SLS-Procedure uses fact-based decision rules that consider both driver speed choice and safety associated with the roadway. The SLS-Procedure was designed to be applicable to all roadway types and contexts by having a set of unique decision rules for different combinations of roadway types and contexts. The combinations included Limited Access, Undeveloped, Developed, and Full Access facilities. With the SLS-Tool having data entry and results on the same screen along with warning and advisory messages on that same screen, it is a transparent product that should help the user understand what factors influenced the SSL calculations.

OPTIONS

The overall goal of this research was to develop guidance so engineers can make informed decisions regarding the setting of speed limits. Employing the SLS-Procedure with the user guide (*1*) and the SLS-Tool can help an agency make those informed decisions and communicate how speed limits are set to a region's leadership and citizens.

For the SLS-Procedure/SLS-Tool to gain acceptance, it must be introduced to the profession, included in key reference documents or on key websites, and discussed by users. Thus, the research team recommends the following:

- Identify ways to encourage use of the tool, such as the following:
  - Identify key groups to receive presentations about the SLS-Procedure/SLS-Tool.
  - Include the availability of the SLS-Tool and user guide on key websites dealing with speed management.
- Identify implementation funds that can help to move this research into practice.
- Make presentations on the research findings and on the availability of the SLS-Procedure, SLS-Tool, and user guide.

- Develop and conduct training on the SLS-Procedure, SLS-Tool, and user guide.

SUGGESTED RESEARCH

Suggestions for additional research include the following:

- Investigate current statutory speeds in all 50 states and develop a roadmap of how a uniform set of best-practice statutory speeds could be established across the country.
- Determine needed collaboration among judicial, enforcement, and engineering industries that will result in more uniform setting, enforcement, and adjudication of reasonable speed limits.
- Identify greater definitions of the other factors used in setting speed limits such that they lead to more uniform application, similar to the use of 85th percentile speed.
- Conduct outreach to the most experienced state and local personnel who have conducted engineering studies that have set speed limits to refine the process to be efficient and effective.
- Perform additional research on the relationships among operating speed, roadway characteristics, posted speed limit, and crashes for city streets to confirm the findings in Austin, Texas (see Appendix D), especially with respect to the relationships with 50th or 85th percentile speeds. Speed data are being collected by more groups, which can assist with making this type of research more affordable; however, the speed data need to be accompanied by the number of vehicles present when the speed reading was made. Preferably, the speed data would represent a time period of about 1 hour or less. Speed readings that represent a typical day or more remove too much of the variability in the speed behavior.
- Conduct similar research for roads with other speed ranges, such as freeways (generally 55 mph and greater), rural highways (subdivided into two speed groups of higher speeds and lower speeds), and local/residential streets.
- Investigate how the presence of a marked bike lane should influence the SLS-Procedure. While it is logical to consider the need to have lower speed limits when a high number of bicyclists are present, and the SLS-Tool considers that condition, additional research is needed on how to consider bicyclist infrastructure and establish related criteria. For example, is the critical element just the presence of the lane, or is it the separation distance between the bike lane and the vehicle lane, or is a minimum bicycle volume also needed?
- Establish criteria for pedestrian volume and bicyclist volume. Currently, the SLS-Procedure uses qualitative criteria for pedestrian volume (negligible, some, or high) and bicyclist volume (high or not high). Research is needed to identify appropriate and acceptable values for these levels. These values need to be sensitive to the roadway type and context. In addition, these values may vary by region; for example, transit-heavy areas like New York City may have different values for high levels of pedestrian activities compared to other large cities that do not have such an extensive transit network.
- Gain additional insights into the relationships with posted speed limit. Research could use the SLS-Tool to set speed limits within a region and then track changes in operating speed and crashes on those streets where the speed limit was modified, along with an appropriate set of reference sites. The study should also explore sites with posted speed limits set by the “safe system” approach.

- Explore alternative approaches for city streets. Several cities—such as Portland, Oregon; Boston, Massachusetts; New York City, New York; Seattle, Washington; and others—are experimenting with alternative approaches for city streets. NACTO is in the process of developing a speed limit setting process for lower speed streets. The results of the SLS-Procedure/SLS-Tool could be compared to these new methods being developed. Depending upon the magnitude of the difference between these methods, safety evaluations could be conducted using sites where the different methods were employed.
- Determine other tools that can be used to manage speed along with the setting of defendable speed limits. These tools could include speed feedback signs or increased enforcement, among others. The effectiveness of these tools should be identified and the results communicated to practitioners. While this effort is ongoing by many researchers, perhaps a central clearinghouse could improve the technology transfer.
- Determine how to integrate target speeds into the decision process (potentially as part of a uniform, best-practice statutory speed framework).

Suggestions for additional research related to improvements/expansion of the SLS-Tool include the following:

- Explore whether the SLS-Tool would be more user friendly (and therefore used more) as a web-based tool rather than a spreadsheet-based tool. NCHRP required that the 17-76 tool be spreadsheet based; however, feedback from some reviewers on a draft version of the tool indicated that a web-based tool may have advantages. Other reviewers preferred the spreadsheet format.
- Revise the SLS-Tool to be able to handle multiple speed zone studies within a corridor.
- Provide more options for sidewalk buffer. A reviewer asked if the sidewalk buffer options should be present, not present, or both. Typically, the user is instructed to use the conditions present for the majority of the segment; however, is there justification to expand the sidewalk buffer options, perhaps to include present, not present, or mixed?
- Have the SLS-Procedure/SLS-Tool consider if the speed zone is within a transitional area. If yes, on the transition area, is the transition zone transitioning up or down in the direction of travel?
- Determine whether select variables should have greater weight. Should the user be able to adjust those weights for a given segment?
- Revise to include a new roadway context. *NCHRP Research Report 855: An Expanded Functional Classification System for Highways and Streets* served as a key reference informing the seventh edition of the American Association of State Highway and Transportation Officials' (AASHTO's) *A Policy on Geometric Design of Highways and Streets* (commonly known as the *Green Book*) (*17*). The *new Green Book* introduces a change in guidance for state transportation officials by introducing a broader set of land use context classifications (i.e., rural, rural town, suburban, urban, and urban core). These context classifications provide a mechanism for better targeting design solutions to specific contexts while providing needed flexibility to address planning and design needs. The AASHTO Committee on Design has begun planning for the eighth edition of the *Green Book* and envisions a major restructuring. This includes organizing design guidance by the context classifications listed in the

seventh edition with the addition of a context classification, “Industrial, Warehouse, or Port Roads.” The SLS-Tool should be updated to incorporate this new context classification of “Industrial, Warehouse, or Port Roads.”

- Revise the average crash rates. The crash rates in USLIMITS2 (*11*) originally reflected data from 2000 to 2004 (depending on the state). A revision to USLIMTS2 (*15*) updated those numbers to reflect data from 2009 to 2012 (depending on the state). The revised average crash rates were incorporated into the SLS-Tool; however, they should be updated again, or per-state or per-regional rates should be identified as funds are available.
- Explore whether safety performance functions (SPFs) rather than average crash rates should be integrated into the SLS-Procedure.
- Conduct focus groups to identify other variables that could be considered within the SLS-Procedure. Investigate those variables for suitability for integration into the SLS-Tool.
- Consider adding a check with respect to pace similar to what is contained in the Florida Department of Transportation (DOT) manual (*18*). The Florida DOT process is to post the speed limit at or near the upper limit of the 10-mph pace when the observed 85th percentile speed falls above the upper limit of the 10-mph pace. The manual notes that an observed 85th percentile speed that exceeds the 10-mph pace could result from a small percentage of vehicles exceeding the posted speed limit to a greater degree than the average driver traveling within the 10-mph pace.

APPENDIX A. RELATIONSHIP AMONG ROADWAY CHARACTERISTICS, SPEED, AND SAFETY FOR URBAN/SUBURBAN STREETS

Several factors are known or are suspected to affect driver speed selection or crashes on a city street. The following sections discuss the findings reported in the research literature on the relationships among traffic crashes, operating speed, and roadway factors, including posted speed limit.

Note that the goal of this literature review was to identify variables that influence driver speed choice and crash potential. These variables would then be considered for inclusion in the SLS-Procedure that was the key objective for this research project (NCHRP Project 17-76).

TRAFFIC—VEHICLES

Annual Average Daily Traffic Relationship with Crashes

Annual average daily traffic (AADT) is positively correlated with crash frequencies (*19*). Greibe (*20*) developed generalized linear models (GLMs) to predict crashes based on data from 88 mi of roads located in urban areas in Denmark. The author divided these roads into 314 homogeneous segments averaging 450 m in length. AADT was the most powerful predictor of crashes. Das and Abdel-Aty (*21*) found higher average daily traffic (ADT) was associated with increased crashes, and the absence of on-street parking was associated with reduced injury severity in crashes. Traffic flow (often referred to as general AADT) is considered the most determinant variable for the occurrence of crashes and, as such, is typically used as the only variable in the model (*22*, *23*, *24*). Other studies have also found that AADT contributes to speed selection (*25*, *26*, *27*, *28*, *29*). The findings of a study conducted by Dong et al. (*30*) suggested that major road traffic volume contributes positively to the frequency of all crash types, and the same results were observed with respect to minor road traffic volume.

Congestion Relationship with Crashes

Kononov et al. (*31*) found a direct relationship between congestion and crashes. Additionally, according to Hanbali and Fornal (*32*), the traffic flow fluctuation in congestion can also cause increased collisions. Stipancic et al. (*33*) also showed that congestion index is positively correlated with crash counts.

Percent Trucks Relationship with Crashes

Results suggest that the involvement of car crashes decreases when truck percentages increase. One possible reason is that the frequency of lane changing and overtaking movements by cars decreases with a higher presence of trucks. On the other hand, the frequencies of truck-involved crashes and car-truck-involved crashes increase as the truck percentage increases. Additionally, one study showed that more trucks are involved in truck-car crashes than in truck-truck and single-truck crashes (*34*).

Operating Speed Relationship with Crashes

Gargoum and El-Basyouny (*10*) used data for 353 two-lane urban roads in the city of Edmonton, Canada, to explore the association between speed and safety. The posted speed limits for these roads ranged between 25 and 56 mph (U.S. standard unit equivalents for speed limits posted with metric values). The average speeds were obtained from on-pavement sensors installed between a couple of days to a week at a site. The speed data were collected over a 5-year period. Only vehicles with a headway of 6 seconds or more (i.e., free flow) were used to determine the average speed. The speed data were linked to the crash frequency at each location during the same time frame, along with other factors such as road, traffic, and climate. The results showed the following as having statistically significant effects on crashes: average speed, traffic volume, segment length, median presence, and horizontal curve. Average speed was found to be positively correlated, indicating that a higher crash frequency is anticipated at road segments with higher average speeds.

Wang et al. (*35*) integrated spatio-temporal speed fluctuation of a single vehicle with speed differences between vehicles using taxi-based high-frequency global positioning system (GPS) data collected from 234 one-way urban arterial segments in Shanghai. The results showed that a 1 percent increase in mean speed was found to be related to a 0.7 percent higher crash frequency.

Percentage of Trucks Relationship with Operating Speed

Islam and El-Basyouny (*36*) showed that the proportion of vans, buses, and trucks was found to have a positive correlation with the free-flow speed.

Vehicle Characteristics Relationship with Operating Speed

Vehicle characteristics, such as vehicle class and vehicle age, also impact speed choice. Wasielewski (*37*) found that drivers of heavy vehicles chose a higher speed than drivers of passenger cars. Giles (*38*) also reached similar conclusions by observing that increases in vehicle length were associated with increased speeds. Studies have also found that newer vehicles seem to be driven at higher speeds than older ones (*37, 39*).

TRAFFIC CONTROL DEVICE

Posted Speed Limit Relationship with Crashes

The earliest study to examine the relationship between speed and crash rate was completed by Solomon (*14*). A subsequent study by Cirillo (*40*) in 1968 confirmed Solomon's findings by using both rural and urban roadways. To identify the relationship between safety and speed variance, Garber and Gadiraju (*41*) examined all types of roads in Virginia, including highways, arterials, and major rural collectors. The developed relationship did not follow Solomon's U-shaped curve. Fildes et al. (*39*) conducted a survey study by conducting interviews with drivers after observing operative speed relative to the speed limit on two urban (35 mph) roads in Australia. Numerous studies since Fildes et al. have sought to identify association between speed and safety. Elvik performed a meta-analysis (*42*) by incorporating 115 studies with 526 effect estimates. Greibe (*20*) found speed limit as a significant factor. Dixit et al. (*43*) found higher speeds were positively correlated with both rear-end and angle crash rates. Tay (*44*) found that crashes on roadways with lower posted speeds (35 mph to 45 mph) were more likely to occur in urban areas. Since higher speed requires longer stopping distance, studies identified a positive relationship between speed and crash counts (*45*, *46*) because higher speed requires longer stopping distance. The negative relationship found in Shi et al. (*47*) is mostly due to the selection of an expressway of interest that is located in the urban area with a high percentage of commuter traffic.

A 2016 study (*10*) matched average speed with crashes for 353 segments in the city of Edmonton, Canada. The study found that higher speeds were associated with more crashes; however, the direct effects of PSL on crash frequency were statistically insignificant. The authors noted that "it is the higher speeds on roads with higher speed limits that cause collisions and not the speed limits (i.e., PSLs affect collisions through their effects on speeds)."

A 2015 study by Islam and El-Basyouny (*36*) included 27 urban residential collector sites where the PSL was reduced from 31 mph to 25 mph. Another 287 sites where the PSL remained at 31 mph were selected as reference sites. All of the treated and reference sites were two-lane (one lane in each direction) urban residential collector road segments. The authors noted that "a comprehensive effort was made, involving various education and enforcement activities, as well as the placement of the new PSL signs along each of the segments. Three years of before and 3 years of after crash data were included in the analyses. The full Bayesian before-after evaluation found that the PSL reduction was effective in reducing crashes of all severities.

Posted Speed Limit Relationship with Operating Speed

Several studies have found posted speed limits have a significant effect on free-flow speed on urban streets (*48, 49, 50, 51, 52, 53, 54*). In 2001, Fitzpatrick et al. (*48*) considered data from 19 horizontal curve sites and 36 straight section sites on four-lane suburban arterials in Texas. When all variables were considered, posted speed limit was the most significant variable for both curves and straight sections. For typical suburban arterials (e.g., 30 to 45 mph), all speed limit values influenced operating speed. Other significant variables for curve sections were deflection angle and access density class. A later Fitzpatrick et al. study (*49*) modeled operating speeds at 78 suburban/urban sites in six states and only found posted speed limit as being a statistically significant predictor of the 85th percentile operating speed. Segment access density was included as a predictor of operating speed in a second model; however, it was not statistically significant. A study by Ali et al. (*50*) examined 35 four-lane urban street segments with posted speed limits between 35 and 45 mph. Median width and segment length ratio (defined as the ratio of study segment length to the maximum signal spacing) were also significant. Figureroa and Tarko (*51*) included both rural and suburban roadways. In addition to posted speed limit, they also found other variables that are statistically significant. Those most commonly associated with suburban roads would include intersection and driveway density along with the presence of a TWLTL.

More recent research has included larger numbers of study locations. A study conducted by Thiessen et al. (*53*) considered 249 tangent segments in Edmonton with equivalent posted speed limits ranging from 24.8 to 62.1 mph (values provided are converted from metric units). They found that arterials with higher PSLs had higher operating speeds. They offered a caution regarding the finding for the collector roads since most had the same posted speed limit. A study by Eluru et al. (*54*) considered 49 collectors, with about half having a 24.8-mph posted speed limit and the other half being 31.1 mph. They also studied 71 arterials with a posted speed limit range of 18.6 to 43.5 mph but with almost all being 31.1 mph. Posted speed limit was only significant for the arterial streets. A 2016 study (*10*) matched average speed with crashes for 353 segments in the city of Edmonton, Canada. The study found that higher average speeds were associated with higher PSLs.

Signalized Intersection Presence Relationship with Crashes

As report in 2013, nearly 21 percent of all crashes and 24 percent of all fatal and injury crashes occurred at signalized intersections in the United States (*55*). In place of examining the presence of a signalized intersection in safety estimation, many studies have used crashes associated with signalized intersections to identify the significant factors (*29*, *56*, *57*).

ROADWAY GEOMETRY

Horizontal Alignment Relationship with Crashes

Past studies have found mixed effects of horizontal curves. Hauer (*58*), Abdel-Aty and Radwan (*59*), and Bonneson et al. (*60*) suggested that sharper curvature would increase the likelihood of crash occurrences. Abdel-Aty and Abdalla (*61*) also found that the presence of horizontal curvature increases the likelihood of a crash occurrence. In contrast, Milton and Mannering (*62*), Haynes et al. (*63*), and Ahmed et al. (*64*) found that sharper horizontal curves were negatively related to crash frequency since drivers tend to drive slowly on those segments.

Horizontal or Vertical Alignment Relationship with Operating Speed

Using data from curved road segments in Australia, McLean (*65*) developed a regression model to predict speeds on horizontal curves. The study found that attributes of horizontal curves (e.g., radius of curve and degree of curvature) had major effects on driver speed choice. Fitzpatrick et al. (*66*) studied 14 horizontal curves and 10 vertical curves on suburban roadways in Texas. Regression analysis indicated that the curve radius for horizontal curves and the inferred design speed for vertical curves can be used to predict the 85th percentile speed on curves for vehicles on the outside lane of a four-lane divided suburban arterial.

A study by Poe and Mason (*67*) collected speed data for 27 urban collectors and found the degree of curve and grade as being significant variables. A study by Eluru et al. (*54*) for local streets found lower speeds for sites with higher vertical grades. In contrast, Yagar and Van Aerde (*68*) used data from Ontario, Canada, to develop a multiple linear regression model. The study found that road curvature had no statistically significant effects on speeds. Similarly, Fildes et al. (*39*) did not find significant differences in speed choice when comparing curved and straight segments.

Vertical Alignment Relationship with Crashes

Yanmaz-Tuzel and Ozbay (*69*) conducted a before-after analysis on four urban arterials in New Jersey with speed limits less than 45 mph. This study examined the effects of increases in lane width, installation of median barriers, and improvements to vertical and horizontal road alignments. Using a full Bayesian approach, this study observed reductions in crash rate after adjusting the vertical alignments.

Median Relationship with Crashes

The Yanmaz-Tuzel and Ozbay (*69*) study described above showed that the increase of median barrier installations was associated with crash rate reduction for an urban principal arterial site in New Jersey.

Two studies showed that installations of a TWLTL on urban four-lane roadways in Louisiana were associated with crash reductions (*70*, *71*). Rahman et al. (*70*) examined nine sites where the four-lane undivided (4U) cross-section was converted to a cross-section with four lanes and a TWLTL (5T). A reduction of crashes was experienced at all the sites, with an estimated overall crash modification factor (CMF) of 0.482. The relationship of CMF with driveway density showed that 4U to 5T conversion performed better in driveway densities up to 55 driveways per mile. The Sun et al. (*71*) study focused on two corridors in Louisiana where the four-lane undivided roadway was converted to a 5T. They found a reduction in crashes, especially in rear-end crashes.

A study by Schultz et al. (*72*) summarized research performed to identify relationships between access management and the safety characteristics of arterial road segments to better quantify the effectiveness of access management principles and techniques. The CMF Clearinghouse (*73*) reported that its study found a CMF of 0.29 for all crash types on urban principal arterials with the installation of a raised median.

Median Relationship with Operating Speed

In the 2001 Fitzpatrick et al. study (*48*), when the posted speed was not included in the model on curve sections, median presence and roadside development were significant variables with respect to operating speed. Speeds were lower when either the median with a TWLTL or no median was present as compared to when a raised median was present. This finding is similar to the Bonneson and McCoy study (*74*).

Median Width Relationship with Crashes

Previous studies suggested that wider median widths are associated with higher car and car-truck crash frequencies. Wider median widths allow greater degrees of spatial freedom for turning vehicles. Moreover, wider medians increase the likelihood of wrong-way driving. Medians with openings increase U-turn movements that have a negative effect on traffic safety. The potential for such problems is limited where crossroad and U-turn volumes are low but may increase at higher volumes (*30*). In the same context, increasing the median width also reduces rear-end, sideswipe, total, and fatal/injury crashes. Another study showed that a reduction in median width could increase rear-end, sideswipe, total, and fatal/injury crashes (*75*).

Median Width Relationship with Operating Speed

The study by Eluru et al. (*54*) found an increase in operating speeds for an increase in median width. Lu et al.'s (*76*) study also found that speed increases with the increase of median width.

Number of Lanes Relationship with Crashes

To develop safety prediction models for different geometric characteristics, EI-Basyouny and Sayed (*27*) conducted a study on 392 urban road segments in Vancouver. They found that the number of lanes is positively associated with crash frequency. Gomes (*28*) developed a crash prediction model for urban roads located in Lisbon, Portugal. He used a negative binomial (NB) model to examine crashes in relation to vehicle and pedestrian traffic flow and highway geometric design features. The crash prediction model identified that roadways with four lanes or more are associated with crash frequencies on urban roads.

Number of Lanes Relationship with Operating Speed

A study by Wang et al. (*77*) that considered 35 tangent corridors in Atlanta, Georgia, and a study by Eluru et al. (*54*) that considered 49 local streets and 71 arterials found that the number of lanes was positively associated with operating speed. Similar results were found in another study (*78*). Aarts et al. (*79*) developed the SaCredSpeed algorithm by using input data of design, image, and traffic characteristics to assess a safe speed and found the number of lanes as a significant variable, as opposed to the Lu et al. (*76*) study that did not find any association between number of lanes and speed.

Lane Width Relationship with Crashes

Yanmaz-Tuzel and Ozbay (*69*) observed that an increase in lane width is associated with crash rate reduction. Other studies indicated that drivers show improved lane keeping, more accurate steering behavior, and reduced driving speed with decreased lane width (*80*). The results in Dong et al.'s (*30*) study show that decreased lane width has positive effects on intersection safety for passenger cars. The safety effects of the roadways with narrow lane width can be higher than the roadways with wide lane width for specific roadway conditions (*81*, *82*).

Lane Width Relationship with Operating Speed

In the 2001 Fitzpatrick et al. (*48*) study, when the posted speed was not included in the model, only lane width was a significant variable for straight sections, with higher speeds associated with wider lane widths. The study by Poe and Mason (*67*) found lane width as being one of the significant variables. Speeds increase on wider lanes for the tangent segment and decrease for wider lanes at the point of curvature and the midpoint of the curve, attributed to wider lanes within the curve. Yagar and Van Aerde (*68*) used data from Ontario, Canada, to develop a multiple linear regression model. Lane width was found to be statistically significant. The findings of Islam and El-Basyouny (*36*) contradicted the common finding that wider roadways encourage speeding.

Shoulder Width Relationship with Crashes

Haleem et al. (*75*) found that increasing the outside shoulder could reduce the total, rear-end, and fatal/injury crashes.

Curb or Shoulder Relationship with Operating Speed

A study by Wang et al. (*77*) considered 35 tangent corridors in Atlanta, Georgia, and found the presence of curb as being positively associated with operating speed.

Bicycle Lanes Relationship with Crashes

Park et al. (*83*) estimated the safety effectiveness of bike lanes using the cross-sectional method. This study showed that installation of bike lanes has positive safety effects on reducing four different crash types: total crashes, injury crashes, bike crashes, and bike injury crashes. Chen et al. (*84*) evaluated the safety effects of the installation of on-street bicycle lanes in New York. The results showed that the installation of bicycle lanes did not lead to an increase in crashes. One possible explanation is that speeding nature and number of collisions between vehicles and bicyclists decreased due to the presence of bike lanes. Sadek et al. (*85*) performed a survey analysis on bike lane installations. The results showed that bike lanes increased awareness of drivers and bicyclists. On the other hand, Rodegerdts et al. (*86*) suggested that adding a bike lane reduces bike-related crashes (KABCO). Nosal and Miranda-Moreno (*87*) estimated the injury risk of bicycle facilities (cycle tracks, bicycle lanes) and explored the differences in injury risk between different types of bicycle facilities in Montreal, Canada. The study compared injury risk between the treated sites and control streets to assess the impact of bicycle facilities. The results showed that the safety effects of cycle tracks and bicycle lanes of treated streets were higher than the corresponding control streets. Similar to this study, Lusk et al. (*88*) also found that relative risk of riding bicycles on the cycle tracks versus on regular streets was lower in injury rates. Reynolds et al. (*89*) reviewed 23 studies that assessed the effect of transportation infrastructure on bicyclist safety. Based on the previous studies that examined impacts of infrastructures at straightaways (e.g., bike lanes or paths) and intersections (e.g., roundabouts, traffic lights), they found that bicycle-specific facilities generally reduced crashes and injuries. On the other hand, Jensen (*90*) concluded that adding a bike lane increased frequencies of all crashes (KABCO, KABC) and bike crashes (KABCO) for roadways in Copenhagen, Denmark.

Bicycle Lane Presence Relationship with Operating Speed

The study by Eluru et al. (*54*) that considered 49 local streets of Montreal along with the study by Thiessen et al. (*53*) of 249 tangent segments in Edmonton found the presence of bicycle lanes being associated with higher vehicle speeds. They commented that the variable was probably a reflection that bicycle lanes are typically installed on wider roads with high vehicular flow.

Segment Length Relationship with Crashes

EI-Basyouny and Sayed (*27*) collected data from 392 arterials in Vancouver, British Columbia, and found segment length as a significant factor. Wang et al. (*91*) extracted GPS data from taxis operating on Shanghai's urban roadways. They observed that segment length is positively related to crash frequency. This finding is in line with Greibe's (*20*) findings that longer segment lengths are associated with higher crash frequencies.

Segment Limit Relationship with Operating Speed

The roadway features that define the end limits of a segment along with the length of the segment can obviously influence operating speed. For example, a signalized intersection can cause a vehicle to need to either accelerate from a stop or decelerate to a stop. Selecting speed measurement points away from such influences would allow a study to focus on other roadway features; however, in an urban environment, sufficient distances between influential end features may not be common. In the Thiessen et al. (*53*) study of 249 tangent segments in Edmonton, an increase in speed was found with an increase in segment length.

Intersection Angle Relationship with Crashes

Dong et al. (*30*) found that intersection angle is associated with car, car-truck, and truck crash frequencies.

Intersection Lighting Relationship with Crashes

Intersection lighting has a statistically significant impact on the crash count for all crash types (*30*). As expected, intersection lighting appears to significantly decrease car, truck, and car-truck crash frequencies.

On-Street Parking Relationship with Operating Speed

A study by Wang et al. (*77*) that considered 35 tangent corridors in Atlanta, Georgia, and a study by Eluru et al. (*54*) that considered 49 local streets found the presence of on-street parking to be negatively associated with operating speed. Nissan et al.'s (*92*) study concluded that the frequency of parking maneuvers along the roads significantly reduces moving vehicles' speed. These results are in line with other studies (*93*).

SURROUNDINGS/ROADSIDE

Access Density (Driveways and Intersections) Relationship with Crashes

Ferreira and Couto (*29*) found that the density of minor intersections is associated with crash counts. Driveway density is positively correlated with crash frequencies (*95*). EI-Basyouny and Sayed (*27*) found that unsignalized intersection density is positively correlated with crash frequency. This result is in line with the findings from Wang et al. (*91*).

Urban interchange ramp density has a positive influence on the crash frequency (*94*).

Access Density (Driveways and Intersections) Relationship with Operating Speed

Several measures have been used to represent the presence or quantity of interruptions within a suburban or urban street, including the presence of an intersection or signalized intersection within the segment or the number of driveways and/or intersections, sometimes expressed as density (number of access points within a mile).

A study by Wang et al. (*77*) found driveway density and T-intersection density as being negatively associated with operating speed. The study by Eluru et al. (*54*) found operating speed decreased as access increased. By using data from Shanghai's 50,000+ taxis equipped with GPSs, Wang et al. (*95*) found that speed variation would increase as access points increased in the urban arterials.

School/School Zone Relationship with Crashes

The presence of a school zone requires a driver's careful attention in speed reduction and cautious driving. Many studies examined different factors associated with school-zone-related crashes. The dominant factors were types of school zones (school zone compared to playground) (*44, 96*), types of schools (*97*), number of lanes (*44*, *96*), and length of speed zone (*96*).

School/School Zone Relationship with Operating Speed

School zones are used to reduce operating speeds during select times of the day when students are moving between home and school. Several studies have investigated the relationship between the school zone speed limit and operating speed (*98, 99, 100, 101, 102*). While speeds are typically lower during an active school zone, drivers are still not in full compliance with the speed limit.

Parking Relationship with Crashes

Greibe (*20*) found parking as a statistically significant factor. Islam and El-Basyouny (*36*) observed that the presence of street parking was associated with an increase in property damage only (PDO) crashes but demonstrated a statistically insignificant association with severe crashes. Since street parking leaves fewer driving spaces on the road, there is a high likelihood of crash involvement. Few studies (*103, 104*) found association between parking and crashes associated with older pedestrians and bicyclists.

Liquor Store Relationship with Crashes

Islam and El-Basyouny (*36*) found that the presence of licensed liquor stores was associated with increases in severe and PDO crashes. This result is intuitive since the percentage of impaired driving is expected to be higher near licensed premises.

Sidewalk Presence Relationship with Operating Speed

Wang et al. (*77*) found that the presence of sidewalks was negatively associated with operating speed. The study by Eluru et al. (*54*) that considered 49 Montreal local streets found that the number of sidewalks (coded as 0, 1, or 2) tended to increase vehicle speed; however, they cautioned that the variable had a large standard deviation. In the Thiessen et al. (*53*) study, sidewalks were categorized by whether they were connected to the curb and gutter (called monolithic walk) or if there was a space between the curb and sidewalk (called boulevard walk). They found that roads with sidewalks that were farther away from the road (boulevard) were associated with higher operating speed, while locations with monolithic walks on both sides of the road had lower operating speeds. Other studies have shown that vulnerable road users along the road or crossing the road significantly influence vehicle speed and road capacity (*105, 106*).

Roadside Hazard Rating or Pole/Tree Density Relationship with Operating Speed

The study by Poe and Mason (*67*) found roadside hazard rating to be one of the significant variables for tangents and within horizontal curves. A study by Wang et al. (*77*) found that roadside density was negatively associated with operating speed. Roadside density was defined as the density of trees and utility poles (number/mile) divided by their average offset from the roadway. The study by Eluru et al. (*54*) found that roads with low object density and/or tree density were associated with higher operating speed.

Development (Surrounding Land Use) Relationship with Operating Speed

In the 2001 Fitzpatrick et al. (*48*) study, when posted speed was not included in the model, median presence and roadside development were significant variables for curve sections. The categories used within roadside development included residential, commercial, park, or school. A study by Wang et al. (*77*) found that commercial and residential lane use was positively associated with operating speed. The study by Eluru et al. (*54*) found the type of development to be significant (categorized as being either downtown commercial, mixed high to medium density, mixed low density, and open urban). Mixed low-density areas had the highest operating speed, while the mixed high to medium density had the lowest operating speeds. Wilmot and Khanal (*107*) mentioned that land use plays a role in driver perception of a safe speed limit at a certain location. On arterial roads, locations of direct control land use recorded the highest compliance rates with a relative drop in probability in both commercial and agricultural areas by 39 percent and 94 percent, respectively, in the study of Gargoum et al. (*108*). It is worth noting that Marshall et al. (*93*) and Lu et al. (*76*) also observed significance of land use in operating speed.

OTHER VARIABLES

One-Way or Two-Way Relationship with Operating Speed

In the Thiessen et al. (*53*) study of 249 tangent segments in Edmonton, one-way roads had lower operating speeds when compared to two-way roads. This finding agrees with a study that used 49 local street segments in Montreal by Eluru et al. (*54*).

Functional Classification Relationship with Operating Speed

Thiessen et al. (*53*) subdivided their data into collectors and arterials. They identified different variables as being significant between the two functional classes. For example, the presence of a pedestrian crossing was significant in the collector model but not in the arterial model. They also found that some of the variables had an opposite effect on arterials compared to collectors. For example, the presence of bus stops was associated with higher speeds on arterials and lower speeds on collectors.

Weather Relationship with Operating Speed

Wilmot and Khanal (*107*) found that weather conditions play a role in the driver's perception of a safe speed limit at a certain location. Giles (*38*) observed the effects of weather condition and found that regardless of the posted speed limit, inclement weather does have an effect on driver speed choice. Gargoum et al. (*108*) found that dry and fine weather encouraged significantly higher speeds compared to wet and cloudy conditions. Although visibility is weather related, Gargoum et al. (*108*), similar to the findings of Goldenbeld and Van Schagen (*109*), concluded that a driver's perceived safe speed limit is higher on good visibility roads where vegetation or trees are less or absent. Romancyshyn et al. (*110*) showed snow as a hindrance to travel speed on urban arterials. Rising temperature was found to slightly increase travel speeds as it increased.

Time of the Day Relationship with Operating Speed

One study by Giles (*38*) observed the effects of the time of day and determined that regardless of the PSL, this factor does have an effect on driver speed choice. The effect of time of day on speed limit violations was also assessed by Nouvier (*111*) using data from France. The study found that non-compliance was more common in the early morning compared to midday. Similarly, ONISR (*112*) also found that more violations were observed at night compared to daytime. For local roads, Eluru et al. (*54*) showed that the only temporal variable that was significant in the analysis for local roads was the late-night hours (12 a.m.–6 a.m.) indicator variable. The variable indicates that vehicle speed during these time periods is usually lower than other time periods. Drivers were most likely careful during these times on local roads. Islam and El-Basyouny (*36*) showed that the parameter for the time-of-day indicator was found to be negative and therefore indicated that nighttime hour was associated with a higher free-flow speed than daytime hour. Bassani et al. (*113*) showed that average speeds and deviations from the average speed are significantly affected by changes in lighting parameters for the different weather condition and time of the day.

OVERVIEW OF VARIABLE RELATIONSHIP WITH SPEED AND CRASHES

Based upon information in the literature, several roadway segment characteristics are known or suspected to affect a driver's speed choice and the likelihood of crashes. Table 1 summarizes the factors that affect crashes on urban/suburban city streets. Table 2 summarizes the characteristics that affect operating speed on urban/suburban city streets. In general, the following relationships were found:

- Operating speeds decrease as the access density increases.
- Operating speeds decrease as the roadside becomes fuller with objects.
- Operating speeds are higher with higher posted speed limits.
- Operating speeds are lower on horizontal curves with small radii or larger deflection angle.

Table 1. Factors of urban/suburban city streets that affect crashes.

Category	Factor	Key Findings	Source
Traffic control device	Posted speed limit	Mixed effect	*14, 20, 36, 39, 40, 41, 42, 43, 44, 45, 46, 47, 69*
Traffic control device	Presence of signalized intersection	Positively associated	*29, 55, 56, 57, 36*
Traffic	AADT	Positively associated	*10, 19, 20, 21, 22, 23, 24, 25, 26, 30, 27, 28, 29*
Traffic	Congestion	Positively associated	*31, 32*
Traffic	Operating speed	Mixed effect	*10*
Traffic	Percent trucks	Negatively associated with crash frequencies, positively associated with car-truck crash frequencies	*34*
Surroundings	Access density	Positively associated	*63, 27, 91, 29, 94, 89*
Surroundings	Liquor store	Positively associated	*36*
Surroundings	Parking	Positively associated	*20, 36*
Surroundings	Schools	Negatively associated	*96, 97, 44*
Geometry	Bike lanes	Negatively associated	*83, 84, 85, 87, 88, 89, 90*
Geometry	Horizontal alignment	Mixed effect	*10, 58, 59, 60, 61, 62, 63, 64*
Geometry	Intersection angle	Positively associated	*30*
Geometry	Intersection lighting	Negatively associated	*30*
Geometry	Lane width	Mixed effect	*30, 69, 80, 81, 82*
Geometry	Median	See references	*10, 69*
Geometry	Median width	Positively associated	*30, 75*
Geometry	Number of lanes	Positively associated	*27, 28*
Geometry	Segment length	Positively associated	*10, 20, 27, 91*
Geometry	Shoulder width	Negatively associated	*62*
Geometry	Vertical alignment	See reference	*69*

Table 2. Factors of urban/suburban streets that affect operating speed.

Category	Factor	Key Findings	Source
Traffic control device	Posted speed limit	Positively associated	*10, 48, 50, 51 52, 53, 54*
Traffic	Percent trucks	Positively associated	*36*
Surroundings	Access density	Negatively associated	*54, 77*
Surroundings	Development	Negatively associated	*48, 54, 77, 76, 93, 107, 108*
Surroundings	Hazard ratings	Negatively associated	*54, 67, 77*
Surroundings	Presence of sidewalks	Negatively associated	*53, 54, 77, 105, 106*
Surroundings	Schools/school zones	Negatively associated	*98, 100, 101, 102*
Geometry	Horizontal or vertical alignment	Mixed	*54, 65, 66, 67, 68, 39*
Geometry	Lane width	Positively associated	*48, 67, 68, 36*
Geometry	Median		*48, 74*
Geometry	Median width	Positively associated	*54, 76*
Geometry	Number of lanes	Positively associated	*77, 78, 79, 76*
Geometry	Parking	Negatively associated	*54, 77, 92, 93*
Geometry	Presence of bike routes	See references	*53, 54*
Geometry	Segment limits	Positively associated	*53*
Geometry	Shoulder or curb	See reference	*77*
Other factors	Functional classification	See reference	*53*
Other factors	One way or two way	One-way roads had lower operating speeds compared to two-way roads	*53, 54*
Other factors	Time of the day	Positively associated in nighttime	*54, 36, 38, 111, 112*
Other factors	Vehicle characteristics	Positively associated (new, heavy and long vehicles) with operating speed	*39, 37, 38*
Other factors	Weather	Negatively associated	*107, 108, 38, 109*

APPENDIX B. RELATIONSHIP AMONG ROADWAY CHARACTERISTICS, SPEED, AND SAFETY FOR HIGH-SPEED HIGHWAYS

Several factors are known or suspected to affect safety on rural or high-speed highways, such as horizontal/vertical alignment, shoulder width, passing zone and passing lane presence, and access point density. As documented in the Transportation Research Board (TRB) *Modeling Operating Speed Synthesis Report* (*114*), several factors influence operating speed. Most studies focused on how horizontal curvature influences the free-flow speed selected by roadway users. The following sections discuss the findings reported in the research literature on the relationship among crashes, operating speed, and rural highway roadway characteristics including posted speed limit.

Note that the goal of this literature review was to identify variables that influence driver speed choice as well as crash potential. These variables were then considered for inclusion in the SLS-Procedure that was the key objective for this research project (NCHRP Project 17-76).

TRAFFIC—VEHICLES

Average Daily Traffic Relationship with Crashes

The amount of AADT present is associated with crashes (*115*). The relationship between traffic and crashes can be affected by whether the section is undivided or divided (*115*). Nightingale et al. (*116*) investigated the influence of factors affecting crash frequency at high-speed rural intersections. The study found that AADT of both major and minor roadways is positively associated with crash frequencies.

Average Daily Traffic Relationship with Operating Speed

The amount of AADT present may be associated with operating speed (*115*). For two-lane rural highways, Lamm et al. (*117*) found that speed increases as AADT increases, while Jessen et al. (*118*) found lower speeds to be associated with higher AADT. The AADT for the Lamm et al. study ranged from 400 to 5,000 vehicles per hour (vph). The Jessen et al. study is valid for AADTs less than or equal to 5,000 veh/d; the researchers in this study commented that motorists may view increases in volume as a motivation to slow down. Robertson et al. (*119*) conducted a study on four-lane highways and found that the hourly directional volume was significant for cars during the day, with higher speeds associated with a larger volume. However, the increase was small and the range of volume available was not very large for a highway (average of 379 vph during daytime). In another study, Dong et al. (*120*) found that AADT is associated with different speed profiles.

Percent Trucks Relationship with Crashes

Prior research has demonstrated that the percentage of commercial trucks is associated with an increase in observed crashes (*115*).

Percent Trucks Relationship with Operating Speed

Robertson et al. (*119*) and Himes and Donnell (*121*) identified the percentage of trucks as a relevant factor in their study of rural four-lane highways.

Operating Speed Relationship with Crashes

A study using 179 roadway sections in Israel explored the relationship between free-flow speeds (obtained from GPS devices) and crashes on rural, two-lane highways with a typical speed limit of 50 mph (*9*). NB statistical models were developed, and these models considered day hours and night hours separately. The models used speed indicators, section length, traffic volume, and homogeneous road groups, where the road groups reflected various road design conditions. The main finding of the study was that in both day and night hours, the number of injury crashes increased with an increase in the segment mean speed, while controlling for traffic exposure and road infrastructure conditions.

Wang et al. (*122*) reviewed several previous studies to identify factors, especially traffic and road-related factors, related to crashes. They concluded that some studies found increased speed reduces safety and other studies found the opposite. Another observation was that "speed itself may not be a safety problem but speed variation is."

TRAFFIC CONTROL DEVICES

Posted Speed Limit Relationship with Crashes

For rural high-speed highways, posted speed limits are typically established with consideration of several factors, including the roadway design speed. Vehicular operating speeds along tangent sections of two-lane highways have been shown to be impacted by the posted speed limit, with vehicular speeds tending to increase as the posted speed limit increases (*123, 124*). However, the magnitude of the increase in operating speed is typically only a fraction of the amount of the actual speed limit increase. For undivided roadways, mean speeds generally increase by 3 to 5 mph for every 10-mph increase in speed limit above 55 mph, with diminishing effects at higher speed limits (*123, 125, 126*).

The research literature generally suggests that the resulting change in operating speeds would likely lead to an increase in the overall crash rate and would shift the severity distribution toward crashes of greater severity (*123*). Specifically, Kockelman showed that increasing the non-freeway speed limit would increase the total crash rate, and the probability of a fatality would increase. The injury crash probability was also expected to increase with increasing speed limits, while the property damage crash probability was expected to decrease slightly. The study by Park et al. (*127*) conducted a full Bayesian before-after safety evaluation based on 33 treatment sites and 44 comparison sites to assess the effects of decreasing speed limits on crashes on expressways in Korea. They found that the reductions in speed limit were associated with reductions in crashes. Russo et al. (*128*) found that increased speed limits led to a statistically significant increase in fatal and injury crashes (around 11 percent). Warner et al. (*129*) showed that increased posted speed is associated with higher fatal crashes.

Gayah et al. (*130*) examined the operational and safety impacts of setting posted speed limits below engineering recommendations. The exploration on the rural roads in Montana showed a statistically significant reduction in total, fatal and injury, and non-injury crashes at segments with posted speed limits set 5 mph lower than engineering recommendations.

Wilmot and Jayadevan (*131*) used a Louisiana crash database for 1999–2004 to examine crash rates before and after a speed limit change on rural roads. The findings showed that increase in posted speed limit had an impact on crash rate for six out of the 39 cases at the 5 percent level of significance.

Posted Speed Limit Relationship with Operating Speed

For rural high-speed highways, posted speed limits are typically established by taking several factors into consideration, including the roadway design speed. Vehicular operating speeds along tangent sections of two-lane highways have been shown to be impacted by the posted speed limit, with vehicular speeds increasing as the posted speed limit increases (*123, 124, 118*). Operating speed has also been found to be related to posted speed on curves (*132, 118*).

The magnitude of the change in operating speed when there is an increase (or decrease) in posted speed is typically only a fraction of the amount of the actual speed limit change (*123, 125, 126, 133*). For undivided high-speed rural roadways, mean speeds are generally 3 to 5 mph higher for every 10-mph increase in speed limit above 55 mph, with smaller increases at higher speed limits (*123, 125, 126*). Hu (*134*) showed that raising the posted speed limit from 75 to 80 mph on rural interstate roadways leads to higher travel speeds and an increased probability of exceeding the new speed limit.

The *Highway Capacity Manual* (HCM), version 6.0 (*135*), states in Exhibit 12-18 that the base free-flow speed under ideal conditions exceeds the speed limit by 5 mph for freeway segments with a posted speed limit range of 55 to 75 mph as well as for multilane highway segments with a posted speed limit of 45 to 70 mph. The HCM also provides additional information in Chapter 12 about adjusting the freeway free-flow speed using adjustment factors for lane width, right-side lateral clearance, and total ramp density. The adjustment factors for multilane highway segments include lane width, total lateral clearance, median type, and access point density.

Dixon et al. (*136*) reviewed speed data for 12 rural multilane sites in Georgia to evaluate the effects of repealing the 55-mph national speed limit. They found that operating speeds were higher after the increase in the posted speed limit. Himes and Donnell (*121*) identified the posted speed limit as relevant to their study of rural four-lane highways. Robertson et al. (*119*) found the daytime posted speed limit to be a significant variable based on data from 36 rural four-lane non-limited-access roadways. The findings from Gayah et al. (*130*) showed that operating speeds closely comply with the posted speed limit when the posted speed limit is set equal to or 5 mph lower than engineering recommendations.

No-Passing Zone Relationship with Crashes

In a Michigan study, as the proportion of each segment with no-passing zones increased, the frequency of total and injury crashes also tended to increase (*115*).

Passing Lane Relationship with Crashes

While the presence, length, and location of passing zones on two-lane highways likely has an effect on their safety performance, this effect has not been well documented in the previous literature. In fact, the HSM (*16*) notes the following treatments related to passing zones as having an unknown effect on traffic crashes:

- Different passing sight distances.
- Presence of access points/driveways around no-passing zones.
- Different lengths of no-passing zones.
- Different frequency of passing zones.
- Passing zones for various weather, cross-section, and operational conditions (*16*).

Passing Lane Relationship with Operating Speed

Freedman and Kaisy (*137*) investigated the passing maneuvers within a passing lane section on a rural two-lane, two-way highway located on a U.S. highway in Montana. This study considered speed differentials for different passing maneuvers.

ROADWAY GEOMETRY

Horizontal Alignment Relationship with Crashes

Horizontal curves have been identified as the geometric variable that is the most influential on driver speed behavior and crash risk (*138*). Horizontal curves with radii less than 2,600 ft tend to cause highway operating speeds to drop below those of adjacent tangent sections, with substantial speed declines in speed observed for curves with radii less than 800 ft (*139*).

Horizontal alignment is also associated with negatively affecting safety, as shown in the HSM (*16*). Prior research has shown that crash frequency increases with the length and/or degree of horizontal curvature (*115, 123, 140, 141, 142, 143,*). On two-lane rural highways, design speed at horizontal curves inconsistent with a driver's desired speed could create operating speed irregularities by increasing the driver's work load, which may incur higher crash potential (*138, 144*), particularly if operating speeds through the curve are reduced by more than 3 mph from the adjacent tangent section (*138*). Camacho-Torregrosa et al. (*145*) developed safe operating speed profiles for 33 Spanish two-lane rural road segments (including curved segments) and checked several consistency measurements based on the global and local operating speed.

Horizontal Alignment Relationship with Operating Speed

Horizontal curves have been identified as the geometric variable that is the most influential on driver speed behavior and crash risk. Two-lane rural highway studies that have found a horizontal curvature measure include Wooldridge et al. (*138*), Lamm et al. (*117*), Morrall and Talarico (*146*), Islam and Senevirantne (*147*), Krammes et al. (*148*), Voigt and Krammes (*149*), Passetti and Fambro (*150*), McFadden and Elefteriadou (*151*), Fitzpatrick et al. (*152*), Gibreel et al. (*153*), Schurr et al. (*132*), Figueroa and Tarko (*78*), and Misaghi and Hasson (*154*). The measures used in the studies varied and included degree of curve, length of curve, deflection angle, and/or superelevation rate.

Horizontal curves with radii less than 2,600 ft tend to cause highway operating speeds to drop below those of adjacent tangent sections, with substantial speed declines observed for curves with radii less than 800 ft (*139*).

Polus et al. (*124*) used the characteristics of the horizontal curves prior to and following a tangent, along with the tangent length, to predict the 85th percentile speed.

A study on rural four-lane highways in Kentucky (*155*) developed a speed prediction model that considered factors like lane (inside or outside), horizontal curve length or radius, and indicator variables for shoulder type (surfaced), median barrier presence, pavement type (concrete or asphalt), approaching section grade, and curve presence on approach. In a study on rural four-lane highways in Texas (*119*), the angle of the next downstream horizontal curve influenced the speed of the daytime car drivers on the approach tangent. Bassani et al. (*156*) showed that an increase in the horizontal alignment results in a decrease in the observed average speed. Llopis-Castello et al. (*157*) analyzed truck speeds on 105 horizontal curves of rural two-lane roadways. The study showed that the radius of the horizontal curve and the grade at the point of curvature have a significant influence on heavy vehicle speeds.

Vertical Alignment Relationship with Crashes

Prior research has shown that steeper vertical alignments could induce higher crash potentials (*16*, *123*). Total crash rates typically increased with the degree of vertical alignments (*123*), mainly in the presence of hidden horizontal curves, intersections, or driveways (*158*). Safety risks associated with higher speed limits increased on segments with steeper vertical curves (*123*). Furthermore, Kyte (*159*) suggested that vertical alignment is associated with higher crash likelihood in wet-weather conditions.

Vertical Alignment Relationship with Operating Speed

Fitzpatrick et al. (*152*) conducted a study on two-lane rural highways and determined that passenger car speeds on vertical curves with limited sight distance and horizontal tangent could be predicted using the rate of vertical curvature as the independent variable. Fambro et al. (*160*) used inferred design speed to predict the 85th percentile speed on vertical curves. Jessen et al. (*118*) reported that the approach grade affected vehicle speeds at the location with minimum available sight distance along the crest vertical curve. They also commented that the posted speed of the road had the most influence on speed. Schurr et al. (*132*) found that speed decreases as approach grade increases on horizontal curves. Figueroa et al. (*78*) found decreasing speed as grade increases on tangents. In another study, Gibreel et al. (*153*) included several vertical alignment measures in their speed prediction models for horizontal curves combined with vertical curves, such as length of vertical curve and grades.

For rural two-lane highway tangent sections with a non-limited crest vertical curve or a sag vertical curve, the recommendation was to assume the desired speed as being the expected 85th percentile speed. A study on rural four-lane highways in Kentucky (*155*) found the approaching section grade to be related to operating speed. Llopis-Castello et al. (*157*) showed that the difference between both speed percentiles was lower as the grade increased for the loaded trucks. On the contrary, the speed difference increased as the grade increased for unloaded trucks.

Terrain Relationship with Crashes

Rolling terrain, which may serve as an indication of vertical curvature, has been associated with an increase in crashes for undivided highways (*115*). Garach et al. (*161*) developed SPFs for Spanish two-lane rural highways on flat terrain.

Median Relationship with Crashes

The presence of a median on multilane, non-freeway facilities could decrease expected crash rates. Kockelman showed that the inclusion of a median on a multilane roadway was associated with an approximate 9 percent reduction in traffic crash rates (*123*).

A Michigan study found that the presence of a TWLTL was associated with a significant increase in total and injury crashes but was also associated with a significant decrease in fatal crashes (*115*).

Median Width Relationship with Crashes

Hu and Donnell (*162*) found that narrower medians are associated with severe injury outcomes in cross-median crashes.

Median Relationship with Operating Speed

A study on rural four-lane highways in Kentucky (*155*) found that the presence of a median barrier is related to operating speed. Dong et al. (*120*) conducted speed studies at 32 sites that had been upgraded from two-lane roadways to four- or five-lane roadways. The study found that median type is associated with different speed profiles.

Median Width Relationship with Operating Speed

Dong et al. (*120*) found that median width is associated with different speed profiles.

Number of Lanes Relationship with Crashes

A Michigan study found that four-lane, undivided facilities tended to observe significantly more crashes across all severity levels compared to two-lane, undivided facilities (*115*).

Lane Width Relationship with Crashes

Past research has shown that the width of travel lanes is related to the safety performance of both two-lane and multilane highways (*16*). Wider lanes in particular have been associated with reductions in single-vehicle run-off-the-road, head-on, and sideswipe type crashes (*16*). It is important to note that the effect of lane width on safety performance is reduced for multilane highways compared to two-lane highways (*163*).

Lane Width Relationship with Operating Speed

For two-lane rural highways, Lamm et al. (*117*) found that speeds increase with wider lane width, while Figueroa et al. (*78*) found a similar relationship using pavement width. Bassani et al. (*156*) found that an increase in pavement width results in both an increase in mean speed and a decrease in speed deviation along tangent segments.

Shoulder Width Relationship with Crashes

The HSM suggests that the width of the paved shoulder along non-freeways has a similar effect on crashes as travel lane widths (*16*). This occurs partially due to the increased recovery and vehicle storage space as well as increased separation from roadside hazards. While this effect depends on traffic volumes, the frequency of traffic crashes tends to increase as paved shoulder widths are reduced below 6 ft. Furthermore, safety performance decreases as the paved shoulder width decreases below 2 ft on roadways with greater than 2,000 vehicles per day (veh/d) (*16*).

Shoulder Width Relationship with Operating Speed

For two-lane rural highways, Lamm et al. (*117*) found that speeds increase with wider shoulder width. A study on rural four-lane highways in Kentucky (*155*) found the presence of shoulders to be related to operating speed. In a study on rural four-lane highways in Texas (*119*), the left and right shoulder widths influenced the speed of daytime car drivers.

Lane Position Relationship with Operating Speed

Himes and Donnell (*121*) measured different speeds in the left and right lanes for rural and urban four-lane highways and identified the following variables as relevant to their study: heavy vehicle percentage, posted speed limit, and adjacent land use. Gong and Stamatiadis (*155*) also found the factor of whether the lane was inside or outside to be significant in their study on rural four-lane highways in Kentucky.

SURROUNDINGS

Access Density (Driveways and Intersections) Relationship with Crashes

Prior studies have demonstrated that as the density of access points (or the number of intersections and/or driveways per mile of highway) increases, the frequency of traffic crashes also increases (*16, 164, 165*). This occurs partially due to driving errors caused by intersections and/or driveways that may result in rear-end and/or sideswipe type crashes (*16*). Specifically, *NCHRP Report 420* concluded that an increase in crashes occurs due to the higher number of access points (*165*).

The density of access points significantly affected the safety performance of undivided and divided highways in a Michigan study (*115*). The following were identified:

- Undivided segments that included 5–15 access points per mile tended to observe approximately 20 percent more total crashes than those segments with fewer than five access points per mile. Further, undivided segments that included greater than 15 access points per mile were associated with increases in observed crashes across all severity levels (*115*).
- The number of access points per mile also had a significant impact on the frequency of total and injury crashes. Divided segments that included 10–20 access points per mile observed an increase of approximately 24 percent for total crashes and an increase of approximately 27 percent for injury crashes compared to segments with fewer than five access points per mile. Furthermore, divided segments that included greater than 20 access points per mile observed a 73 percent increase in total crashes and a 96 percent increase in injury crashes compared to segments with fewer than five access points (*115*). These effects are much more pronounced than those for undivided segments. The findings are in general agreement with prior research, which has shown the number of access points to have a significant impact on safety performance, particularly at densities greater than 20 per mile (*165*).

Access Density (Driveways and Intersections) Relationship with Operating Speed

Figueroa et al. (*78*) found lower speed when an intersection was present for two-lane rural highways. Gong and Stamatiadis (*155*) conducted a study on four rural four-lane highways in Kentucky and found access point density to have an inverse relationship with vehicular speeds; mean speeds decrease as the density of access points increases.

For rural four-lane non-limited-access roadways, Robertson et al. (*119*) found the number of access points significant for only trucks during the daytime. The researchers hypothesized that drivers changed lanes to avoid the effects of vehicles entering and exiting driveways because there were two lanes and relatively low volumes. The dataset also included only free-flow speeds, so vehicles close to each other, which could happen at a driveway access point, were removed.

Urban or Rural Relationship with Crashes

Whether the roadway segment is in a rural area or an urban area has been found to be significantly related to crashes (*115*).

School Relationship with Crashes

Larger numbers of schools near a roadway segment have been found to be associated with a greater number of crashes (*115*).

Development (Surrounding Land Use) Relationship with Operating Speed

Figueroa et al. (*78*) found lower speed to be associated with residential development for two-lane rural highways. Himes and Donnell (*121*) identified adjacent land use as relevant to their study of rural four-lane highways.

OTHER VARIABLES

Time of the Day Relationship with Operating Speed

Robertson et al. (*119*) identified time of day as relevant to their study of rural four-lane highways.

OVERVIEW OF VARIABLE RELATIONSHIP WITH SPEED AND CRASHES

Based upon information in the literature, several roadway segment factors are known or suspected to affect a driver's speed choice and the likelihood of crashes. Table 3 summarizes the high-speed highway factors that affect crashes. Table 4 summarizes the high-speed highway factors that affect operation speed.

Table 3. Factors of high-speed highways that affect crashes.

Category	Factor	Key Findings	Source
Traffic control device	Passing lane or no-passing zone(s), length or percent of segment	Unknown	*16*, *115*, *116*
Traffic control device	Posted speed limit	Mixed effect	*123*, *124*, *125*, *126*, *127*, *128*, *129*, *130*, *131*
Traffic	AADT, percent trucks or commercial AADT	Positively associated	*115*, *116*
Traffic	Operating speed	Mixed effect	*9*, *122*
Surroundings	Access (driveways and intersections)	Negatively associated	*16*, *115*, *164*, *165*
Surroundings	Development (e.g. school)	Positively associated	*115*
Roadway geometry	Horizontal alignment, terrain	Positively associated	*138*, *139*, *16*, *140*, *141*, *142*, *143*, *115*, *144*, *145*, *161*
Roadway geometry	Vertical alignment	Positively associated	*16*, *158*, *159*, *123*
Roadway geometry	Median type (e.g., undivided, divided)	Two-way left-turn lane associated with a significant increase in total and injury crashes but also associated with a significant decrease in fatal crashes	*115*, *123*
Roadway geometry	Median width	Negatively associated	*162*
Roadway geometry	Number of lanes	Positively associated	*115*
Roadway geometry	Lane width	Negatively associated	*16*, *163*
▪ Roadway geometry	Shoulder (paved) width	Negatively associated	*16*

Table 4. Factors of high-speed highways that affect operating speed.

Category	Factor	Key Findings	Source
Traffic control device	Passing lane present	Speed differentials for different passing maneuvers	*137*
Traffic control device	Posted speed limit	Positively associated	*123, 124, 125, 126, 129,,130, 133, 134, 135, 136, 121, 119, 132, 118*
Traffic	AADT	Mixed effect	*115, 117, 118, 119*
Traffic	Percent trucks or commercial AADT	Unknown	*121, 119*
Surroundings	Access (driveways and intersections)	Negatively associated	*78, 119*
Surroundings	Development	Negatively associated	*78, 121*
Roadway geometry	Horizontal alignment (curve radii and length)	Negatively associated	*78, 139, 124, 138, 117, 146, 147, 148, 149, 150, 151, 152, 153, 132, 154, 155, 156, 157*
Roadway geometry	Lane width	Positively associated	*78, 117, 156*
Roadway geometry	Median type	Median type associated with different speed profiles	*155*
Roadway geometry	Median width	Positively associated	*120*
Roadway geometry	Number of lanes	Positively associated	*121, 155*
Roadway geometry	Shoulder (paved) width	Positively associated	*117, 155, 119*
Roadway geometry	Vertical alignment	Negatively associated	*78, 152, 153, 132, 155, 160, 118, 157*
Other factors	Time of day	Positively associated with nighttime	*119*

APPENDIX C. SPEED LIMIT SETTING APPROACHES

A well-developed approach to setting speed limits should consider the factors that affect operating speeds. Several factors, including the posted speed limit, can influence a driver's speed choice. Table 5 provides a list of factors that are believed to affect a driver's speed choices; however, the exact relationships may not be clear or may not have been conclusively proven. Adding to the challenge of quantifying the relationship is the interaction between these factors and the overall visual scene for the driver. The "look and feel" of the road can communicate an appropriate speed to a driver. Of course, the driver must be willing to accept that message. Appendix A (urban/suburban streets) and Appendix B (high-speed roads) include findings on the relationships among safety, operating speed, and roadway characteristics including posted speed limit.

Table 5. Example of factors that could influence a driver's speed choice.

Categories	**Factors**
Crash/Incident	Number and/or type of crashes, nearby crash, vehicle on shoulder or roadside
Enforcement	Presence of enforcement personnel, suspected enforcement levels, tolerance
Environment	Weather, light (dawn, day, dusk, night), visibility
Function	Functional classification, overall visual scene for driver
Human	Driver age, driver skill, personality of driver, emotional and/or physical condition of driver, familiarity of driver with roadway, influence of alcohol or drugs, number of passengers, type of passengers
Other	Work zone, school zone
Pavement	Pavement type and condition, pavement roughness, surface condition (e.g., wet, ice, etc.)
Road	Number of lanes, lane width, median type, roadside clearance, roadway alignment (horizontal and vertical), on-street parking, on-road bicyclist facilities, available sight distance, shoulder presence/width, sidewalk characteristics
Roadside	Land use, signal spacing, driveway/intersection (access) density, development type, zoning
Traffic	Vehicle volume, percent heavy trucks, speed of other vehicles, pedestrians, children, bicyclists (presence and location)
Traffic control devices	Signs (including posted speed limit), signals, pavement markings
Trip	Time of day, purpose of trip, urgency of trip, length of trip
Vehicle	Type of vehicle, condition of vehicle, vehicle size

A limited-access road (freeway) with multiple lanes and wide roadside clear zone communicates the appropriateness of high operating speeds, while a residential street with on-street parking, multiple driveways, and pedestrian activity communicates the need for low speeds. The posted speed limit needs to be in agreement with the design of the road if desired operating speeds are to be achieved. When the design of the road—in terms to how it visually looks to a driver—results in implying that a higher operating speed is reasonable, engineering treatments may be needed to adjust the message being communicated to the driver.

Forbes et al. (*166*) stated that the methodologies for setting speed limits typically are designed to result in recommended speed limits that:

- Are related to crash risk.
- Provide a reasonable basis for enforcement.

- Are fair in the context of traffic law.
- Are accepted as reasonable by a majority of road users.

RECENT KEY PUBLICATIONS CALLING FOR CHANGES TO HOW SPEED LIMITS ARE SET

Recently, the speed limit debate has increased with two publications. In March 2017, NACTO released a policy statement (*6*). One of the action items in that statement would "permit local control of city speed limits." NACTO recommends that "state rules or laws that set speed limits at the 85th percentile speed should be repealed."

In July 2017, NTSB published a report on speeding (*Reducing Speeding-Related Crashes Involving Passenger Vehicles*) (*7*). That document included several recommendations for reducing speed-related crashes including two recommendations directed to FHWA for changes to the MUTCD (*8*, pp. 57):

- Revise Section 2B.13 of the Manual on Uniform Traffic Control Devices so that the factors currently listed as optional for all engineering studies are required, require that an expert system such as USLIMITS2 be used as a validation tool, and remove the guidance that speed limits in speed zones should be within 5 mph of the 85th percentile speed (H-17-27).
- Revise Section 2B.13 of the Manual on Uniform Traffic Control Devices to, at a minimum, incorporate the safe system approach for urban roads to strengthen protection for vulnerable road users (H-17-28).

OVERVIEW ON APPROACHES TO SETTING SPEED LIMITS

Several approaches are used to set speed limits, and Table 6 summarized those approaches. Advantages and disadvantages are provided in Table 7. Two approaches to setting speed limits that have gained attention in recent years include the citywide default speed limit and the greater use of slow zones that include the implementation of a lower speed limit for a region.

When adjusting or modifying a statutory speed limit for a roadway segment, the most common approach for setting speed limit is the engineering operating speed approach.

Engineering (Operating Speed)

The operating speed (engineering) approach relies on the 85th percentile speed with adjustments used to account for existing roadway geometry or crash experience. It is the most common method used in the United States. Additional details about this approach are discussed in later sections of this appendix (see MUTCD and Online Review of State Guidance sections on setting speed limits).

Engineering (Road Risk)

With a road risk engineering approach, the speed limit is determined by the risks associated with the physical design of the road and the expected traffic conditions. Essentially, the approach sets the speed limit according to the function or classification of the road and then adjusts the speed limit based on the relative risk introduced by various road and roadside design features. Discussion on two examples of this approach follows.

The road risk (engineering) approach uses the risks associated with the physical design of the road and the expected traffic conditions to set the speed limit. Typically, the functional classification of the road sets the initial value, which is then adjusted based on the relative risks introduced by road or roadside features. While existing operating speeds are not used to set the speed limit, users are encouraged to compare the operating speeds to the proposed posted speed limit and, when the operating speed is higher, to consider engineering techniques that could be used to lower vehicle operating speeds.

Table 6. Approaches to setting speed limits.

Approach	Description	Examples
Engineering (Operating Speed)	A two-step process where a base speed limit is set according to the 85th percentile speed, the design speed for the road, or other criterion. This base speed limit is adjusted according to traffic and infrastructure conditions such as pedestrian use, median presence, etc.	Most states and cities in the United States
Engineering (Road Risk)	Speed limit is determined by the risks associated with the physical design of the road and the expected traffic conditions. Essentially, the approach sets the speed limit according to the function or classification of the road and then adjusts the speed limit based on the relative risk introduced by various road and roadside design features.	Canada, New Zealand
Expert System	Speed limits are set by a computer program that uses knowledge and inference procedures that simulate the judgment and behavior of speed limit experts. The system contains a set of rules for applying the knowledge to each situation.	United States (e.g., USLIMITS2), Australia
Optimization	Speed limits are set to minimize the total societal costs of transport. Travel time, vehicle operating costs, road crashes, traffic noise, and air pollution are considered in the determination of optimal speed limits.	Approach is a concept that has not yet been adopted by any road authority
Injury Minimization/ Safe System	Speed limits are set according to the crash types that are likely to occur, the impact forces that result, and the human body’s tolerance to withstand those forces.	Sweden, Netherlands, Australia
Citywide or Default	Speed limits are set based on region (e.g., a city) or type of street (i.e., neighborhood streets) within a region.	Boston, Massachusetts; New York City, New York; Seattle, Washington; Portland, Oregon
Slow Zones	Small area consisting primarily of local streets with signs and markings that alert drivers to the reduced speed limit.	New York City, New York; London, England

Source: Table created using (a) material provided in FHWA-SA-12-004 (*166*), pages 9–24, especially for engineering, expert system, optimization, and injury minimization; and (b) material generated by authors of this report.

Table 7. Advantages and disadvantages for approaches to set speed limits.

Approach	Data Required	Advantages	Disadvantages
Engineering (Operating Speed)	The existing speed profile as well as data on accesses, pedestrian/bicycle traffic, curbside parking, safety performance, etc.	Using the 85th percentile speed ensures that the speed limit does not place an undue burden on enforcement and provides residents and businesses with a valid indication of actual travel speeds.	Drivers may not be adequate judges of the externalities of their actions and may not be able to self-select the most appropriate travel speed. Speed limits are often set lower than the 85th percentile speed.
Engineering (Road Risk)	Functional classification of the road, setting (urban/ rural), surrounding land uses, access, design features of the road.	The speed limit and the function of the road are aligned. The function of the road also dictates many of the design elements of the road, so this method aligns the speed limits with the design of the road.	The road risk methods may result in speed limits that are well below the 85th percentile speeds, resulting in an increased burden on enforcement if remedial measures are not employed (i.e., traffic calming, etc.).
Expert System	Data needs depend on the system, but generally expert systems require the same data as used in the engineering approaches.	A systematic and consistent method of examining and weighing factors other than vehicle operating speeds in determining an appropriate speed limit. It is reproducible and provides consistency in setting speed limits.	Practitioners may need to rely on output from the expert system without applying a critical review of the results.
Injury Minimization/ Safe System	Crash types and patterns for different road types, and survivability rates for different operating speeds.	There is a sound scientific link between speed limits and serious crash prevention. Places a high priority on road safety.	This method is based solely on a road safety premise and may not be accepted as appropriate in some jurisdictions.
Citywide or Default	City must have authority to set speed limits within its region.	Consistency within a region. Fewer signs since signs may only be needed at entrances to region.	Removes connection between driver's interpretation of appropriate speed for the facility.
Slow Zones	Applications for a slow zone need to contain the streets to include along with letters of support from key stakeholders.	Focuses on the needs of all users within an area.	Limited to certain roadway types. Could be labor intensive for a city to implement. Roadway changes may be needed for the revised speed limit to be effective.

Source: Table created using (a) material provided in FHWA-SA-12-004 (*166*), pages 9–24, especially for engineering, expert system, optimization, and injury minimization; and (b) material generated by authors of this report.

New Zealand Speed Limits

The objective from New Zealand's speed limit policy (dated 2003) was "to balance the interests of mobility and safety by ensuring speed limits are safe, appropriate, and credible for the level of roadside development and the category of road for which they are set" (*13*). The selection of the proposed posted speed limit is based on a review of the roadside development and the general road information. Rating units are assigned to each 100-m section within the study area. The rating units consider frontage and side road development characteristics, pedestrians, cyclists, parking, geometry, traffic control, and development type. The average rating for the section is then used within one of three flow charts (rural, in between, or urban) to determine the speed limit. A flow chart is used to show the connection between the average rating and the speed limit, for example, in a rural area, an average rating of 6 or more and less than 11 would result in a 43.5 mph (70 km/h) speed limit.

A November 2016 publication replaced the guidance discuss in the previous paragraph (*167*). The *New Zealand Speed Management Guide First Edition* outlines a speed management framework that encompasses elements of the Safe System approach to reduce the risk of death and serious injury, while supporting overall economic productivity.

Canadian Guidelines for Establishing Posted Speed Limits

The Transportation Association of Canada has a publication that provides an evaluation tool to assess appropriate posted speed limits based on the classification, function, and physical characteristics of a roadway. It is called the *Canadian Guidelines for Establishing Posted Speed Limits* (*168*). The methodology is based on risks associated with engineering factors with the lower recommended posted speed limits for higher risk. The guidelines were developed through a review of current domestic and international practices, technical documentation, and testing. An automated spreadsheet is provided to facilitate the evaluation of posted speed limits.

Elements considered are geometry, roadside, classification, land use, access and intersection density, and vulnerable road users. The 85th percentile speed is used as a check, not as the determining factor.

Expert System Example

With an expert system, speed limits are identified with a computer program that applies a set of rules for each situation. An expert system currently in use in the United States is USLIMITS2.

USLIMITS2

USLIMITS is a web-based tool. The FHWA website (*169*) describes it as:

> a web-based tool designed to help practitioners set reasonable, safe, and consistent speed limits for specific segments of roads. USLIMITS is applicable to all types of roads ranging from rural local roads and residential streets to urban freeways. User friendly, logical, and objective, USLIMITS2 is of particular benefit to local communities and agencies without ready access to engineers experienced in conducting speed studies for setting appropriate speed limits. For experienced engineers, USLIMITS2 can provide an objective second opinion and increase confidence in speed limit setting decisions.

Links available on the FHWA website provide access to the software to run USLIMTS2 along with links to the following resources:

- User Guide (*15*).
- Decision Rules (*170*).
- NCHRP 3-67 Project Report (*11*).
- Frequently Asked Questions.

The core of USLIMITS2 is a set of decision rules developed by two selected groups of experts. One of the flow charts within the decision rules shows that the three roadway types included are:

- Limited-access freeway.
- Road section in undeveloped areas.
- Road section in developed areas, which is subdivided into:
    - Residential subdivision/neighborhood street (posted speed limits generally range from 25 mph to 35 mph).
    - Residential collector street (posted speed limits generally range from 25 mph to 45 mph).
    - Commercial street (posted speed limits generally range from 25 mph to 45 mph).
    - Street serving large complexes (posted speed limits generally range from 35 mph to 50 mph).

The needed input variables are listed in Table 8. For the crash statistics, the user is to provide (a) total number of crashes in the section, (b) total number of injury and fatal crashes in the section, and (c) the average AADT for the study period. The calculated rate of total crashes and rate of injury and fatal crashes are compared to average rates. The average rates are determined based on user-provided data for similar sections (i.e., number of lanes, median type, traffic volumes, area type, etc.). If the user does not provide the average rates, USLIMTS2 uses default values from the Highway Safety Information System (HSIS). Per the user manual (*11*), the average crash and injury rates were calculated using the latest 3 years of data available from California (2000–2002), Illinois (2001–2003), Maine (2002–2004), Minnesota (2002–2004), North Carolina (2001–2003), Ohio (2002–2004), Utah (1998–2000), and Washington (2002–2004).

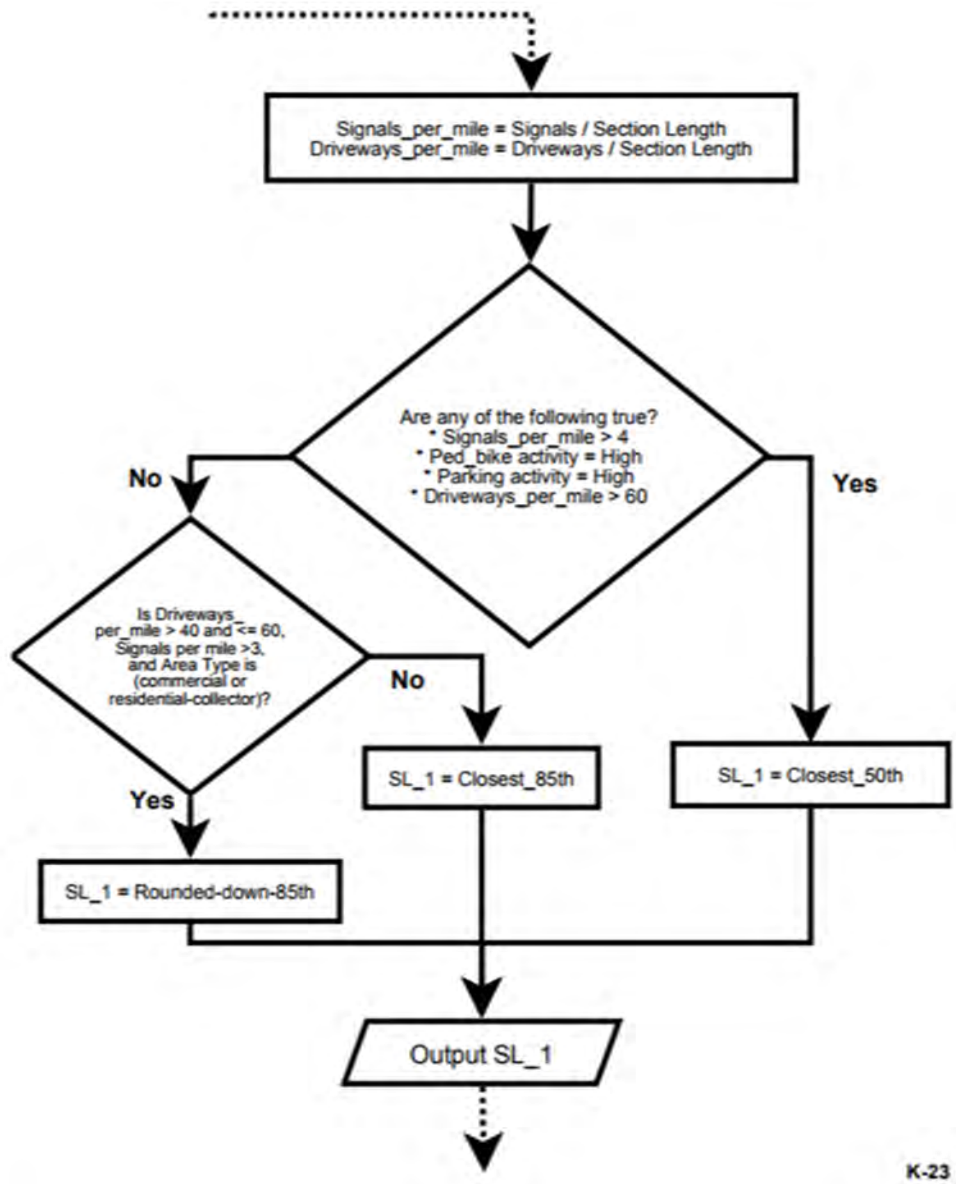
The 2017 USLIMITS2 user manual (*15*) has updated crash rates and injury rates. They were calculated using the latest 3 years of data that were available at the time of the update: California (2009–2011), Minnesota (2010–2012), North Carolina (2011–2013), Ohio (2010–2012), and Washington (2010–2012).

Several flow charts are available to illustrate the decision process within USLIMITS2. An example flow chart for speed limit calculations without crash data for a roadway section in developed areas is shown in Figure 3.

For the “extent of pedestrian/bicyclist activity” variable, the users are asked to select between “high” and “not high.” Examples of areas with high pedestrian and bicycle activity include the following:

- Residential developments with four or more housing units per acre interspersed with multifamily dwellings.
- Hotels located with 1/2 mi of other attractions such as retail stores, recreation areas, or senior centers.
- Downtown or central business district (CBD) areas.
- Areas with paved sidewalks, marked crosswalks, and pedestrian signals.

USLIMTS provides suggested minimum section lengths (see Table 9). The program provides warnings when the 85th percentile speed exceeds 77 mph for a limited-access freeway, 67 mph for a non-limited-access road in an undeveloped area, and 52 mph for a non-limited-access road in a developed area.



Source: USLIMITS decision rules flow chart (*170*), page K-23.

Transportation Research Board. 2006. Expert System for Recommending Speed Limits in Speed Zones: NCHRP 03-67. Adapted and Reproduced with permission from the National Academy of Sciences, Washington, DC.

Figure 3. USLIMITS2 flow chart for speed limit calculation without crash data for roadway section in developed areas.

Table 8. Input variables required for USLIMITS2.

Input Variables	Limited-Access Freeway	Road Section in Undeveloped Area	Road Section in Developed Area
Operating speed (85th and 50th percentile speed)	Yes	Yes	Yes
Section length	Yes	Yes	Yes
AADT	Yes	Yes	Yes
Presence/absence of adverse alignment	Yes	Yes	Yes
Current statutory limit for this type of road	Yes	Yes	Yes
Terrain	Yes	No	No
Is this section transitioning to a non-limited-access highway?	Yes	No	No
Is this section transitioning to a road section in a developed area?	No	Yes	No
Number of interchanges within this section	Yes	No	No
Crash statistics[a]	Yes	Yes	Yes
Roadside rating	No	Yes	No
Divided/undivided section	No	Yes	No
Number of through lanes	No	Yes	Yes
Whether it is a one-way street	No	No	Yes
Area type	No	No	Yes
Number of driveways within the section	No	No	Yes
Number of traffic signals within the section	No	No	Yes
Presence/usage of on-street parking	No	No	Yes
Extent of pedestrian/bicyclist activity	No	No	Yes

[a] At least 3 years of crash data recommended; if less than 1 year of data, USLIMITS2 suggests that additional data should be collected and the process repeated.
Source: Table created from list provided in USLIMITS user guide (*11*), page L-17.

Table 9. USLIMITS2 suggested minimum length per speed limit.

Speed Limit (mph)	Minimum Length (mi)	Speed Limit (mph)	Minimum Length (mi)
30	0.30	55	0.55
35	0.35	60	1.20
40	0.40	65	3.00
45	0.45	70	6.20
50	0.50	75	6.20

Source: USLIMITS user guide (*11*), Table L.2, page L-34.

Citywide or Default Speed Limits

Default speed limit is the speed limit set by government action, typically a state or city for an area. The default speed limit can depend on the type of the road and its location (e.g., rural or urban) and the vehicle type and its properties.

Several U.S. cities have recently campaigned to be able to set lower citywide default speed limits. For example, Boston, Massachusetts; New York City, New York; and Seattle, Washington, now have the ability to set a 25-mph speed limit citywide. Portland, Oregon, has the authority to set residential streets at 20 mph. Other countries are also implementing citywide speed limits.

In Bristol, UK, a 20-mph speed limit policy was implemented between 2010 and 2015 in phases within seven areas of the city. Researchers (*171*) used crash data from 2008 to 2016 to investigate the change in crashes. The 20-mph speed limit intervention was associated with a city-level reduction of fatal injuries of around 63 percent after controlling for trends over time and areas. There was also a general trend of reduction of the total number of injuries at the city level and on 20-mph roads. The authors hypothesized that a citywide speed limit approach may encourage a general behavior change in drivers that, in turn, may contribute to reducing injuries across the city.

Hu and Cicchino (*172*) investigated the effects of a speed limit reduction on speeds in Boston. On January 9, 2017, the default speed limit on City of Boston streets was reduced from 30 mph to 25 mph. The researchers collected vehicle speeds at 50 sites in Boston where the speed limit was lowered from 30 mph to 25 mph. They also collected vehicle speeds at 50 control sites in Providence, Rhode Island, where the speed limit remained at 25 mph before and after the speed limit change in Boston. Table 10 shows the findings from the speed studies. The researchers used a log-linear regression model to estimate the change in vehicle speeds associated with the speed limit reduction and separate logistic regression models to estimate changes in the odds of vehicles exceeding 25 mph, 30 mph, and 35 mph. They found a 0.3 percent reduction in mean speeds (p=0.065) and reductions of 2.9 percent, 8.5 percent, and 29.3 percent in the odds of vehicles exceeding 25 mph, 30 mph, and 35 mph, respectively. The authors concluded that while the average and 85th percentile speeds did not change meaningfully, the reductions in the proportions of vehicles traveling at higher speeds have important implications for nonmotorists.

Table 10. Speeds and proportion of vehicles exceeding a speed from Boston citywide speed limit change study.

Period	**Boston (50 study sites, speed limit changed from 30 mph to 25 mph)**					**Providence (50 control sites, speed limits at 25 mph)**				
Measure	Mean Speed (mph)	85th %-ile Speed (mph)	% above 25 mph	% above 30 mph	% above 35 mph	Mean Speed (mph)	85th %-ile Speed (mph)	% above 25 mph	% above 30 mph	% above 35 mph
Before	24.8	31.0	47.9	18.2	4.9	24.8	31.0	45.9	15.9	3.5
After	24.8	31.0	46.9	18.1	3.8	24.9	31.0	46.2	17.5	4.1
Before-to-after change	0%	0%	−2.1%	−0.5%	−22.4%	0.4%	0%	0.7%	10.1%	17.1%

Source: Hu W., & Cicchino J. B. (2019) Lowering the Speed Limit From 30 mph to 25 mph in Boston: Effects on Vehicle Speeds. Injury Prevention, 0, 1-4. (*172*), Table 1, page 7.

On October 24, 2016, Oregon provided the City of Portland approval to begin use of its proposed experimental alternative speed zone investigation method. The alternative method (*12*) is to be used on streets that are under the jurisdiction of the City of Portland. The justification for the alternative method is safety, with the principle factors to determine risk being the speed of adjacent motor vehicles and proximity of those vehicles to the more vulnerable road users, namely pedestrians and cyclists. The determination of the recommended posted speed limit for a corridor is the lowest recommended speed for each road user—pedestrian, bicyclist, and auto.

Portland notes on its website (*173*) that speeds “must account for people traveling in different ways: walking, driving, using mobility devices, biking, skateboarding, etc.” and that “it is important to consider people traveling outside of motor vehicles because they are not protected from the impact of crashes.” Portland provides the following four methods that the city can use to request speed limit changes:

- Alternative method. For use on non-arterial streets with speed limits above 25 mph. Uses a streamlined request process that places greater emphasis on vulnerable users and the risk of a future crash relative to the traditional method.
- Traditional method. Required on arterial streets except on sections eligible for business district statutory speed limits. Uses multiple factors to determine speed limits, including 85th percentile speeds, crash history, roadside culture, traffic volumes, roadway alignment, width, and surface.
- Statutory method. For streets with a speed limit specified by law.
- Special clauses. Allows for 5 mph below statutory speed limits on certain streets such as low-traffic neighborhood greenways and certain residential streets.

Slow Zones

Slow zones are corridors or regions with a lower speed limit than surrounding areas. An example of a slow zone program is the Neighborhood Slow Zones program implemented by New York City (*174*). The goals of the Neighborhood Slow Zones program are to lower the incidence and severity of crashes and to enhance quality of life by reducing cut-through traffic and traffic noise in residential neighborhoods. Within the slow zone area, speed limits are reduced from 25 mph to 20 mph, and roadway geometric treatments—such as speed bumps or other traffic calming treatments—are added with the intention of changing driver behavior. Gateway signs and markings are used at intersections to alert drivers to the reduced speed limit.

Neighborhood Slow Zones are typically established in small, self-contained areas that consist primarily of local streets where the streets within the zones can be self-enforcing due to the roadway characteristics. They are implemented in areas with low-traffic volumes and minimal through traffic, where reducing the speed limit will not cause traffic congestion. New York City has reported that areas where Neighborhood Slow Zones have been implemented experienced a 10–15 percent decrease in speeds, 14 percent reduction in crashes with injuries, and 31 percent reduction in vehicle injuries (*174*).

MANUAL ON UNIFORM TRAFFIC CONTROL DEVICES

The MUTCD (*8*) provides information on setting non-statutory speed limits. Within Section 2B.13 of the MUTCD are several paragraphs related to the selection of the posted speed limit value, including Paragraph 1 (standard), Paragraph 12 (guidance), and Paragraph 16 (option). Other paragraphs within Section 2B.13 focus on statutory speed limits, the need for engineering studies, requiring limits to be multiples of 5 mph, placement of signs, use of warning signs with speed limit signs, where to conduct speed studies, special speed limits, changeable message signs, and school zones. Relative to setting speed limits, the key paragraphs in Section 2B.13 are:

> 01 Speed zones (other than statutory speed limits) shall only be established on the basis of an engineering study that has been performed in accordance with traffic engineering practices. The engineering study shall include an analysis of the current speed distribution of free-flowing vehicles.

12 When a speed limit within a speed zone is posted, it should be within 5 mph of the 85th-percentile speed of free-flowing traffic.
16 Other factors that may be considered when establishing or reevaluating speed limits are the following:

- Road characteristics, shoulder condition, grade, alignment, and sight distance,
- The pace,
- Roadside development and environment,
- Parking practices and pedestrian activity, and
- Reported crash experience for at least a 12-month period.

To address the NTSB recommendations (*7*), the NCUTCD Regulatory and Warning Signs (RW) Technical Committee established a task force to explore current and potential approaches to the setting of posted speed limits. The task force started the process by creating and distributing the survey in the spring of 2018 to gather an understanding of how practitioners actually applied current practices in setting speed limits and queried their opinions on the topic.

The availability of the web-based survey was announced to members of the following groups: NCUTCD, Institute of Transportation Engineers, AASHTO Committee on Traffic Engineering, American Public Works Association, National Association of County Engineers, American Society of Civil Engineers, NACTO, Association of Pedestrian and Bicycle Professionals, and TRB. The survey included 13 questions, with the initial questions focusing on individuals' backgrounds and the remaining questions focusing on how they conduct speed studies or what they think a speed study should consider. A total of 740 participants completed the survey. Details on the survey and key findings are documented elsewhere (*175*, *176*). The following general revisions to the MUTCD were suggested based on the survey and discussions within the committee and elsewhere:

- Change the MUTCD to reinforce the stated understanding that other factors have a role in setting speed limits (in addition to 85th percentile). Refine the factors in Paragraph 16 and group the paragraphs that speak to setting of speed limits.
- Retain references to 85th percentile as a factor that should be considered, particularly for freeways, expressways, and rural areas.
- Keep the MUTCD broad. While it could be reorganized to better present the material for setting speed limits (with minor reorganization), it should not be expanded into greater detail. The detail will ideally be provided from national research, state / local procedures and promoted by FHWA.
- Not include references to specific processes, such as USLIMITS2, but promote this level of detail in state/local procedures and investigate more deeply the reasons why after more than 20 years, only a small fraction of practitioners utilize this expert system.

Details on the specific recommendations forwarded to FHWA are available on the NCUTCD website (*177*). The survey along with discussions within NCUTCD generated the following questions (and suggested direction) that need additional consideration (*175*):

- To what extent should the MUTCD define procedures/criteria for posted speed limit engineering studies?
  - There is support on both sides of the question as to whether the MUTCD should be focused on simply traffic control device criteria (e.g., sign size, color, or shape)

or both traffic control device criteria and the criteria for setting of speed limits. After review of the survey results and discussion with the NCUTCD Council, the direction was to keep the MUTCD material regarding setting speed limits broad, allowing states/local agencies to define the procedures in more detail.

- Given the implicit understanding of what 85th percentile means, is there a need to better define the five items in Section 2B.13, Paragraph 16 to build a more uniform level of understanding (e.g., what defines crash experience comparable to our understanding of the 85th percentile)?
  - Greater definition should be left to national research and state/local procedures rather than expanding upon them in the MUTCD.
- Why are bicyclists not noted in Paragraph 16? Should any criteria be added to Paragraph 16?
  - In reviewing the MUTCD history, this list was added in 1971.
  - It is reasonable to add several factors to Paragraph 16, such as road context, bicyclists, lane width, median type, and/or number of driveways.
- What is the balance between “analysis of the current speed distribution of free-flowing vehicles” (MUTCD standard Paragraph 1) to other criteria (MUTCD Paragraph 12) as part of an engineering study? How might this affect Paragraph 12?
  - This should be left to guidelines, not the MUTCD.
- Is a specific reference to USLIMITS2 appropriate?
  - Given the survey finding that 84 percent of the respondents had not utilized USLIMITS2, the question as to “why” should be answered before change to the MUTCD is considered. Adding USLIMITS2 would substantially further the MUTCD role of defining the process or procedure of setting speed limits. This level of detail would be inconsistent with the MUTCD establishing broad criteria of setting speed limits and could impact state/local agencies who have detailed procedures.
- Should the rounding approach to speed data be defined?
  - This is a detail of setting a speed limit that would not be appropriate for the MUTCD. It should be part of state/local agency policy documents.
- What will enforcement and/or the judicial system accept if not the 85th percentile (Paragraph 12)? Could speed limits for high crash corridors be set below the 85th percentile, and is this an MUTCD role or a state/local role in defining the speed limit process?
  - This should be left to guideline documents and national research rather than the MUTCD.
- Given the commonality of responses to target speed for various facility types from the survey, should a reference be provided that would guide practitioners to further study when to set speeds above/below certain levels nationally (for example, the 50th percentile response levels of the survey for each facility type)?
  - This is a detail of setting speed limits and would be better in guidelines (or statutory change/requirements) rather than the MUTCD.
- A criterion suggested for setting speed limits that is relatively new is “context—location.” Some may consider “road characteristics” or “environment”—terms currently in the MUTCD—to be similar in concept. *NCHRP Research Report 855* (*3*) recommends an expanded functional classification system with five roadway types

(freeways, principal arterial, minor arterial, collector, and local) and five contexts (rural, rural town, suburban, urban, and urban core). These contexts "have been determined to not only represent unique land use environments, but also identify distinctions that require wholly different geometric design practices in terms of desired operating speeds, mobility/access demands and user groups." Should the MUTCD recognize these different roadway type/context combinations, especially if different speed limit setting practices are suggested for the different roadway type/context combinations? Table 11 shows the suggested target speeds from *NCHRP Research Report 855* (*3*), and Table 12 summarizes the primary factors associated with each roadway context.

- This is a detail of setting speed limits and would be better as a subject of guidelines (or statutory change/requirements) rather than the MUTCD.

Table 11. *NCHRP Research Report 855* suggested target speed for context/roadway.

Context / Roadway	Rural	Rural Town	Suburban	Urban	Urban Core
Freeways	Not addressed in *NCHRP Research Report 855* since "designs are based on federally developed standards with little flexibility." Assumed to be high.				
Principal Arterial	High	Low/Med	Med/High	Low/Med	Low
Minor Arterial	High	Low/Med	Med	Low/Med	Low
Collector	Med	Low	Med	Low	Low
Local	Med	Low	Low	Low	Low

Note: Suggested target speeds: low (<30 mph), med (30 to 45 mph), high (>45 mph).
Source: Adapted from Source: Transportation Research Board. 2018. *An Expanded Functional Classification System for Highways and Streets.* HTTPS://DOI.ORG/10.17226/24775. Reproduced with permission from the National Academy of Sciences (*3*), Figure 25, page 37.

Table 12. Characteristics of roadway contexts.

Context	Density	Land Use	Setback
Rural	Lowest (few houses or other structures)	Agricultural, natural resource preservation, and outdoor recreation uses with some isolated residential and commercial uses	Usually large setbacks
Rural Town	Low to medium (single-family houses and other single-purpose structures)	Primarily commercial uses along a main street (some adjacent single-family residential uses)	On-street parking and sidewalks with predominately small setbacks
Suburban	Low to medium (single- and multifamily structures and multistory commercial)	Mixed residential neighborhood and commercial clusters (including town centers, commercial corridors, big-box commercial, and light industrial uses)	Varied setbacks with some sidewalks and mostly off-street parking
Urban	High (multistory, low-rise structures with designated off-street parking)	Mixed residential and commercial uses, with some intuitional and industrial uses and prominent destinations	On-street parking and sidewalks with mixed setbacks
Urban Core	Highest (multistory and high-rise structures)	Mixed commercial, residential, and institutional uses within and among predominately high-rise structures	Small setbacks with sidewalks and pedestrian plazas

Source: Based on Source: Transportation Research Board. 2018. *An Expanded Functional Classification System for Highways and Streets.* HTTPS://DOI.ORG/10.17226/24775. Reproduced with permission from the National Academy of Sciences (*3*), Table 1, page 10.

POSTED SPEED LIMIT COMPARED TO OPERATING SPEED

While the MUTCD (*8*) recommends setting the posted speed limits near the 85th percentile speed, and traffic engineers say that agencies are using the 85th percentile speed to set speed limits, in reality the speed limit is often set much lower (*178*). At these locations, the 85th percentile operating speeds exceed the posted speed limits, and in many cases, the 50th percentile operating speed is either near or exceeds that posted speed limit as well (*48*).

City Streets Using Donated Spot Speed Studies

As part of this NCHRP project, the research team collected operating speed data for several city streets; however, all collected speed data were concentrated in one Texas city. Members of the research team participated in the volunteer NCUTCD Task Force on speed limits, including making presentations on the findings. During some of those presentations, requests for donations of spot speed studies were made. In addition, the chair of the NCUTCD Task Force sent emails requesting the donation of spot speed studies. Several communities provided spot speed studies, most of which were collected using road tubes where the speed data are binned in 5-mph increments. Table 13 lists the number of available speed studies by roadway type and state.

Using data collected as a part of this project along with the data donated by several communities, graphs of operating speed versus posted speed limit were developed. Because this project created a database of speeds for the City of Austin, Texas, many of the speed studies are from Texas, but over half are from states other than Texas (see Table 13). The speed studies were assigned as either an arterial, a collector, or a local street for this comparison, and only speed studies on city streets (i.e., urban or suburban roadway context) were included. Figure 4 shows the plot for urban arterial, Figure 5 for urban collectors, Figure 6 for urban local streets, and Figure 7 for all 875 urban street speed studies. Figure 8 shows the distribution of average operating speed by posted speed limit using box plots for all 875 urban street speed studies.

Table 13. Number of speed studies by roadway type and state.

State	Arterial	Collector	Local	Total
AR	5	3	0	8
AZ	18	0	0	18
CA	0	116	0	116
DE	4	0	0	4
FL	0	5	0	5
IL	0	93	62	155
MA	7	1	0	8
MD	0	6	0	6
MI	1	14	2	17
MO	6	3	2	11
NH	10	48	8	66
OR	3	7	2	12
TN	5	3	3	11
TX	133	182	116	431
VA	2	5	0	7
Total	194	486	195	875

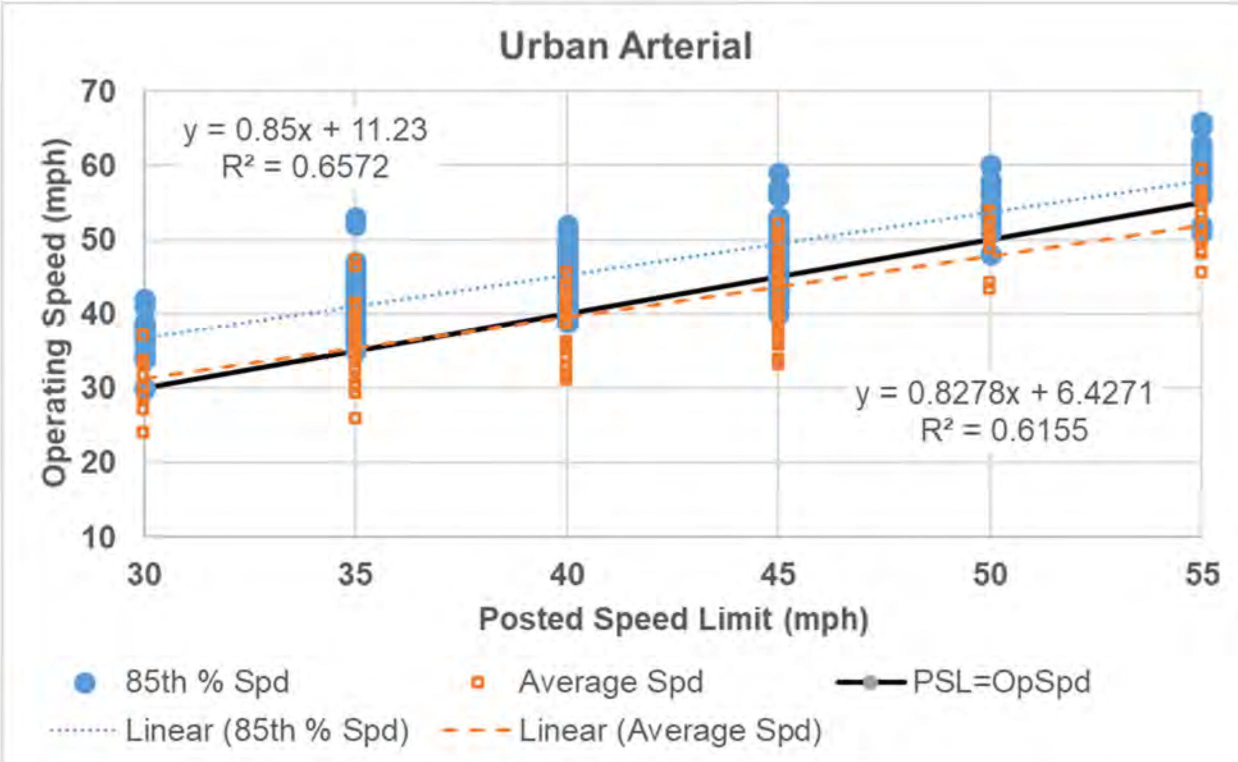


Figure 4. Operating speed by posted speed limit for urban arterials.

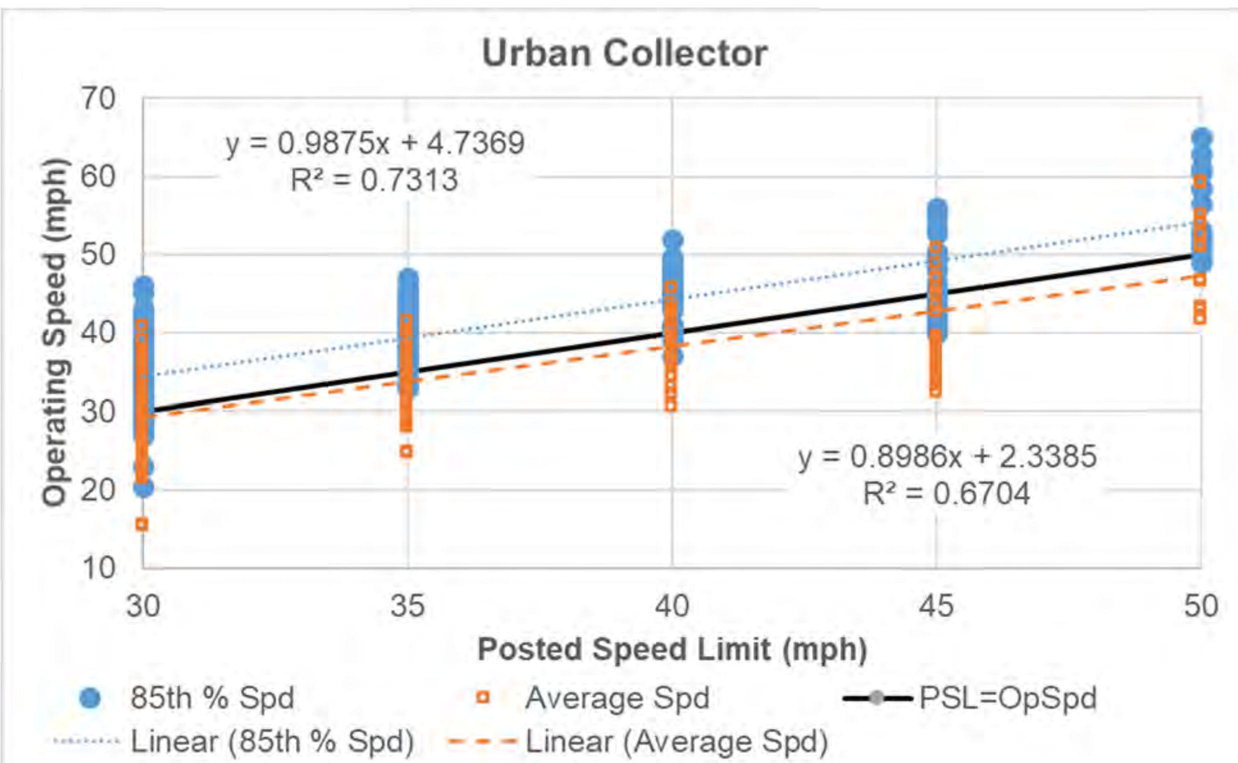


Figure 5. Operating speed by posted speed limit for urban collectors.

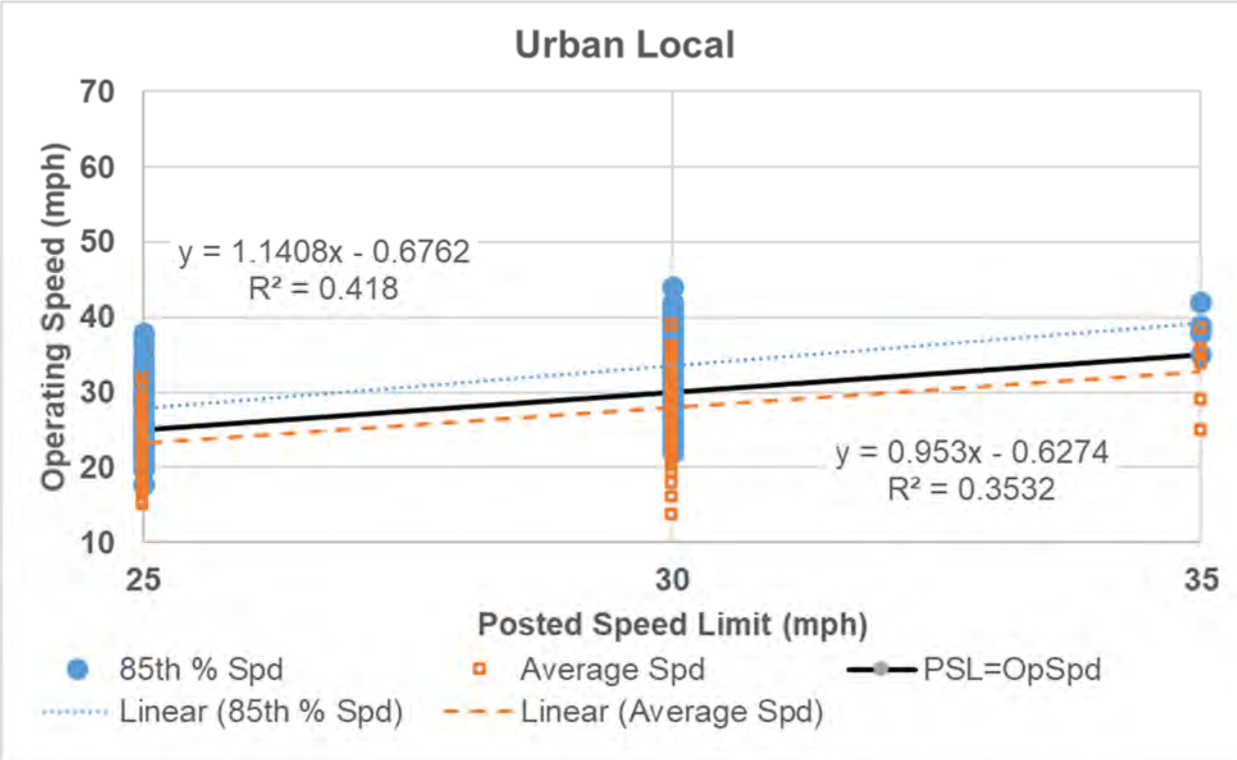


Figure 6. Operating speed by posted speed limit for urban locals.

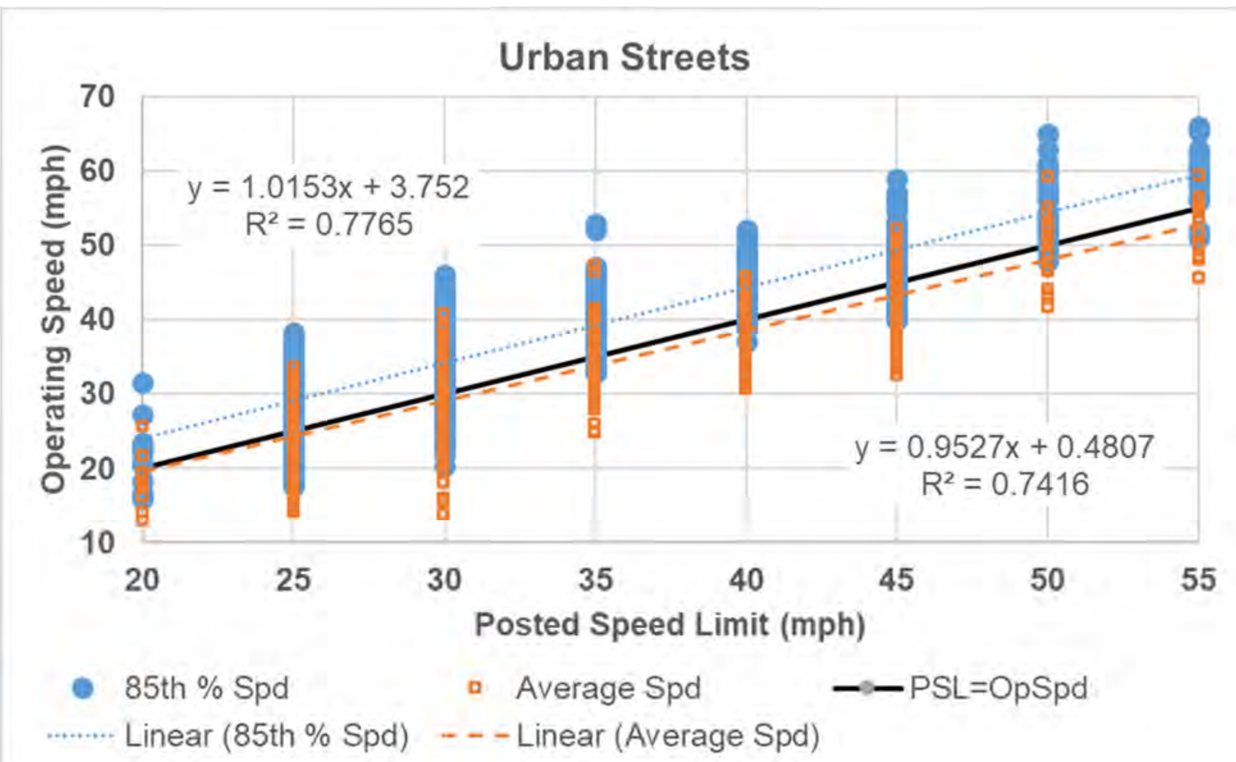


Figure 7. Operating speed by posted speed limit for city streets.

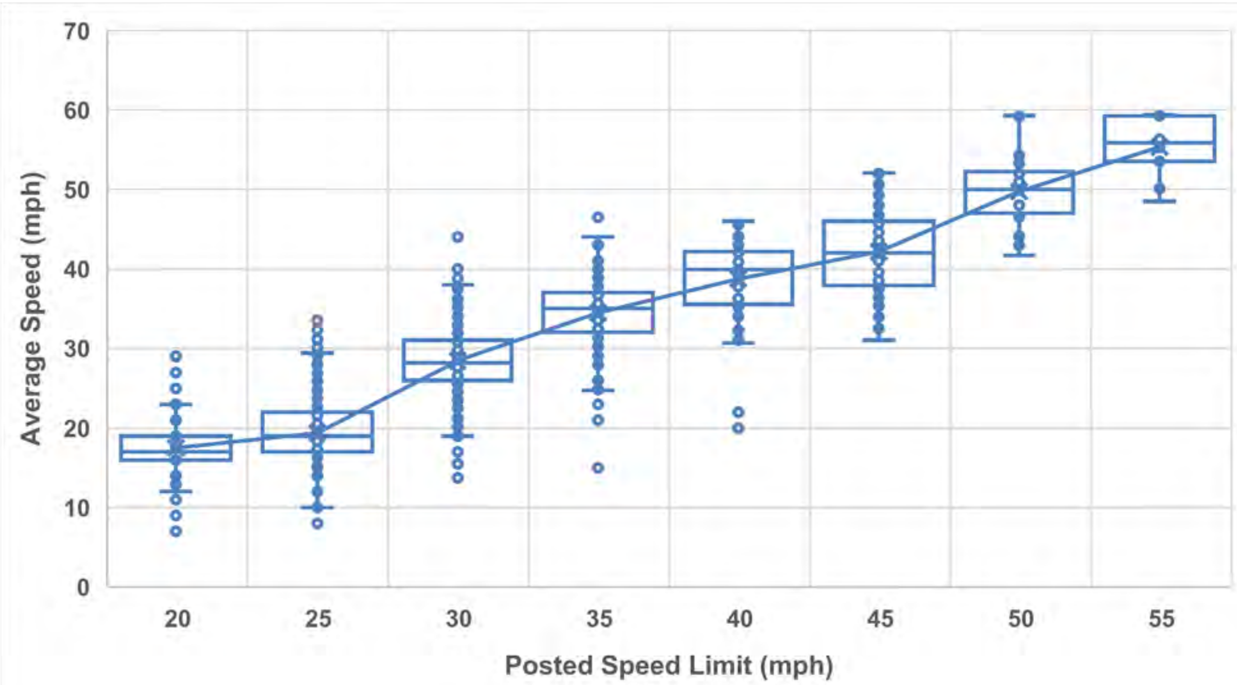


Figure 8. Using box plots to illustrate average operating speed by posted speed limit for city streets.

The four graphs clearly show a large range of values for both the average speed and the 85th percentile speed within each posted speed limit. For example, the 39 arterials with a 40-mph posted speed limit in Figure 4 show an average speed that ranges from 31 to 46 mph and an 85th percentile speed that ranges from 39 to 52 mph. These ranges indicate that other factors are influencing drivers' speeds in addition to posted speed limit. A general observation from the graphs is that the political process could also be influencing the setting of a speed limit below the 85th percentile at some of the sites.

Overall, trendlines can provide an appreciation of whether the posted speed limit is more similar to the average speed or the 85th percentile speed. As illustrated in each graph, the trendline for the average speed is closer to the posted speed limit than the trendline for the 85th percentile speed. As shown in Figure 7 for all city streets, the average speed is about equal to the posted speed limit for posted speed limits below 40 mph and then within about 1 mph for posted speed limits at 40 or above. For this set of city street speed data, the 85th percentile speed could be generalized as being the posted speed limit plus 4 mph.

Freeways and Two-Lane Highways Using Naturalistic Driving Study Data

Savolainen et al. (*179*), using data from the Second Strategic Highway Research Program (SHRP2) Naturalistic Driving Study (NDS), identified driver speed and posted speed limit relationships for freeways and rural two-lane highways. The freeway dataset included a total of 4,375 driving traces for 1,975 unique drivers at four different posted speed limits ranging from 55 mph to 70 mph. The authors had the ability to also compare results when traffic was flowing at level of service (LOS) A and found the following:

- 55 mph posted speed limit and LOS A: about 58 mph average speed.
- 60 mph posted speed limit and LOS A: about 63 mph average speed.

- 65 mph posted speed limit and LOS A: about 69 mph average speed.
- 70 mph posted speed limit and LOS A: about 73 mph average speed.

So, during conditions when traffic is light, the average freeway speed is about 3 mph higher than the posted speed limit. This finding is in contrast to the findings for city streets, where the average speed is about equal to the posted speed limit.

The authors developed mixed-effect linear regression models and found that mean speeds are largely affected by the level of traffic congestion. Because they had information on driver age, the authors were able to identify that speeds were higher among younger and middle-aged drivers compared to older drivers. The model that only considered data collected during LOS A conditions found the presence of roadway junctions (i.e., interchanges) to be significant.

The authors created a similar dataset for two-lane highways that included 2,901 driver traces representing posted limits ranging from 25 mph to 60 mph. The authors commented that the interquartile ranges were found to be wider for two-lane highways, which is indicative of more diverse speed choices on those facilities compared to freeways, and that the difference in mean speeds between two consecutive limits seemed to be decreasing when reaching higher posted limits. The average speeds by posted speed limit for LOS A for the two-lane highways were:

- 25 mph posted speed limit and LOS A: about 25 mph average speed.
- 30 mph posted speed limit and LOS A: about 29 mph average speed.
- 35 mph posted speed limit and LOS A: about 37 mph average speed.
- 40 mph posted speed limit and LOS A: about 41 mph average speed.
- 45 mph posted speed limit and LOS A: about 46 mph average speed.
- 50 mph posted speed limit and LOS A: about 48 mph average speed.
- 55 mph posted speed limit and LOS A: about 54 mph average speed.
- 60 mph posted speed limit and LOS A: about 58 mph average speed.

Savolainen et al. (*179*) found that mean speeds were generally near the posted speed limit under lower speed conditions (e.g., 25- and 35-mph limits) but tended to decrease below the posted limit at posted speed limits of 40 mph and above. Speeds were lower in the vicinity of access points (driveways and intersections) and in the presence of on-street parking.

ONLINE REVIEW OF STATE GUIDANCE FOR SETTING SPEED LIMITS

An online search identified 31 states with information on existing speed limit practices or guidelines for setting speed limits. The remaining 19 states either did not have design or traffic control device guidance online or the materials available did not specifically discuss the setting of speed limits. While many of those 19 states probably have guidance available, the 31 states identified should provide a representative review of the current practices regarding speed limits in the United States. The guidance materials included manuals, state statutes on speed limits, brochures, state versions of the MUTCD, and speed limit guidance documents. The documents reviewed included the following:

- Alabama, *Speed Management Manual* (*180*).
- Arizona, website (*181*).
- California, *Manual for Setting Speed Limits* (*182*).
- Colorado, *Establishing Realistic Speed Limits* (*183*).
- Connecticut, Speed Limit Frequently Asked Questions and *Highway Design Manual* (*184*, *185*).

- Florida, *Speed Zoning for Highways, Roads, and Streets* (*18*).
- Indiana, *Design Manual* (*186*).
- Iowa, *Traffic Safety Manual,* Chapter 5—Speed Limits (*187*).
- Illinois, *Policy on Establishing and Posting Speed Limits on the State Highway System* (*188*).
- Kansas, *Establishing Speed Limits: A Case of "Majority Rule"* (*189*).
- Kentucky, *Traffic Operations Guidance Manual* (*190*).
- Louisiana, website (*191*).
- Michigan, *Establishing Realistic Speed Limits* (*192*).
- Missouri, *Traffic Practices: A Guidebook for City and County Agencies* (*193*).
- Maine, *How Are Speed Limits Set?* (*194*).
- Minnesota, Speed Limits in Minnesota (*195*).
- Montana, Speed Limits (*196*).
- Nebraska, *How Are Speed Limits Established?* (*197*).
- New York, *Traffic Control Program: Speed Limits* (*198*).
- North Carolina, Speed Limits (*199*).
- North Dakota, *Speed Limit Guidelines* (*200*).
- Ohio, *Traffic Engineering Manual* (*201*).
- Oregon, *Speed Zone Program: Interstate Speed Limits* (*202*).
- Pennsylvania, *Official Traffic Control Devices* (*203*).
- Texas, *Procedures for Establishing Speed Zones* (*204*).
- Utah, *Establishment of Speed Limits on State Highways* (*205*).
- Vermont, *Setting Speed Limits—A Guide for Vermont Towns* (*206*).
- Virginia, Speed Limits and *Guidelines for Interstate Speed Limits* (*207*, *208*).
- Washington, Speed Limits (*209*).
- Wisconsin, *Traffic Guidelines Manual* (*210*).

Factors Considered, Especially 85th Percentile Speed

For the 31 states where details regarding the setting of posted speed limits were found online, all considered the 85th percentile speed in the process, and most clearly stated that crash history should also be considered. Several states provided other factors to consider when setting a speed limit, with some states using specific terms (i.e., lane width, number of lanes, shoulder width), while other states used more general terms (i.e., driving environment, roadway geometry). Table 14 summarizes factors that influence speed limit setting decisions outlined in state guidance documents by more than three states.

Factors mentioned by fewer than three states included (in alphabetical order) clear zone widths, commercial versus residential, consideration of adjacent speed limits, consistency, design speed used during project, driving environment, operational analysis (traffic volumes, percentage of trucks, congestion, etc.), existing traffic control devices, functional class, hidden driveways, land use characteristics, law enforcement, level of maintenance such as snow and ice removal, local versus regional traffic, narrow roadway pavement, number of lanes, presence of passing zones, right lane/entering traffic conflicts, roadside culture, roadway lighting, roadway width, roadside friction (number of driveways, parking, pedestrians, etc.), special features, surface type, traffic characteristics, traffic signal, transit vehicle activity, and type of area.

Table 14. Factors typically considered by U.S. states in setting posted speed limits based on material found online for 31 states.

Frequency Cited	Factor
All or most of states	85th percentile speed Crash history
Over one-half of states	Roadside development or land use Traffic (pedestrians, bicyclists) condition or volume Maximum or minimum speed allowed in state Sight distances
About one-third of the states	Parking practices Shoulder presence/condition/width Pavement or surface characteristics/condition Access (points such as intersections or driveways), access characteristics including number, type, and design of roadway and driveway intersections
Less than one-third of the states, but greater than three states	Functional class Grade Horizontal and/or vertical curves Lane width Pedestrian activity Roadway alignment Roadway characteristics Roadway geometry Roadway width Traffic control devices Transition zones Urban streets

As illustrated in Table 14, the terminology of factors affecting the speed limit varied between states; for example, some states used the term “roadside development,” while others used “land use.” There were also other factors that were unique to some states that were not included. These factors are:

- Design speed during project (Indiana).
- Narrow roadway pavement (Texas).
- Transit vehicle activity (Alabama).
- Roadway lighting (Washington).
- Width of clear zone (Wisconsin).
- Local versus regional traffic (Wisconsin).
- Presence of passing zones (Vermont).
- Operational analysis (i.e., percent of trucks, congestion; Virginia, Wisconsin).
- Consideration of adjacent speed limits (Virginia).
- Level of maintenance such as snow and ice removal (Wisconsin).
- Right lane/entering traffic conflicts for freeways (Washington).

All states cited that crash history or crash rate influences the speed limit for a road segment. The following four states set a time requirement for the time frame that the crash history is to be analyzed:

- Alabama—3 years minimum, 5 years preferred.
- Kentucky—3 years.

- Maine—3 years.
- Wisconsin—3 to 5 years.

Rounding of Speed Value

The majority of the states that mentioned the use of the 85th percentile speed only gave the guideline that the speed limit should be within 5 mph of the calculated 85th percentile. Some states gave guidance for rounding the values obtained from the speed study. Below are a few examples:

- California—Establish at or near the 85th, establish at the nearest 5-mph increment to the 85th, rounding as standard mathematics direct (*182*).
- Florida—The set speed limit should not differ from the 85th percentile speed or upper limit of the 10-mph pace by more than 3 mph and it shall not be less than 8 mph (*18*).
- Maine—Speed limit is to be within 3 mph of 85th percentile, then rounded to the nearest 5 mph (*194*).
- New York—Engineering judgment shall be used to adjust the value, but it shall not be lower than 3 mph than the upper limit of the 10-mph pace. Should not be lower than the 67th percentile (*198*).
- North Dakota—Within 5 mph of the 85th, shall not exceed statutory maximum speed, shall not be less than the 50th percentile (*200*).
- Texas—The final speed limit may be lowered as much as 5 mph from the 85th percentile. Posted speed limit is the nearest value ending in 5 or 0 (*204*).
- Utah—Any reduction beyond rounding shall not be less than 5 mph from 85th percentile (*205*).

COMPARISON BETWEEN EXISTING SPEED LIMIT SETTING APPROACHES

As part of identifying potential variables to consider for the SLS-Procedure, the research team reviewed the variables being used in several approaches during Phase I of this research project. The approaches included USLIMITS2, New Zealand, Canada, and Portland, Oregon's preliminary revised approach for collector streets. A preliminary dataset consisting of Austin, Texas, segments was used in the investigation. The same dataset was also used with the HCM free-flow speed equations.

While the exercise produced suggested posted speeds or predicted speeds, the value of the effort laid in other areas. The exercise identified the variables being used in the calculations. It also provided experience in how to obtain the value for the variable such as how easy it was to obtain that value or whether an assumed value would be needed or sufficient. It also provided the opportunity to compare and assess the types of variables between the different procedures and to consider the sensitivity of a given variable to the overall answer. While not exhaustive in its analysis, the effort generated the following key observations:

- Several variables used in the HCM free-flow speed prediction are considered in the suggested PSL procedures reviewed, including the following: access density, median type, number of through lanes, one-way/two-way operations, on-street parking, existing posted speed limit, section length, and traffic signal density.
- A variable used in the HCM that was not used in the reviewed PSL procedures was proportion of length with curb on right-hand side. This absence may be more of a

reflection that the procedures examined focused on developed areas that would typically only have roads with curbs.

- For the arterial streets available for the investigation, the HCM procedure resulted in calculated operating speeds greater than PSL when PSL is 30, 35, or 40 mph and operating speeds less than PSL when PSL is 45, 50, and 55 mph. Additional research or calibration may be needed because other research has found that operating speeds are higher than PSL for PSLs of 45 to 55 mph.
- A variable that was used in the HCM but not in USLIMITS2, New Zealand, or Canada is the proportion of the segment with curb and gutter.
- Several assumptions or engineering judgment had to be made to use the preliminary Portland procedure. The procedure determines a suggested PSL for vehicles, pedestrians, and bicyclists, and the lowest value is to be used as the recommended PSL. For the data used in the review and for the early version of the Portland procedure, the conditions for bicyclists dominated the results. This Portland procedure is to only be used on collector streets.
- The New Zealand and Canada procedures base the recommended PSL on an assessment of the conditions at the site (e.g., road classification, function, physical characteristics, engineering factors) rather than on the measured operating speeds. Operating speed is used as a check to determine if additional measures such as engineering, enforcement, education, and publicity are needed.
- While USLIMITS2 also considers a number of roadway characteristics, the procedure ultimately considers existing vehicle operating speeds to determine the recommended PSL. For example, high levels of signal or driveway density or pedestrian/bicycle or parking activity result in a recommendation of using a PSL closest to 50th percentile speed rather than 85th percentile speed.

A comparison of the input variables considered in the various procedures is shown in Table 15 (for variables starting with A to C),

Table 16 (for variables starting with L to O),

Table 17 (for variables starting with P to S), and

Table 18 (for variables starting with T).

Table 15. Comparison of input variables used in speed prediction or suggested posted speed limit procedures for urban/suburban (or developed) areas (variables A–C).

Input Variables	Speed Prediction: HCM	Suggested PSL: USLIMITS2 Developed Area	Suggested PSL: Portland, 2016 version	Suggested PSL: New Zealand	Suggested PSL: Canada
AADT		Yes			
Access (or driveway) density	Yes	Yes: specific values			Yes
Alignment		Yes: based on “presence/ absences of adverse alignment”		Yes: by “limited, average, or open visibility”	Yes: risk is higher when more curves or steep grades are present
Area type/ development		Yes: lower PSL when commercial or residential		Yes: more points when residential	
Bike facility: lane width and separation (distance or barrier)			Bike facility = shared road, by bike lane width, separated	Bike facility = none, narrow road, wide road, separated	Yes
Classification			Only for collectors (not for state highways or arterials)	Yes: arterial, collector, or local	Yes: arterial, collector, etc. Also: major or minor
Crash statistics		Considered in other parts of the USLIMITS2		Indicates when additional engineering/ enforcement is needed	
Curb	Yes: proportion of length with curb on right-hand side				

Blank cell = variable not included in procedure

Table 16. Comparison of input variables used in speed prediction or suggested posted speed limit procedures for urban/suburban (or developed) areas (variables L–O).

Input Variables	Speed Prediction: HCM	Suggested PSL: USLIMITS2 Developed Area	Suggested PSL: Portland, 2016 version	Suggested PSL: New Zealand	Suggested PSL: Canada
Lane width			Yes	Yes: higher PSL when lane ≥ 3.5 m	Yes: narrow, moderate, wide
Lighting				Yes: higher PSL when lighting is present	
Median type	Yes: proportion of length with restrictive median		Yes	Yes: higher PSL when median ≥ 4.5 m or fully protected	Yes: divided or undivided
Number of through lanes	Yes: affects adjustment factor for access density	Yes, per user guide			Yes
One-way to two-way street	Yes	Yes, per user guide		Yes	
On-street parking, presence or usage	Yes: proportion of length with on-street parking	Yes, per user guide		Parking = none, obstruct traffic, do not obstruct, more than 6 ft from moving veh Frequency = none, rare, frequent (long or short duration)	Yes
Operating speed (85th and 50th percentile speed)		Yes		Yes: higher PSL when higher operating speed is present	

Blank cell = variable not included in procedure

Table 17. Comparison of input variables used in speed prediction or suggested posted speed limit procedures for urban/suburban (or developed) areas (variables P–S).

Input Variables	Speed Prediction: HCM	Suggested PSL: USLIMITS2 Developed Area	Suggested PSL: Portland, 2016 version	Suggested PSL: New Zealand	Suggested PSL: Canada
Pavement surface					Yes
Pedestrian facility: sidewalk and separation (distance or barrier)			Sidewalk = none or one side or two sides Separation = yes	Pedestrian facility = none (i.e., on road), shoulder, sidewalk adjacent, sidewalk separated	Yes
Pedestrian/bicyclist activity		Yes, per user guide	Yes: for some cases NCHRP 562 (20 ped/hr)	Yes: more or less than 200 ped/day and more or less than 200 bike/day	
Posted speed limit or statutory limit, existing (mph)	Yes	Yes, per user guide			
Presence of engineering to control speed				Yes	
Roadside			Yes: higher PSL with “roadside object setback or shielding”	Yes: higher PSL when setback to fence line ≥ 6 m	Yes
Section length	Yes: considered in signal and driveway density, and in curb and on-street parking proportions	Yes, per user guide			Yes

Blank cell = variable not included in procedure

Table 18. Comparison of input variables used in speed prediction or suggested posted speed limit procedures for urban/suburban (or developed) areas (variable T).

Input Variables	Speed Prediction: HCM	Suggested PSL: USLIMITS2 Developed Area	Suggested PSL: Portland, 2016 version	Suggested PSL: New Zealand	Suggested PSL: Canada
Traffic control devices				Yes: considers the presence of several types of traffic control device, with more points assigned for presence of pedestrian crossing or stop control on the segment	Yes: part of number of intersections with public roads, considers stop-controlled, signalized, roundabout, crosswalk, at-grade railroad, and side street stop-control intersections
Traffic signal density or spacing	Yes	Yes: specific values			Yes: part of number of intersections with public roads

Blank cell = variable not included in procedure

DISCUSSION OF SPEED LIMIT APPROACHES

The operating speed (engineering) approach is the most common method used in the United States. It relies on the 85th percentile speed with adjustments used to account for existing roadway geometry or crash experience.

Using techniques other than 85th percentile speed to select the posted speed limit is gaining in popularity for other counties. Several cities—such as Portland, Oregon; Boston, Massachusetts; New York City, New York; Seattle, Washington; and others—are also experimenting with alternative approaches for city streets.

In the United States, there are two major trends with respect to speed limits. For some rural highways and freeways, there is a trend to increase posted speed limits. The other major trend is to lower speed limits, especially on city streets or in neighborhoods. Cities concerned with recent increases in pedestrian deaths or as part of their Vision Zero initiatives have explored options to improve safety for all road users. One of those options is a focused effort to lower speed on their streets. As part of these efforts, cities such as Boston, New York City, Portland, and Seattle have lowered their citywide default speed limits recently.

APPENDIX D. RELATIONSHIP AMONG URBAN/SUBURBAN ROADWAY CHARACTERISTICS, OPERATING SPEED, AND CRASHES IN AUSTIN, TEXAS

OVERVIEW

The goal of NCHRP Project 17-76 was to identify the relationships among roadway characteristics (including posted speed limit), travel speeds, and crashes on urban/suburban streets. The database was developed as a fusion of several databases, as discussed below. It includes data for operating speed, crashes, and roadway characteristics, including posted speed limit and vehicle volume.

DATABASE DEVELOPMEMT

Operating Speed Data from On-Road Tubes

On-road tube speed data collection is a common method for obtaining short-term vehicular speed and volume data. Typically, the count of vehicles is stored within 5-mph speed bins. An advantage of on-road tube data is that the speed readings are associated with the volume present during that time period. While the volume for the hour is associated with the speed data, a limitation with on-road tube speed binned data is that free-flow speed cannot be determined for the site.

This study used data from on-road tube sites (RTSs) from two different sources:

- City of Austin traffic count data.
- Data collected from selected sites in Austin as part of this research.

The City of Austin used on-road tubes to collect volume and speed data in several locations between 2016 and 2017. The data were binned in 5-mph increments and were used to investigate conditions for potential traffic calming solutions, among other purposes. The City of Austin made those counts available online (*211*). The research team downloaded the binned speed data and traffic volume data. Table 19 lists the description of the data fields for the counts.

The research team disregarded a few of the sites (around 2 percent of all sites) because it appeared that the speed data were incomplete for the sites. Sites were not considered for analysis if many of the hours had zero vehicles or if the number of readings for one direction was much lower than the number of readings for the opposing direction. Furthermore, speed readings were only available for one one-way street, so that site was also removed from the database. A review of the data available from the City of Austin demonstrated that most of the sites studied were on two-lane roads classified as local streets.

To increase the number of four-lane sites, a local vendor installed road tubes at 26 locations (52 sites). Speed and vehicle volume data were recorded for a 2-week period in July 2018. The dataset contained speed data for 4,128,083 vehicles after filtering out vehicles with an axle value as 0. The data were collected at the individual vehicle level, which provided the following key information:

- Speed of individual vehicle (mph).
- Length of individual vehicle (inches).
- Vehicle class.
- Numbers of axles.

- Gap (seconds).
- Follow (inches).

Figure 9 shows the count locations included in the database. These locations are primarily in Travis County, with a few sites in Williamson County.

Table 19. Austin on-road binned tube data file format.

Field Name	Type	Description
ROW_ID	Text	Unique record identifier
DATA_FILE	Text	Unique identifier assigned to data file
SITE_CODE	Text	Unique identifier assigned to site
DATETIME	Time stamp	Time stamp
YEAR	Integer	Year
LATITUDE	Float	Latitude of the road tube location
LONGITUDE	Float	Longitude of the road tube location
MONTH	Integer	Month
DAY_OF_MONTH	Integer	Day of the month
DAY_OF_WEEK	Integer	Day of the week
TIME	Time stamp	Hour
SPEED_CHANNEL	Text	Direction
COUNT_TOTAL	Integer	Traffic volume count
SPEED_0_14	Integer	Count of vehicles within the speed limit bin
SPEED_15_19	Integer	Count of vehicles within the speed limit bin
SPEED_20_24	Integer	Count of vehicles within the speed limit bin
SPEED_25_29	Integer	Count of vehicles within the speed limit bin
SPEED_30_34	Integer	Count of vehicles within the speed limit bin
SPEED_35_39	Integer	Count of vehicles within the speed limit bin
SPEED_40_44	Integer	Count of vehicles within the speed limit bin
SPEED_45_49	Integer	Count of vehicles within the speed limit bin
SPEED_50_54	Integer	Count of vehicles within the speed limit bin
SPEED_55_59	Integer	Count of vehicles within the speed limit bin
SPEED_60_64	Integer	Count of vehicles within the speed limit bin
SPEED_65_69	Integer	Count of vehicles within the speed limit bin
SPEED_70_200	Integer	Count of vehicles within the speed limit bin

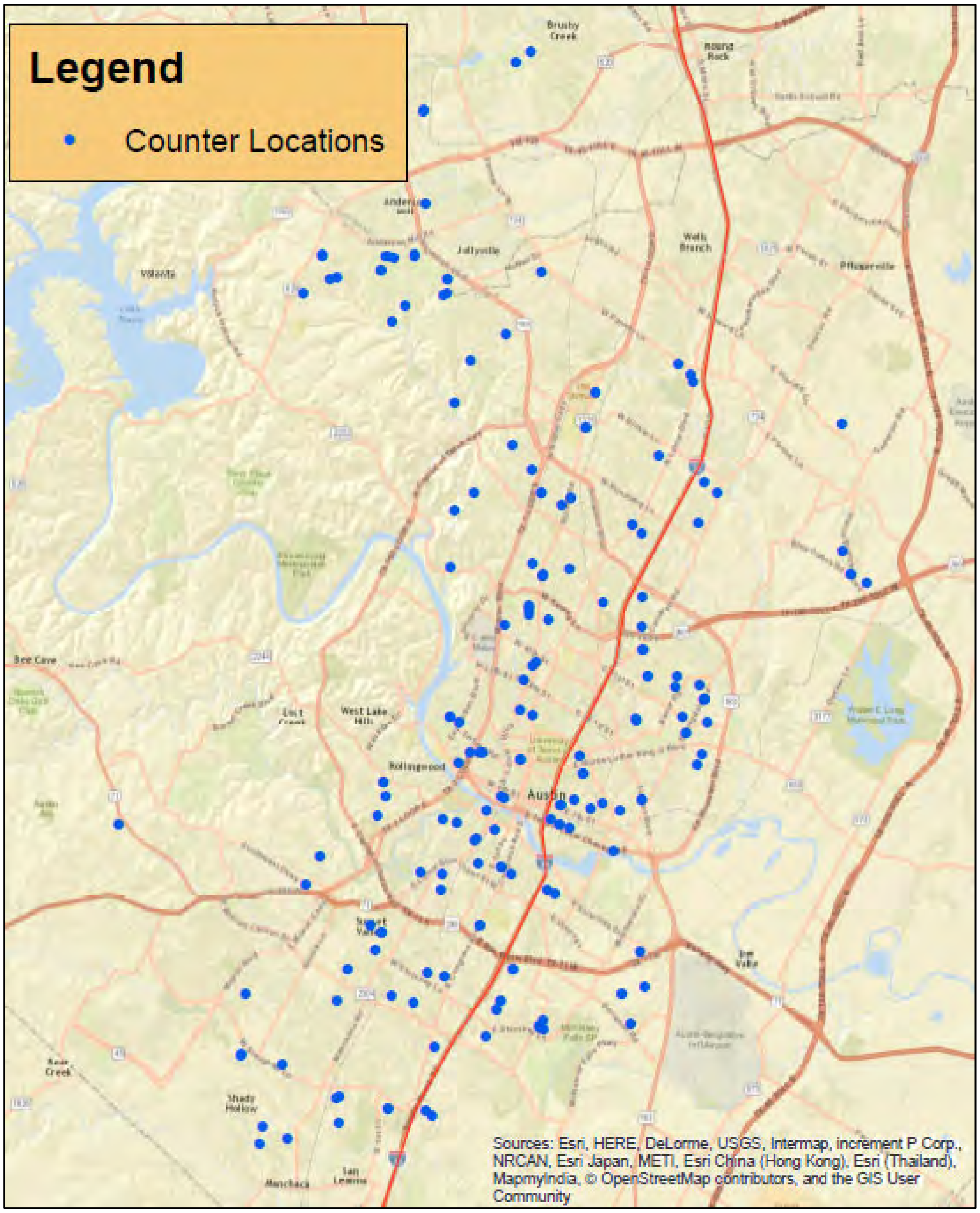


Figure 9. Austin road tube traffic counter locations.

Table 20 lists the distribution of number of segments and total segment length by functional classification. Urban local roadway is the dominant functional class of the collected data, while urban major collector is the second most dominant functional class.

Table 20. Number of segments by functional classification.

Functional Classification	Code	Number of Segments	Length (mi)
Urban Other Principal Arterial	U3	63	31
Urban Minor Arterial	U4	60	44
Urban Major Collector	U5	151	88
Urban Minor Collector	U6	29	11
Urban Local	U7	360	132
All Sites	**All**	**663**	**305**

Table 21 and Table 22 list the distribution of number of segments and total segment length by posted speed limit and number of lanes, respectively. The dominant groups for these variables are roadways with a posted speed limit of 30 mph and two-lane roadways.

Table 21. Number of segments by posted speed limit.

Posted Speed Limit (mph)	Total	Length (mi)
25	169	52
30	318	138
35	68	36
40	51	37
45	43	28
50	12	13
55	2	2
Grand Total	**663**	**305**

Table 22. Number of segments by number of lanes.

Number of Lanes	Total	Length (mi)
2	529	222
4	126	78
6	8	6
Grand Total	**663**	**305**

Crash Records Information System

TxDOT is responsible for assembling and maintaining the traffic crash database known as the Crash Records Information System (CRIS). CRIS contains multiple tables (crash, unit, and person) that are linked by a common crash designation identification number. The research team used data for 7 years (2011–2017).

Average Annual Daily Traffic

TxDOT also maintains a database that includes a variety of roadway characteristics as the Roadway Highway Inventory Network Offload (RHiNO). TxDOT specialists typically associate AADT values with corresponding roadway sections, and the data are stored in RHiNO. The research team used the 2016 RHiNO to extract annual average daily volume (ADT_ADJ) for 2013–2016. The 2017 data were not available at the time this database was assembled.

Roadway Geometry and Traffic Control Device Characteristics Data

Table 23 lists descriptions of the specific geometric variables considered for this investigation. These variables were primarily chosen based on the findings from the literature review.

Table 23. Roadway and traffic control device variables for City of Austin, Texas.

Variable	Description
Site	Unique name for each site, consists of a segment number plus the primary direction for traffic (e.g., NB, SB, EB, or WB).
Beg_IT_Legs	Number of legs for intersection at beginning of segment.
Bike_1yes	Bike lane presence: 1=yes, 0=no.
Curb_1yes	Is curb and gutter present on segment: 1=yes or 0=no.
Develop	Development: Com/Ret/Ind (for commercial, retail, or industrial), Residential, or Rural/Parks (for areas with park-like or rural-like settings).
DrvUsigPerMileBoth	Driveways and unsignalized intersections per mile in both directions.
End_IT_Legs	Number of legs for intersection at ending of segment.
Horz_1tan	Horizontal alignment: 1=straight(tangent), 0=some horizontal curvature.
Len_mi	Segment length (mi).
LnWdG	Lane width (ft) for the segment grouped into N=Narrow (7, 8, 9, or 10 ft), T=Typ (11 or 12 ft), W=Wide (13 ft or more).
Median	Median type: none, TWLTL, raised.
MedWidth	Typical or average median width for the segment (ft).
NumSigInt	Number of signalized intersections along segment, including the signals at the beginning or end of the segment.
OnStreetPark	On-street parking (either marked or unmarked), subdivided by parking width: None, Yes—Nar (6 or 7 ft wide), Yes—Typ (8 or 9 ft wide).
PedAuto	Typical or average distance between the sidewalk and the automobile lane for the segment, sum of the following (when present): parking width, bike width, bike-auto separation, and sidewalk to road separation (ft).
PedCross_1yes	Is a midblock marked pedestrian crossing present within the segment: 1=yes or 0=no.
PSL	Posted speed limit (mph).
RoadSurf	Distance between the driving surface edges, calculated as number of through lanes multiplied by average lane width plus median width plus parking widths plus bike widths.
RU_F_SYSTEM	TxDOT functional classification for street: U3=urban other principal arterial, U4=urban minor arterial, U5=urban major collector, U6=urban minor collector, U7=urban local.
SchZone_1yes	School zone presence: 1=yes, 0=no.
Sidewalk_1yes	Is a sidewalk present within the segment: 1=yes or 0=no.
Vol_Day	Volume per day in both directions. Typically, the value is from TxDOT RHiNO’s ADT_ADJ. If ADT_ADJ is not available or when ADT_ADJ = 405 (a known placeholder), the value is the average daily volume from the on-road counter.

The research team determined that the most efficient approach to building the database was to investigate existing sources to obtain the needed data. TxDOT maintains several datasets and ArcGIS maps; however, none contain all the desired information. Therefore, the research team used Google® Earth to gather the necessary roadway and traffic control device data. The team members gathered the geometric data using the measurement tool, acquired the posted speed limit information using the Street View feature, and used the historical Street View feature to confirm the speed limit that existed at the time the traffic count was made.

Data Integration Overview

To determine the association among operating speed, roadway characteristics, and crash outcomes, this study required the research team to develop a conflated database where the RTS was conflated with RHiNO and CRIS to develop the database for analysis. RTSs have three geo-locations (in latitude and longitude):

- Segment begin location.
- Segment end location.
- Road tube counter location.

The spatial conflation of these datasets is challenging because the RTS locations contain network-level information for each direction, and the RHiNO data are non-directional. Additionally, RHiNO has roadway segments that are not included in the RTS database.

The data integration work was divided into four processes:

- Process 1: Conflate RTS on RHiNO segments.
- Process 2: Assign crashes to RTS.
- Process 3: Develop a wider list of speed measures at site and hour level.
- Process 4: Identify segment and intersection crashes.

It is important to note that RHiNO datasets do not cover all roadway networks, for example, local city streets. The RTS dataset included a site that was outside the boundary of Travis County. When the site was selected for study, it appeared to be within the county border; however, the research team learned later that it was just beyond the county border. In order to not lose that site from the study, the researchers considered crashes from Williamson County.

Process 1: Conflation of Tube Locations with Roadway Inventory Data

The objective of Process 1 was to assign the road tube locations to the RHiNO segments to be able to perform the analysis at the roadway segment level. The following steps were taken to assign the RTS to RHiNO segments:

- Step 0: Create a shapefile of RHiNO data (ArcGIS).
- Step 1: Create point-level shapefiles for the RTS beginning and end locations (ArcGIS).
- Step 2: Use the "Near" function to assign the RTS locations to the nearby RHiNO segments (ArcGIS).
- Step 3: Develop an identifier to separate RHiNO segments that contain several RTSs (ArcGIS).
- Step 4: Divide RHiNO segments to match with RTS beginning and end locations (ArcGIS).
- Step 5: Create segment-level RTS shapefiles with appropriate RHiNO sites (ArcGIS).

Process 2: CRIS Crash Assignment

The objective of Process 2 was to integrate line and point shapefiles (RTS and CRIS crashes) such that each relevant CRIS crash record was associated with a roadway segment that had speed data to allow for the speed and crash analysis. The software used during this effort included ArcGIS and R (*212*). The following steps were taken in Process 2:

- Step 0: Identify relevant crash data from CRIS (2011–2017). Create a shapefile of crash data by converting crashes with available geo-locations into shapefiles, as shown in Figure 10 (Crash Dataset 1). Develop a separate spreadsheet of crash data that do not have geo-locations but where the name of the main road matches with road RTS roadway names (Crash Dataset 2; R and ArcGIS).
- Step 1: Create a 30-ft buffer around the RTS segments (ArcGIS).
- Step 2: Spatially join Crash Dataset 1 with resulting nearest distance (see Figure 11). It is important to note that the beginning and end points of the segments had an additional 30-ft buffer for this analysis. In this step, each crash case was assigned to the closest RTS segments in both directions (ArcGIS).
- Step 3: Generate crash-level output csv file. In these data, each row represents a crash case and is assigned to an RTS when applicable (R).
- Step 4: Produce RTS-level output csv file. This step combines RTS-level manual geometric data, RHiNO attributes, and segment-level crash information (R).

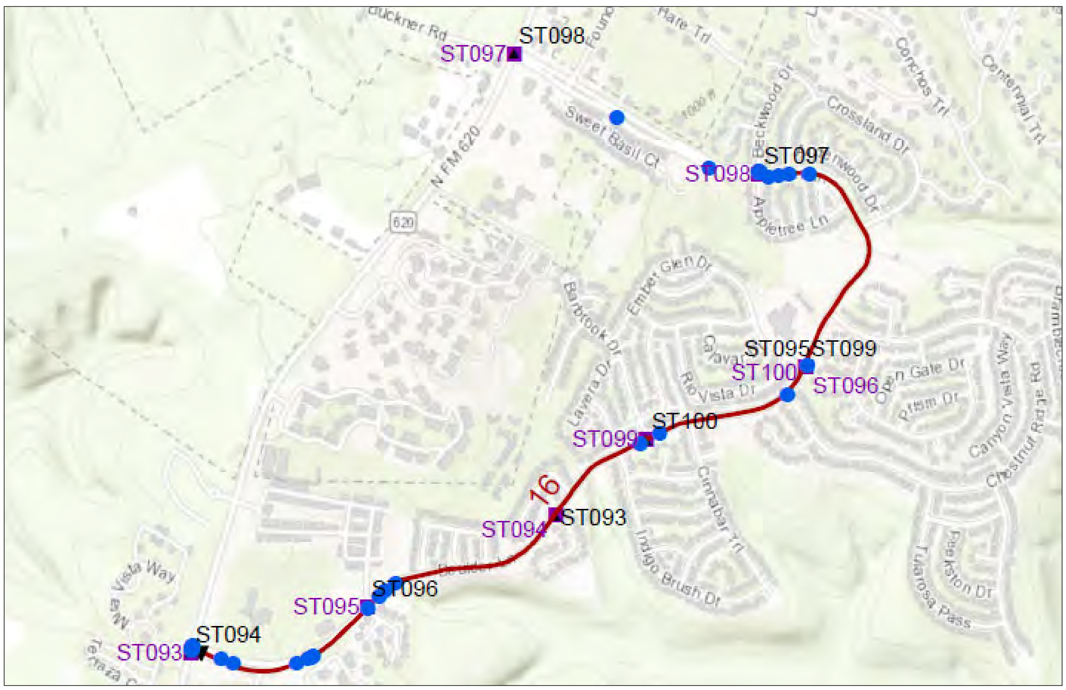


Figure 10. Example of crashes (dots) and road tube locations (squares with labels starting with ST) for a road in Austin.

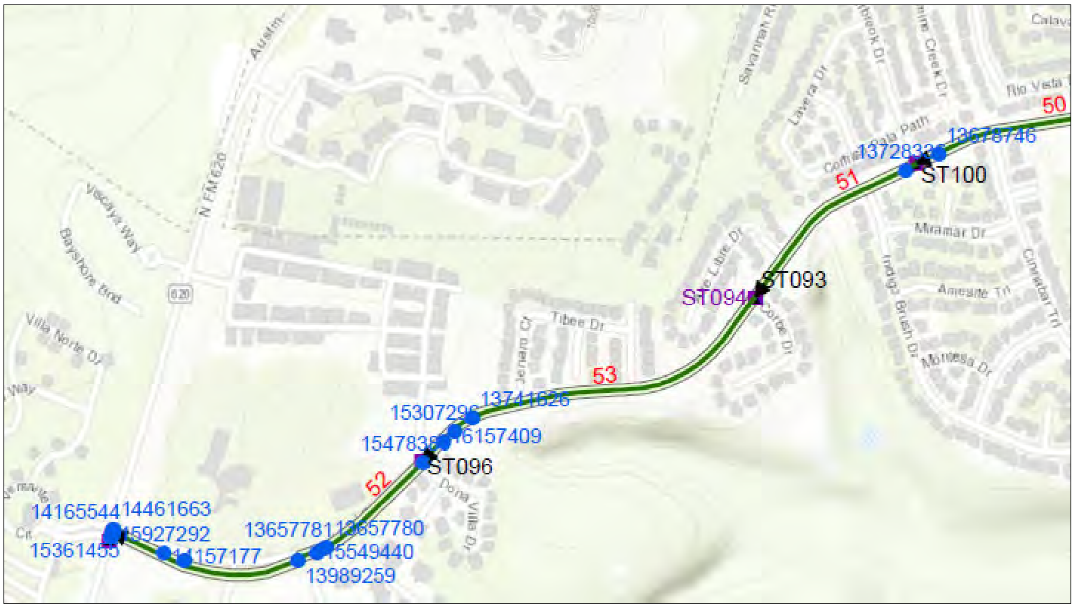


Figure 11. Example of crash assignment using 30-ft buffer along a sample road segment.

Process 3: Calculation of Speed Measures

The objective of Process 3 was to construct candidate speed measures that were suitable to demonstrate the association among speed measures, roadway geometry, traffic volume, and crash outcomes. RTS traffic volume and speed measures were collected from two sources—the City of Austin road tube data and the vendor-collected data. The City of Austin road tube data contain the number of vehicles recorded within the bin limits for a given hour, while the vendor-collected data have the speed for the individual vehicle. Each vehicle within a bin was randomly assigned a value according to a uniform distribution so that the speed measures, especially standard deviation, would better represent a typical value. For example, if there were 50 vehicles within the speed bin of 25 to 29, these vehicles would be randomly assigned a value of 25, 26, 27, 28, or 29.

The field data for 52 sites in Austin had speed data at an individual level. These data were converted to an hour level of speed measures and traffic volume data for consistency. The research team developed a wider list of speed measures for these two datasets. Then, a list of common speed measures between both datasets was developed. Table 24 provides a list of these speed measures.

Table 24. Initial speed measures developed.

Initial Speed Measures	Description
PSLMinusSped85	Posted speed limit minus 85th percentile speed (mph)
Spd85	85th percentile speed (mph)
SpdAve	Average speed for the site (mph)
StdSpd	Standard deviation of speeds for the site (mph)
PerOverPSL	Percent of observations over the speed limit for the site
Pace_LV	Lower speed value of 10-mph pace for the site
Pace_UV	Upper speed value of 10-mph pace for the site
Pace_Bin	Range of the pace
Pace_Per	Percent of vehicles in 10-mph pace for the site
SpdAve_Hr_Ca.Qa	Average speed per hour per site for both the City of Austin traffic count data and the data collected as part of this research (mph)

Process 4: Identify Segment and Intersection Crashes

Segment crashes were identified using the “intersection-related” variable within the CRIS dataset. Crashes coded as “driveway access” or “not intersection” were considered segment crashes, while the remaining levels of “intersection” and “intersection related” were considered intersection crashes. To obtain a shorter variable name, the segment crashes were called NID (for not intersection and driveways), while the intersection crashes were called IRI (for intersection and intersection related). The research team also grouped the crashes by those with fatalities or injuries (i.e., KABC) and those at all severity levels (KABCO).

Descriptive Statistics

The research team developed two different data structures to perform the analysis:

- Site-level data (663 site-level data points).
- Site–temporal-level data (15,446 hourly observations, where each hour had at least 30 vehicles).

Roadway Characteristics

Table 25 provides the descriptive statistics for the variables considered in the analyses.

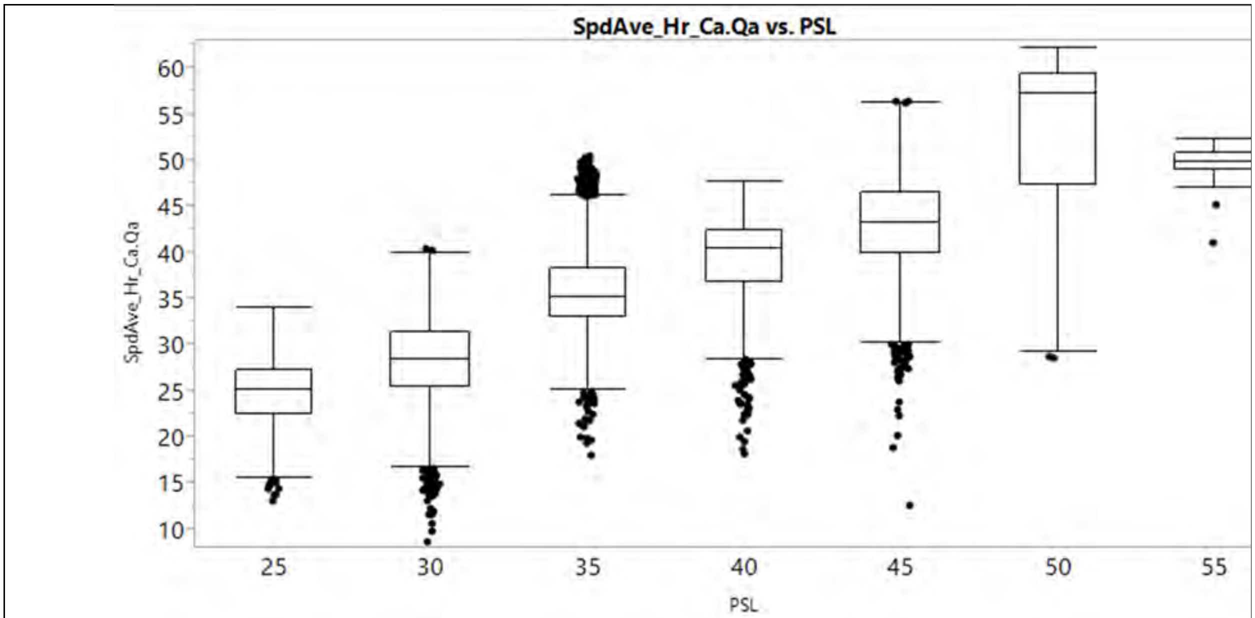
Table 25. Descriptive statistics of variables for City of Austin, Texas.

Variable[a]	Variable Type[b]	Minimum	Maximum	Mean	Std. Deviation
Beg_IT_Legs	Numerical	1	5	3.48	0.59
DrvUsigPerMileBoth	Numerical	0	174.4	47.33	41.76
End_IT_Legs	Numerical	1	5	3.48	0.58
Len_mi	Numerical	0.06	2.77	0.46	0.29
MedWidth	Numerical	0	50	3.01	6.79
NumSigInt	Numerical	0	2	0.68	0.85
PedAuto	Numerical	0	37	5.83	5.62
PSL	Numerical	25	55	31.42	6.20
RoadSurf	Numerical	18	100	41.67	15.07
Vol_Day	Numerical	92	44673	6749.17	9404.19
Bike_1yes	Dichotomous	0	1	0.22	0.42
Curb_1yes	Dichotomous	0	1	0.95	0.22
Horz_1tan	Dichotomous	0	1	0.35	0.48
PedCross_1yes	Dichotomous	0	1	0.10	0.31
SchZone_1yes	Dichotomous	0	1	0.09	0.28
Sidewalk_1yes	Dichotomous	0	1	0.64	0.48
Develop	Polychotomous	ComRetInd (n=130), Residential (n=525), Rural/Parks (n=8)			
LnWdG	Polychotomous	N=Narrow (7 to 10 ft wide) (n=208), T=Typical (11 to 12 ft wide) (n=157), or W=Wide (greater than 13 ft wide) (n=298)			
Median	Polychotomous	Raised (n=53), TWLTL (n=81), None (n=529)			
OnStreetPark	Polychotomous	Yes—Typ=parking lane present with width of 8 or 9 ft (n=82), Yes—Nar=parking lane present with width of 6 or 7 ft (n=117), None (n=464)			
RU_F_SYSTEM	Polychotomous	U3[c] (n=63), U4 (n=60), U5 (n=151), U6 (n=29), U7 (n=360)			

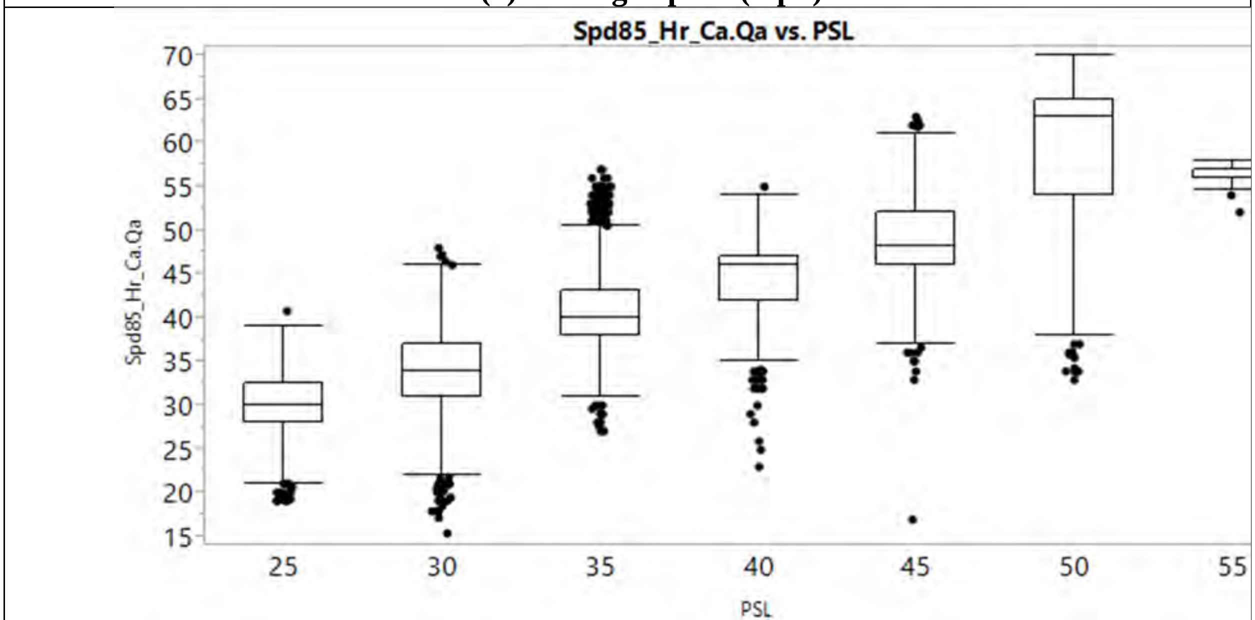
[a] Variable descriptions are in Table 23.
[b] For dichotomous variables, "1" indicates the presence of the feature and "0" indicates its absence. For polychotomous variables, the numbers in parentheses represent frequencies of the corresponding categories.
[c] See Table 20.

Speed Distributions

The research team first performed exploratory data analysis, examining distributions and the empirical relationship between pairs of variables based on plots. Figure 12 shows the basic relationship between average and 85th percentile speed and posted speed limit using the hourly data. Overall, average speed is similar to the posted speed limit, while the 85th percentile speed exceeds the posted speed limit. Note that this plot reflects binned speed data rather than free-flow speed data. Free-flow speed data include vehicles that are not affected by other vehicles, while binned speed data include all vehicles. Free-flow speed is traditionally used to set posted speed limits and is frequently used when relating operating speed to roadway characteristics (*114*); however, the emphasis of this study was to consider crashes, which could be influenced by the speed distribution for all vehicles, not just the free-flow vehicles.



(a) Average Speed (mph)



(b) 85th Percentile Speed (mph)

Figure 12. Operating speed versus posted speed limit for city streets in Austin.

Violin plots are similar to box and whisker plots in that they compare distributions of quantitative data across several levels of categorical variables. They show the variabilities between key contributing factors. Unlike the box plot, the violin plot illustrates a kernel density estimation of the underlying distribution. This can be an effective and attractive way to show multiple distributions of data at once; however, the estimation procedure is influenced by the sample size, so violins for relatively small samples might look misleadingly smooth. Additionally, the lower smoothing points of these estimations go beyond zero values, but the actual speed measures are always greater than zero.

Figure 13 contains several violin plots for average speed. It shows that the average speed is greatest on road segments in rural or park-like areas compared to commercial/retail/industrial or roads in residential areas, which had the lowest mean. It is important to note that only eight of the 663 segments were classified as rural or park development in this study, which could explain why the kernel distribution is so heavily concentrated around the mean. Another observation from Figure 13 is that road segments with a raised median and road segments with a TWLTL had similar means and kernel distributions for average speed, while road segments with no median present had a lower mean with a kernel distribution that was more heavily concentrated below the mean. The violin plots also reveal that roads with wide lane width have a lower mean speed average than narrow or typical lane widths. The presence of a sidewalk was also associated with a greater average speed, while the presence of on-street parking was associated with a lower average speed. Figure 13 also shows that road segments classified as either U3 (urban other principal) or U4 (urban minor arterial) had the highest average speed, while U5 (urban major collector), U6 (urban minor collector), and U7 (urban local) streets each had a lower mean than the previous.

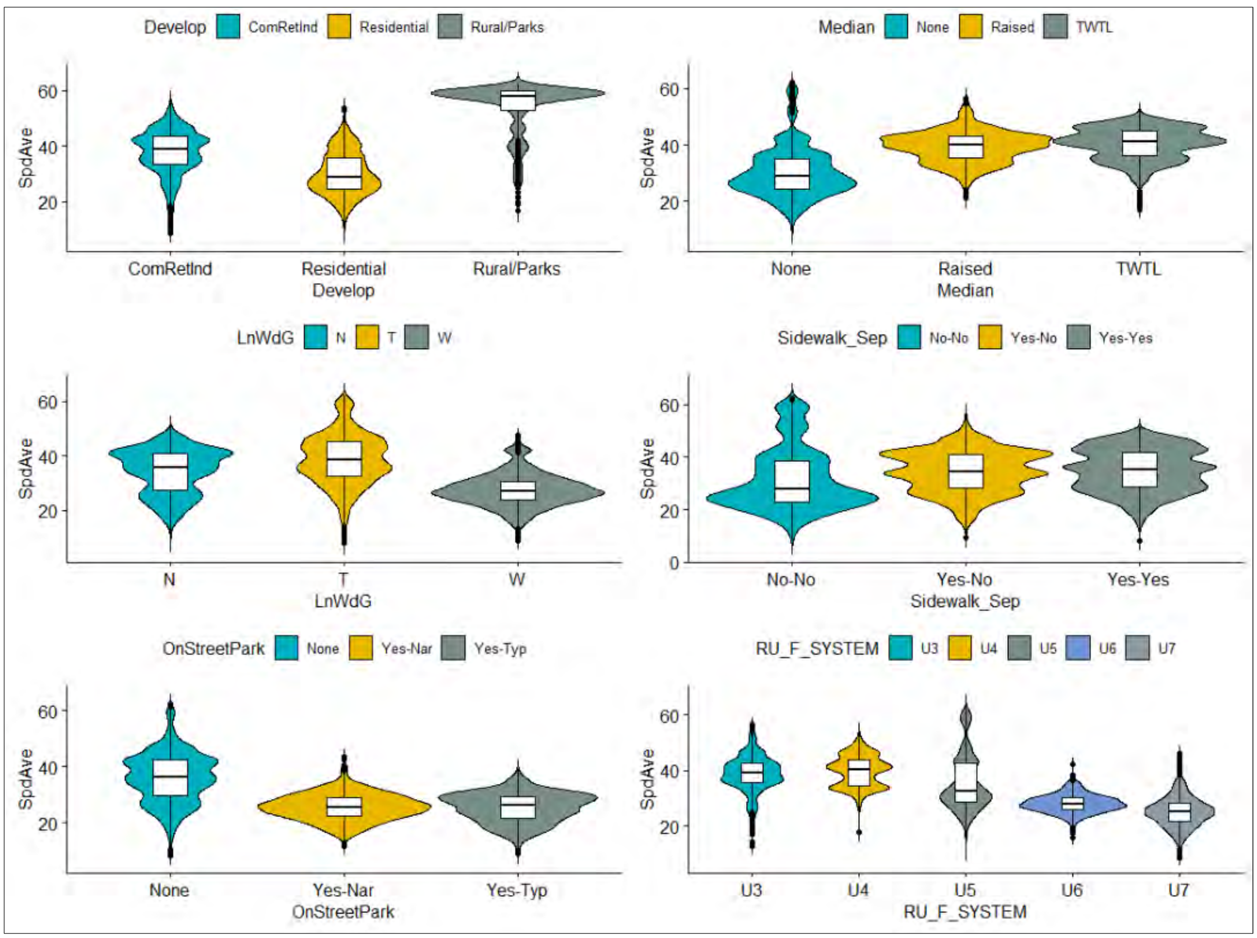


Figure 13. Violin plots for average speed (SpdAve) for different geometric features.

Figure 14 provides the violin plots for the percent of vehicles over the speed limit by several roadway characteristics. It shows that the percent of observations over the speed limit is greatest on road segments in rural or park-like areas compared to commercial/retail/industrial or roads in residential areas; commercial development had the lowest mean. As noted previously, only eight of the 663 segments were classified as rural or park development in this study, which could explain why the kernel distribution is so heavily concentrated around the mean. Another finding shown in Figure 14 is that road segments with a raised median had the greatest mean for percent over the speed limit and the kernel distribution was more concentrated above the mean in comparison to road segments with a TWLTL and road segments with no median present. The violin plots also reveal that roads with wide lane width have a lower mean value than narrow or typical lane widths. The presence of a sidewalk did not seem to have a significant effect on the percent over the speed limit, although road segments with no sidewalk did have a slightly lower mean. The presence of on-street parking was associated with a lower percent over the speed limit. Road segments classified as either U4 (urban minor arterial) or U5 (urban major collector) had the highest percent of drivers over the posted speed limit.

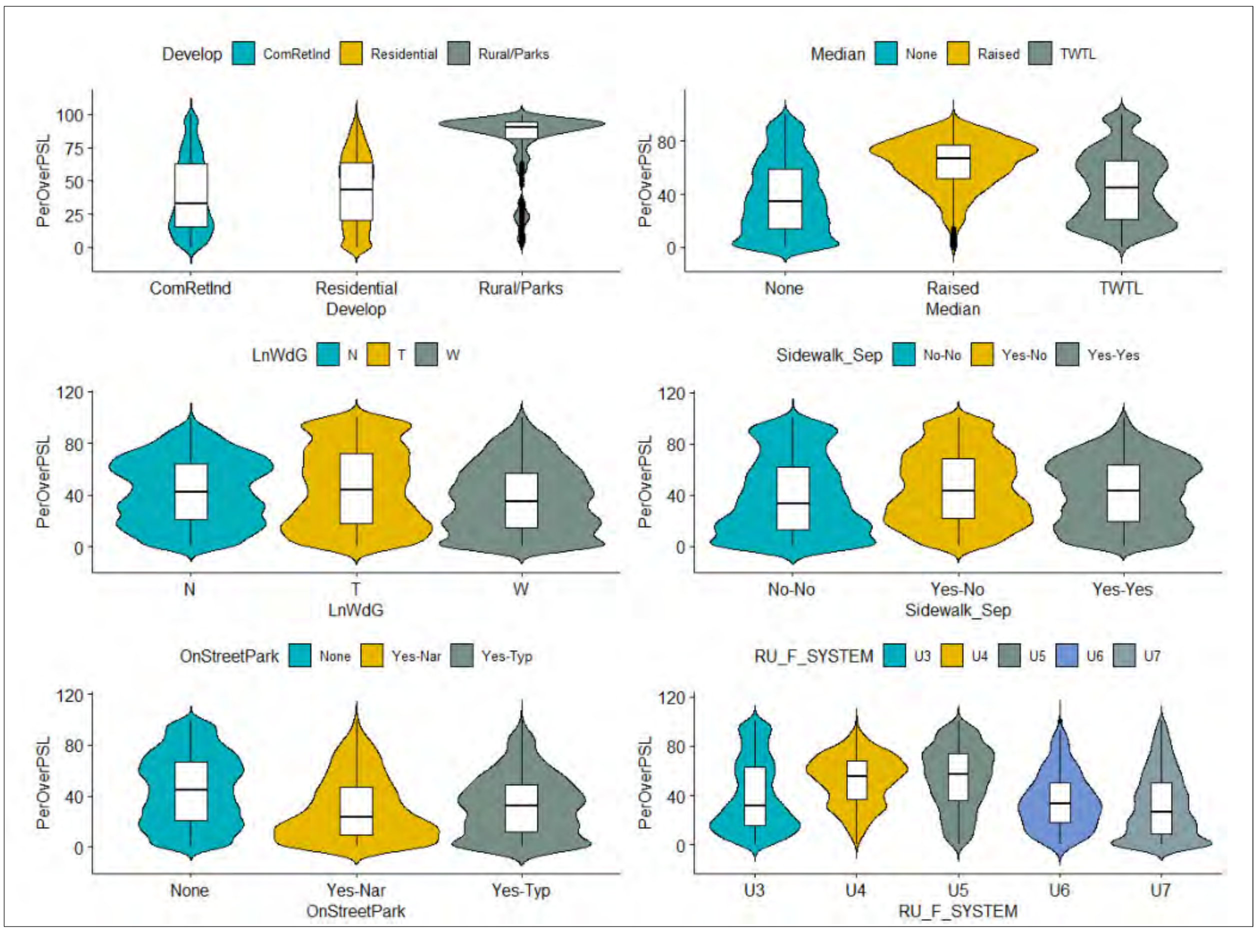


Figure 14. Violin plots for percent of vehicles over the posted speed limit (PerOverPSL) for different geometric features.

ROUND 1: DATA ANALYSIS USING NEGATIVE BINOMIAL REGRESSION

Overview

Researchers applied NB regression models to the site-level data to investigate the relationship between crashes and speed measures while controlling for the effects of other variables including AADT and roadway geometry variables. The research team examined several NB regression models. The models included the log of segment length as an offset variable. To account for correlations in crash counts from the same road segment in estimation, the generalized estimating equations (GEE) procedure was used to estimate NB regression models. The same crash count (segment-level crash count) was used for both directions of travel at a site. When multiple hours or days of speed data were available at a site, all speed data were used to generate a representative single speed measure for each direction of travel.

Variable Relationships with Crashes

To examine the relationships among crashes and roadway characteristics, including posted speed limit and volume, the research team selected non-intersection or segment crashes rather than all crashes. All crashes would have included intersection crashes, especially signalized intersection crashes. Focusing on segment crashes was expected to make it easier to identify a relationship between crashes and posted speed limit. The research team conducted evaluations using crashes with injuries (i.e., KABC) and all severity-level crashes (KABCO) in case the evaluations that included only the fatal/injury crashes were limited by sample size.

Fatal and Injury Segment Crashes (KABC_NID)

Multiple NB regression models were developed in order to identify a model that was physically meaningful as well as statistically significant (containing variables that were significant with p-values about 0.1 or lower). Table 26 provides the significance per variable, while Table 27 provides the estimate along with the p-value for each variable/level combination for the selected model. Key observations include the following:

- As expected, greater vehicle volume was associated with a higher number of crashes.
- Presence of a TWLTL was associated with more KABC segment crashes compared to no median, and presence of a raised median was associated with fewer segment crashes compared to no median or TWLTL. Care must be taken in interpreting higher KABC segment crashes at TWLTL segments compared to no median segments because road segments with no median present had lower speeds on average compared to road segments with TWLTL (or raised medians), as can be seen from Figure 5, while speeds of road segments with TWLTL and raised medians were similar. This finding suggests that more KABC segment crashes at TWLTL segments compared to no median segments could have been due (at least in part) to higher speeds (as well as other extraneous factors) at TWLTL segments compared to those at segments with no median present.
- Wider medians were associated with fewer KABC segment crashes.
- More signals (1 versus 0 or 2 versus 1 since the variable only had values of 0, 1, 2) were associated with more KABC crashes, even for segment (midblock) crashes.
- The presence of on-street parking was associated with more KABC crashes. When the available space for the on-street parking was narrow (6 to 7 ft), there were more crashes than when the on-street parking was a typical width (8 to 9 ft).
- Larger standard deviations (more variability) of speeds were associated with more KABC crashes.
- The presence of curb and gutter was associated with fewer KABC crashes.

Table 26. Score statistics for model shown in Table 27.

Variable	DF	Chi-Square	Pr > ChiSq
NumSigInt	1	15.51	<.0001
LnVol	1	21.53	<.0001
StdSpd_Ca_Qa	1	7.72	0.0055
Median	2	8.41	0.0149
OnStreetPark	2	5.22	0.0735
MedWidth	1	4.25	0.0392
Sidewalk_1yes	1	3.66	0.0556
Curb_1yes	1	2.67	0.1020

Note: Score statistics for Type 3 GEE analysis. Variable descriptions are in Table 23. LnVol=Log(Vol_Day).

Table 27. Variables with significant effects on KABC segment (KABC_NID) crashes.

Variable	Level	Estimate	Standard Error	95% Confidence Limits		Z	Pr > |Z|
Intercept		−4.2184	0.9168	−6.0152	−2.4215	−4.60	<.0001
NumSigInt		0.6834	0.1230	0.4424	0.9244	5.56	<.0001
LnVol		0.5887	0.1057	0.3816	0.7958	5.57	<.0001
StdSpd_Ca_Qa		0.1758	0.0508	0.0762	0.2754	3.46	0.0005
Median	Raised	−0.0422	0.3352	−0.6991	0.6147	−0.13	0.8999
Median	TWLTL	0.5902	0.2794	0.0427	1.1378	2.11	0.0346
Median	None	0.0000	0.0000	0.0000	0.0000	.	.
OnStreetPark	Yes—Typ	0.0731	0.2707	−0.4575	0.6037	0.27	0.7872
OnStreetPark	Yes—Nar	0.3970	0.1458	0.1112	0.6829	2.72	0.0065
OnStreetPark	None	0.0000	0.0000	0.0000	0.0000	.	.
MedWidth		−0.0435	0.0160	−0.0749	−0.0121	−2.71	0.0067
Sidewalk_1yes		0.2597	0.1528	−0.0397	0.5591	1.70	0.0891
Curb_1yes		−0.9195	0.3396	−1.5850	−0.2540	−2.71	0.0068

Notes: Analysis of GEE parameter estimates. Empirical standard error estimates. Variable descriptions are in Table 23. LnVol=Log(Vol_Day).
. = value is not relevant since this level is the base for the variable.
{blank} = value not relevant because the variable is not a multicategory variable.

The presence of a sidewalk was associated with more KABC crashes. Caution needs to be taken when interpreting this finding because association does not imply causation. That is, it does not imply that the presence of a sidewalk results in more crashes. The research team currently does not have a theory as to why the presence of a sidewalk would be associated with more vehicle crashes. It is possible that a confounding factor or lurking variable such as the location where a sidewalk is present (recall that the presence of a sidewalk was associated with a greater average speed in Figure 13) may explain this outcome.

All Segment Crashes (KABCO_NID)

Similar to the effort for segment (midblock) injury crashes, the research team developed several NB regression models to understand the relationship between all segment crashes and roadway characteristics. Table 28 provides the significance per variable, while Table 29 provides the estimate along with the p-value for each variable/level combination for the selected model. The following observations are similar to the findings for midblock injury crashes:

- As expected, more vehicle volume was associated with more crashes.

- Presence of a TWLTL was associated with more segment crashes compared to no median, and presence of a raised median was associated with fewer segment crashes compared to no median or TWLTL. Care must be taken in interpreting higher segment crashes at TWLTL segments compared to no median segments because road segments with no median present had lower speeds on average compared to road segments with TWLTL (or raised medians), as can be seen from Figure 5, while speeds of road segments with TWLTL and raised medians were similar. This finding suggests that more segment crashes at TWLTL segments compared to no median segments could have been due (at least in part) to higher speeds (as well as other extraneous factors) at TWLTL segments compared to those at segments with no median present.
- Wider medians were associated with fewer segment crashes.
- More signals were associated with more crashes.
- The only speed measure that was significant was standard deviation (of speeds). Larger standard deviations were associated with more crashes.
- Presence of a curb and gutter was associated with fewer crashes.
- Presence of a sidewalk was associated with more crashes. The research team currently does not have a theory as to why the presence of a sidewalk would be associated with more vehicle crashes. Note again that this is not a causal relationship, as mentioned before.

An observation that is different from the midblock injury crash findings is:

- Presence of on-street parking was not significant when examining midblock crashes that included all severity levels.

Table 28. Score statistics for model shown in Table 29.

Source	DF	Chi-Square	Pr > ChiSq
NumSigInt	1	16.52	<.0001
LnVol	1	26.23	<.0001
Sidewalk_1yes	1	9.67	0.0019
Median	2	9.92	0.0070
StdSpd_Ca_Qa	1	6.94	0.0084
MedWidth	1	3.50	0.0613
Curb_1yes	1	2.66	0.1028

Note: Score statistics for Type 3 GEE analysis. Variable descriptions are in Table 23. LnVol=Log(Vol_Day).

Table 29. Variables with significant effects on KABCO segment (KABCO_NID) crashes.

Variable	Level	Estimate	Standard Error	95% Confidence Limits		Z	Pr > |Z|
Intercept		−2.0840	0.7516	−3.5572	−0.6108	−2.77	0.0056
Curb_1yes		−0.7279	0.2919	−1.2999	−0.1558	−2.49	0.0126
Median	Raised	−0.3299	0.2271	−0.7750	0.1151	−1.45	0.1462
Median	TWLTL	0.4068	0.1968	0.0210	0.7926	2.07	0.0388
Median	None	0.0000	0.0000	0.0000	0.0000	.	.
MedWidth		−0.0285	0.0091	−0.0464	−0.0106	−3.12	0.0018
NumSigInt		0.5533	0.0986	0.3601	0.7465	5.61	<.0001
Sidewalk_1yes		0.3892	0.1331	0.1284	0.6500	2.93	0.0034
StdSpd_Ca_Qa		0.1478	0.0445	0.0607	0.2350	3.33	0.0009
LnVol		0.4601	0.0840	0.2954	0.6248	5.47	<.0001

Note: Variable descriptions are in Table 23. LnVol=Log(Vol_Day).
. = value is not relevant since this level is the base for the variable.
{blank} = value not relevant because the variable is not a multicategory variable.

Variable Relationships with Posted Speed Limit

A better understanding of relationships between roadway characteristics and posted speed limit may assist with identifying how the context—sometimes referred to as the look and feel—of a road could help to communicate the anticipated speed and the anticipated posted speed for the facility. Table 30 provides a summary of the variables with statistically significant effects on posted speed limit. These results illustrate how certain roadway characteristics tend to be associated with different posted speed limits.

Key observations include the following:

- Roads with on-street parking were associated with lower speed limits.
- Higher access density (i.e., DrvUsigPerMileBoth) was associated with lower speed limits.
- Lower speed limits were associated with the presence of bike lanes and curb/gutter.
- Higher speed limits were associated with straight roads.
- For this Austin database, roads with raised medians had lower posted speed limits, while roads with TWLTL had higher posted speed limits, compared to roads with no medians.
- For this database, roads with rural or park-like development had higher posted speeds limits compared to the other development types (i.e., residential or commercial/retail/industrial). This finding should be used with caution due to the low number of segments with rural/park development (only eight of the 663 segments).

Table 30. Variables with significant effects on posted speed limit.

Parameter	Level	DF	Estimate	Standard Error	Wald 95% Confidence Limits		Wald Chi-Square	Pr > ChiSq
Intercept		1	31.7757	1.4273	28.9782	34.5731	495.64	<.0001
Bike_1yes		1	−1.3754	0.4205	−2.1996	−0.5512	10.70	0.0011
Curb_1yes		1	−1.7321	0.6196	−2.9466	−0.5177	7.81	0.0052
Develop	ComRetInd	1	−6.4299	1.3017	−8.9811	−3.8787	24.40	<.0001
Develop	Residential	1	−7.5124	1.2292	−9.9217	−5.1031	37.35	<.0001
Develop	Rural/Parks	0	0.0000	0.0000	0.0000	0.0000	.	.
DrvUsigPerMileBoth		1	−0.0132	0.0035	−0.0202	−0.0063	14.00	0.0002
Horz_1tan		1	−0.7000	0.2721	−1.2333	−0.1667	6.62	0.0101
LnWdG	N	1	1.3765	0.4203	0.5528	2.2002	10.73	0.0011
LnWdG	T	1	1.9571	0.3678	1.2363	2.6780	28.32	<.0001
LnWdG	W	0	0.0000	0.0000	0.0000	0.0000	.	.
Median	Raised	1	−2.2826	0.6774	−3.6102	−0.9550	11.36	0.0008
Median	TWLTL	1	0.4392	0.5785	−0.6947	1.5731	0.58	0.4478
Median	None	0	0.0000	0.0000	0.0000	0.0000	.	.
NumSigInt		1	0.6765	0.2096	0.2656	1.0874	10.41	0.0013
OnStreetPark	Yes—Typ	1	−4.1290	0.5339	−5.1754	−3.0826	59.81	<.0001
OnStreetPark	Yes—Nar	1	−2.6834	0.4490	−3.5635	−1.8033	35.71	<.0001
OnStreetPark	None	0	0.0000	0.0000	0.0000	0.0000	.	.
PedAuto		1	0.0659	0.0322	0.0028	0.1290	4.19	0.0407
RoadSurf		1	0.1619	0.0164	0.1298	0.1940	97.87	<.0001
Vol_Day		1	0.0002	0.0000	0.0001	0.0002	46.62	<.0001
Len_mi		1	2.5828	0.5452	1.5143	3.6513	22.45	<.0001
Scale		1	2.9643	0.0814	2.8089	3.1282	NR	NR

Notes: Analysis of maximum likelihood parameter estimates. Variable descriptions are in Table 23.
. = value is not relevant since this level is the base for the variable.
{blank} = value not relevant because the variable is not a multicategory variable.
NR = value not relevant for the scale parameter.

ROUND 2: DATA ANALYSIS USING PATH ANALYSIS APPROACH

Overview

There are two primary relationships of interest among variables: the relationship between speed-related variables (speed measures) and roadway characteristics, including traffic volume and other roadway geometry and traffic control device variables; and the relationship between crashes and speed-related variables while accounting for other roadway characteristic variables that may confound the relationship between speeds and crashes if not taken into account. In the previous analysis (Round 1 data analysis), the relationship between speed-related variables and roadway characteristic variables and the relationship between crashes and speed-related variables along with roadway characteristic variables were assessed separately. In Round 2 data analysis, the research team analyzed the relationships among variables using a more enhanced statistical modeling approach.

For speed, researchers considered several different measures of speed that can quantify various aspects of speed distributions at each segment, including newly developed measures as well as some previous speed measures explored in the Round 1 analysis. Table 31 contains the speed measures, and Table 32 lists the roadway characteristic variables considered in this analysis.

Table 31. Round 2 speed measures considered.

Round 2 Speed Measures	Description
Abs(PSL−Avg)	Absolute value of posted speed limit minus average speed (mph)
CoefVar	Coefficient of variation of speed
Pace	Percent of vehicles in 10-mph pace for the site (%)
PerOvPSL	Percent of observations over the speed limit for the site (%)
PSL	Posted speed limit (mph)
PSL−Avg	Posted speed limit minus average speed (mph)
PSL−S85	Posted speed limit minus 85th percentile speed (mph)
S85−Avg	85th percentile speed minus average speed (mph)
SpdAve	Average speed (mph)
StdSpd	Standard deviation (mph)

Table 32. Roadway characteristic variables considered in path analysis.

Path Analysis Variable	Original Variable
Bike1yes	Bike_1yes
Curb1yes	Curb_1yes
DUPMBoth	DrvUsigPerMileBoth
Horz1tan	Horz_1tan
MedWidth	MedWidth
NSigInt	NumSigInt
PedAuto	PedAuto
PdCr1yes	PedCross_1yes
RoadSurf	RoadSurf
ScZn1yes	SchZone_1yes
SdWk1yes	Sidewalk_1yes
LnVol	Log(Vol_Day)
LnLen	Log(Len_mi)
Median2 (with 2 categories: Raised=1, NotRaised=0)	Median (3 categories: Raised, TWLTL, None)
OnStPk2 (with 2 categories: OnStrPrk=1, None=0)	OnStreetPark (3 categories: Yes—Typ, Yes—Nar, None)
Develop2 (with 2 categories: Resident=1, Other=0)	Develop (3 categories: Residential, ComRetInd, Rural/Parks)
RU_F_rev (with 2 categories: Local [U7]=1, Not-Loc [U3-U6]=0)	RU_F_SYSTEM (5 categories: U3, U4, U5, U6, U7)

The focus of this analysis was to assess the effect of speed on crashes while accounting for the effects of other roadway characteristic variables on speed and crashes. Note that while roadway characteristic variables (e.g., traffic volume) may affect both speed and crashes, some variables such as posted speed limit may affect crashes only through speeds and only indirectly affect crashes. A speed variable plays the role of a mediator variable (or intervening variable) between crashes and other variables that affect crashes only indirectly in this case. In addition to assessing the speed-crash relationship, it is also of interest to evaluate indirect effects of roadway characteristics on crashes through a mediator variable (speed) as well as direct effects of roadway characteristics on crashes.

To accommodate these general relationships among variables, researchers jointly modeled the relationship between speeds and roadway characteristics and the relationship between crashes and speeds along with roadway characteristics as well as the speed limit simultaneously based on a coherent structural equation modeling (SEM) framework (*213*), specifically using path analysis. Path analysis is a special case of SEM where there is no latent variable in the model (i.e., all variables in the model are measured variables). Regardless of its many advantages, path analysis has not been widely used in safety analysis yet. A notable exception is the study by Gargoum and El-Basyouny (*10*).

The path analysis model consists of two submodels in this case: (1) crash model (Model 1) describing the relationship between crashes (outcome variable) and speed (mediator variable) as well as other roadway characteristic variables (independent variables); and (2) speed model (Model 2) describing the relationship between speed and other roadway characteristic variables.

For the crash model (Model 1), an NB model with the mean given in Equation (1), which expresses the log mean crash rate as a function of covariates corresponding to a speed variable and other roadway characteristic variables in Table 31 and Table 32, was adopted.

$$\mu_i = \exp\left(\beta_0 + m_i\beta_m + X_{1i}\beta_1 + \cdots + X_{Ki}\beta_K\right), \tag{1}$$

where y_i denotes the observed outcome variable (the number of crashes that occurred on the segment in 7 years) on segment *i* ($i = 1, \cdots, I$); $\mu_i = E(y_i)$ is the expected number of crashes for 7 years; m_i is the mediator variable (a measure of speed); $X_{1i}, \quad \cdots, \quad X_{Ki}$ are *K* covariates; and $\beta_0, \beta_m, \beta_1, \cdots, \beta_K$ denote regression coefficients for the outcome variable.

For the speed model (Model 2), a normal linear model given in Equation (2) was employed.

$$m_i = \alpha_0 + X_{1i}\alpha_1 + \cdots + X_{Li}\alpha_L + \varepsilon_i, \tag{2}$$

where $\alpha_0, \alpha_1, \cdots, \alpha_L$ are regression coefficients.

Estimation was performed by SEM software Mplus version 8.3 (*214*). Several different models (with different sets of independent variables) for each mediator variable in Table 31 were explored. Table 32 shows the roadway characteristic variables used in the path analysis. Note that categorical variables with three or more categories needed to be recoded as two-category variables by regrouping because Mplus does not allow multicategory variables. Researchers kept variables in the model if the corresponding p-values were less than 0.2. Note, however, that there may be multiple models that may be adequate for any given dataset. Researchers used a penalized-likelihood criterion, the Bayesian information criterion (BIC), which is a popular tool used for model selection in various applications (see, for example, Kass and Raftery [*215*]), to select an appropriate model. Although a model with lower BIC is preferred in general, a more physically meaningful model can be selected whenever there is not much difference in BIC values among competing models. Note that BIC can be used for comparing models with different independent variables but not models with different dependent variables. That is, BIC values should not be compared across different outcome variables or mediator variables since they represent different datasets.

Results and Discussion

The estimated regression coefficients for crashes in Equations (1) and (2), having each of the speed variables in Table 31 as a mediator variable and roadway characteristic variables selected from those in Table 32, are given in Table 33, Table 34, Table 35, and Table 36 The results for KABC_NID crashes are presented in Table 33 and Table 34, and the results for KABCO_NID (all) crashes are presented in Table 35 and Table 36.

Table 33. Estimated regression coefficients for KABC_NID crashes by path analysis (mediator variable: PSL, CoefVar, PerOvPSL, StdSpd, Pace, or SpdAve).

Outcome Variable	Independent Variable	Mediator / Coefficient	PSL	CoefVar	PerOvPSL	StdSpd	Pace	SpdAve
KABC_NID crashes	Intercept	β_0	−3.259	−3.076	−2.144	−3.386	−0.856	−3.359
	Mediator	$\beta_{Mediator}$	0.032	2.059	−0.004	0.143	−0.023	−0.001
	Curb1yes	$\beta_{Cirb1yes}$	−0.827	−1.037	−1.069	−0.916	−0.872	−0.921
	Dvelop2	$\beta_{Develop2}$	−0.362	−0.429	−0.438	−0.399	−0.368	−0.402
	Median2	$\beta_{Median2}$	−0.723	−0.641	−0.632	−0.684	−0.668	−0.680
	NSigInt	$\beta_{NSigInt}$	0.602	0.644	0.642	0.638	0.629	0.639
	SdWk1yes	$\beta_{SdWk1yes}$	0.263	0.249	0.260	0.246	0.260	0.245
	ONSTPK2	$\beta_{ONSTPK2}$	0.194	0	0	0.173	0.167	0.171
	LnVol	β_{LnVol}	0.488	0.584	0.545	0.542	0.526	0.545
	LnLen	β_{LnLen}	0.720	0.877	0.853	0.828	0.836	0.836
	StdSpd	β_{StdSpd}	0	0	0	NA	0	0.144
Speed	Intercept	α_0	27.534	0.336	66.776	5.218	76.743	8.817
	PSL	α_{PSL}	0	0	−2.004	0.061	−0.413	0.433
	BIKE1YES	$\alpha_{BIKE1YES}$	−0.615	0	0	0	1.482	0
	Curb1yes	$\alpha_{Cirb1yes}$	−2.585	−0.029	0	−0.780	4.196	0
	Dvelop2	$\alpha_{Develop2}$	−1.940	−0.025	0	−0.335	3.905	0
	DUPMBoth	$\alpha_{DUPMBoth}$	−0.020	0.000	−0.099	0.003	0	−0.022
	Horz1tan	$\alpha_{Horz1tan}$	0	0.023	0	0.265	−1.259	−0.941
	Median2	$\alpha_{Median2}$	−1.601	0	0	0	0	0
	NSigInt	$\alpha_{NSigInt}$	0.656	−0.019	6.480	−0.145	0	1.342
	ONSTPK2	$\alpha_{ONSTPK2}$	−2.731	0.021	−11.864	0.335	0	−2.167
	ROADSURF	$\alpha_{ROADSURF}$	0.150	−0.001	0.487	0	0	0.095
	PedAuto	$\alpha_{PedAuto}$	0	0	0	−0.025	0	0
	VOL/1000	$\alpha_{VOL/1000}$	0.179	−0.001	0	0	0	0.044
	LEN_MI	α_{LEN_MI}	4.167	−0.061	36.210	0	0	7.084
Model fit	BIC		5968.8	777.5	8471.8	4424.7	6915.4	6210.5

Notes: The coefficient "0" denotes that the corresponding variable was excluded from the model. Cells are highlighted in light gray when the p-value is between 0.05 and 0.1. Cells are highlighted in dark gray when the p-value is less than 0.05.

Table 33 and Table 34 show that the mediator variables—StdSpd, Pace, Abs(PSL−Avg), PSL−Avg, PSL−S85, and S85−Avg—had statistically significant effects at α=0.05 on KABC_NID crash frequency. The association was positive for Abs(PSL−Avg), PSL−Avg, PSL−S85, S85−Avg, and StdSpd (i.e., as the values of those mediators increased, crash frequency increased), but negative for Pace (i.e., as the value of Pace increased, crash frequency decreased). Also, the presence of curb and gutter, residential area, and raised medians were associated with lower crash frequency. The number of signalized intersections, traffic volumes, and segment length were found to be positively correlated with crash frequency. As expected, higher PSL was associated with higher Abs(PSL−Avg), PSL−Avg, PSL−S85, S85−Avg, StdSpd, and AvgSpd, but with lower Pace and PerOvPSL. This finding implies that PSL has indirect effects on crashes through its effect on those speed measures.

Table 34. Estimated regression coefficients for KABC_NID crashes by path analysis (mediator variable: Abs(PSL−Avg), PSL−Avg, PSL−S85, or S85−Avg).

Outcome Variable	Independent Variable	Mediator / Coefficient	Abs(PSL−Avg)	PSL−Avg		PSL−S85	S85−Avg
KABC_NID crashes	Intercept	β_0	−2.877	−2.400	−3.021	−2.199	−3.171
	Mediator	$\beta_{Mediator}$	0.052	0.036	0.025	0.031	0.127
	Curb1yes	$\beta_{Cirb1yes}$	−0.883	−0.941	−0.858	−0.992	−0.881
	Dvelop2	$\beta_{Develop2}$	−0.378	−0.427	−0.402	−0.438	−0.412
	Median2	$\beta_{Median2}$	−0.615	−0.599	−0.630	−0.603	−0.687
	NSigInt	$\beta_{NSigInt}$	0.635	0.632	0.627	0.635	0.639
	SdWk1yes	$\beta_{SdWk1yes}$	0.224	0.245	0.247	0.250	0.249
	ONSTPK2	$\beta_{ONSTPK2}$	0.144	0	0	0	0
	LnVol	β_{LnVol}	0.565	0.541	0.528	0.544	0.535
	LnLen	β_{LnLen}	0.875	0.909	0.887	0.887	0.811
	StdSpd	β_{StdSpd}	0	0	0.103	0	0
Speed	Intercept	α_0	−1.346	−8.817	−8.817	−12.625	5.623
	PSL	α_{PSL}	0.357	0.567	0.567	0.497	0.044
	BIKE1YES	$\alpha_{BIKE1YES}$	0.039	0	0	0	0
	Curb1yes	$\alpha_{Cirb1yes}$	−0.633	0	0	0	−0.950
	Dvelop2	$\alpha_{Develop2}$	−1.291	0	0	0	−0.424
	DUPMBoth	$\alpha_{DUPMBoth}$	0.008	0.022	0.022	0.019	0.003
	Horz1tan	$\alpha_{Horz1tan}$	0.576	0.941	0.941	0.732	0
	Median2	$\alpha_{Median2}$	−0.194	0	0	0	0
	NSigInt	$\alpha_{NSigInt}$	−0.793	−1.342	−1.342	−1.188	−0.127
	ONSTPK2	$\alpha_{ONSTPK2}$	0.634	2.167	2.167	1.931	0.420
	ROADSURF	$\alpha_{ROADSURF}$	−0.058	−0.095	−0.095	−0.087	0
	PedAuto	$\alpha_{PedAuto}$	0.031	0	0	0	−0.023
	VOL/1000	$\alpha_{VOL/1000}$	−0.078	−0.044	−0.044	−0.050	0
	LEN_MI	α_{LEN_MI}	−3.367	−7.084	−7.084	−6.914	0
Model fit	BIC		5907.6	6200.4	6200.4	6172.7	4489.2

Notes: The coefficient "0" denotes that the corresponding variable was excluded from the model. Cells are highlighted in light gray when the p-value is between 0.05 and 0.1. Cells are highlighted in dark gray when the p-value is less than 0.05.

Table 35 and Table 36 illustrate that S85−Avg had statistically significant effects at α=0.05, and PSL and PSL−Avg had statistically significant effects at α=0.1 on all crash frequency. The association between those mediator variables and crashes was positive (i.e., as the values of those mediators increased, crash frequency increased). Other mediator variables were, however, statistically insignificant. Also, the presence of curb and gutter and raised medians were associated with lower crash frequency. The number of signalized intersections, presence of a sidewalk, presence of on-street parking, traffic volumes, and segment length were found to be positively correlated with all crash frequency. It can also be observed that higher PSL was associated with higher PSL−Avg and S85−Avg, which implies that PSL has indirect effects on crashes through its effect on those speed measures.

Table 35. Estimated regression coefficients for KABCO_NID crashes by path analysis (mediator variable: PSL, CoefVar, PerOvPSL, StdSpd, Pace, or SpdAve).

Outcome Variable	Independent Variable	Mediator / Coefficient	PSL	CoefVar	PerOvPSL	StdSpd	Pace	AvgSpd
KABCO_NID	Intercept	β_0	−1.970	−1.699	−1.183	−2.132	0.322	−2.247
	Mediator	$\beta_{Mediator}$	0.027	1.215	−0.001	0.127	−0.022	0.005
	Curb1yes	$\beta_{Cirb1yes}$	−0.854	−1.034	−1.048	−0.905	−0.849	−0.884
	Dvelop2	$\beta_{Develop2}$	−0.261	−0.318	−0.329	−0.289	−0.255	−0.279
	Median2	$\beta_{Median2}$	−0.706	−0.648	−0.650	−0.678	−0.654	−0.697
	NSigInt	$\beta_{NSigInt}$	0.491	0.537	0.537	0.522	0.519	0.516
	SdWk1yes	$\beta_{SdWk1yes}$	0.346	0.340	0.343	0.340	0.347	0.343
	ONSTPK2	$\beta_{ONSTPK2}$	0.366	0.324	0.326	0.348	0.347	0.356
	LnVol	β_{LnVol}	0.454	0.530	0.505	0.499	0.475	0.489
	LnLen	β_{LnLen}	0.682	0.793	0.763	0.764	0.762	0.736
	StdSpd	β_{StdSpd}	0	0	0	0	0	0.126
Speed	Intercept	α_0	27.534	0.336	66.776	5.218	75.661	8.817
	PSL	α_{PSL}	NA	0	−2.004	0.061	−0.379	0.433
	BIKE1YES	$\alpha_{BIKE1YES}$	−0.615	0	0	0	0	0
	Curb1yes	$\alpha_{Cirb1yes}$	−2.585	−0.029	0	−0.780	4.693	0
	Dvelop2	$\alpha_{Develop2}$	−1.940	−0.025	0	−0.335	3.760	0
	DUPMBoth	$\alpha_{DUPMBoth}$	−0.020	0.000	−0.099	0.003	0	−0.022
	Horz1tan	$\alpha_{Horz1tan}$	0	0.023	0	0.265	−1.333	−0.941
	Median2	$\alpha_{Median2}$	−1.601	0	0	0	0	0
	NSigInt	$\alpha_{NSigInt}$	0.656	−0.019	6.480	−0.145	0	1.342
	ONSTPK2	$\alpha_{ONSTPK2}$	−2.731	0.021	−11.864	0.335	0	−2.167
	ROADSURF	$\alpha_{ROADSURF}$	0.150	−0.001	0.487	0	0	0.095
	PedAuto	$\alpha_{PedAuto}$	0	0	0	−0.025	0	0
	VOL/1000	$\alpha_{VOL/1000}$	0.179	−0.001	0	0	0	0.044
	LEN_MI	α_{LEN_MI}	4.167	−0.061	36.210	0	0	7.084
Model fit	BIC		6915.0	1731.3	9426.0	5369.8	7855.2	7155.1

Notes: The coefficient “0” denotes that the corresponding variable was excluded from the model. Cells are highlighted in light gray when the p-value is between 0.05 and 0.1. Cells are highlighted in dark gray when the p-value is less than 0.05.

Table 36. Estimated regression coefficients for KABCO_NID crashes by path analysis (mediator variable: Abs(PSL−Avg), PSL−Avg, PSL−S85, or S85−Avg).

Outcome Variable	Independent Variable	Mediator / Coefficient	Abs(PSL−Avg)	PSL−Avg		PSL−S85	S85−Avg
KABCO_NID	Intercept	β_0	−1.433	−1.316	−2.055	−1.187	−2.101
	Mediator	$\beta_{Mediator}$	0.022	0.023	0.012	0.016	0.123
	Curb1yes	$\beta_{Cirb1yes}$	−0.970	−0.988	−0.894	−1.022	−0.885
	Dvelop2	$\beta_{Develop2}$	−0.304	−0.314	−0.284	−0.324	−0.293
	Median2	$\beta_{Median2}$	−0.641	−0.613	−0.649	−0.626	−0.675
	NSigInt	$\beta_{NSigInt}$	0.529	0.526	0.517	0.531	0.529
	SdWk1yes	$\beta_{SdWk1yes}$	0.334	0.335	0.336	0.339	0.330
	ONSTPK2	$\beta_{ONSTPK2}$	0.328	0.323	0.341	0.325	0.332
	LnVol	β_{LnVol}	0.509	0.507	0.502	0.506	0.503
	LnLen	β_{LnLen}	0.771	0.815	0.800	0.791	0.764
	StdSpd	β_{StdSpd}	0	0	0.111	0	0
Speed	Intercept	α_0	−1.346	−8.817	−8.817	−12.625	5.623
	PSL	α_{PSL}	0.357	0.567	0.567	0.497	0.044
	BIKE1YES	$\alpha_{BIKE1YES}$	0.039	0	0	0	0
	Curb1yes	$\alpha_{Cirb1yes}$	−0.633	0	0	0	−0.950
	Dvelop2	$\alpha_{Develop2}$	−1.291	0	0	0	−0.424
	DUPMBoth	$\alpha_{DUPMBoth}$	0.008	0.022	0.022	0.019	0.003
	Horz1tan	$\alpha_{Horz1tan}$	0.576	0.941	0.941	0.732	0
	Median2	$\alpha_{Median2}$	−0.194	0	0	0	0
	NSigInt	$\alpha_{NSigInt}$	−0.793	−1.342	−1.342	−1.188	−0.127
	ONSTPK2	$\alpha_{ONSTPK2}$	0.634	2.167	2.167	1.931	0.420
	ROADSURF	$\alpha_{ROADSURF}$	−0.058	−0.095	−0.095	−0.087	0
	PedAuto	$\alpha_{PedAuto}$	0.031	0	0	0	−0.023
	VOL/1000	$\alpha_{VOL/1000}$	−0.078	−0.044	−0.044	−0.050	0
	LEN_MI	α_{LEN_MI}	−3.367	−7.084	−7.084	−6.914	0
Model fit	BIC		6862.8	7157.4	7153.8	7129.3	5437.2

Notes: The coefficient “0” denotes that the corresponding variable was excluded from the model. Cells are highlighted in light gray when the p-value is between 0.05 and 0.1. Cells are highlighted in dark gray when the p-value is less than 0.05.

ROUND 3: DATA ANALYSIS USING PATH ANALYSIS APPROACH AND SEGMENTS WITH POSTED SPEED LIMITS OF 45 MPH AND LOWER

Overview

Researchers refitted the path analysis model for KABC crashes with Abs(PSL−Avg) as a mediator variable after excluding the road segments with posted speed limits of 50 and 55 mph because streets with those speed limits may be considered as non-city streets. There was one segment with 55 mph as the PSL and six segments with 50 mph as the PSL in the original data. Excluding those segments resulted in removal of 14 out of 663 sites, leaving 649 sites corresponding to 25- to 45-mph segments in the data. Initially, a full model with all of the roadway characteristic variables in Table 23 was fitted to the dataset consisting of 649 sites, and then the model was refitted after removing variables that were insignificant at α=0.1.

The crash rate for the Austin data was calculated and graphed with the speed metric of PSL−Avg (difference between posted speed limit and average speed) to provide an appreciation of the potential relationship (see Figure 15). While Figure 15 shows crash rate, crash frequency along with segment length and volume were used in the statistical analyses. Figure 15 includes a simple trendline to help illustrate the relationship. The minimum crash rate appears to be near the point when posted speed limit equals average speed. Another observation is that the crash rate is lower when vehicles are traveling within about 5 mph of the posted speed limit. These observations do come with some cautions. The reason the specific speed limit was posted for each of the 649 sites is not known, such as whether the engineer's decision for the posted speed limit was influenced by existing crashes or if the posted speed limit represents a default speed limit for the road (in Texas the default speed limit for residential streets is 30 mph). Another notable observation is that for many 25- to 45-mph roads, a 5-mph increase from average speed is very close to a typical 85th percentile speed.

When PSL−S85 is compared to crash rate, the low point is below the zero point, which adds challenges to interpreting the findings. Therefore, the Abs(PSL−Avg) may be an easier speed measure (in terms of interpretation) to identify variables that are affecting safety on city streets.

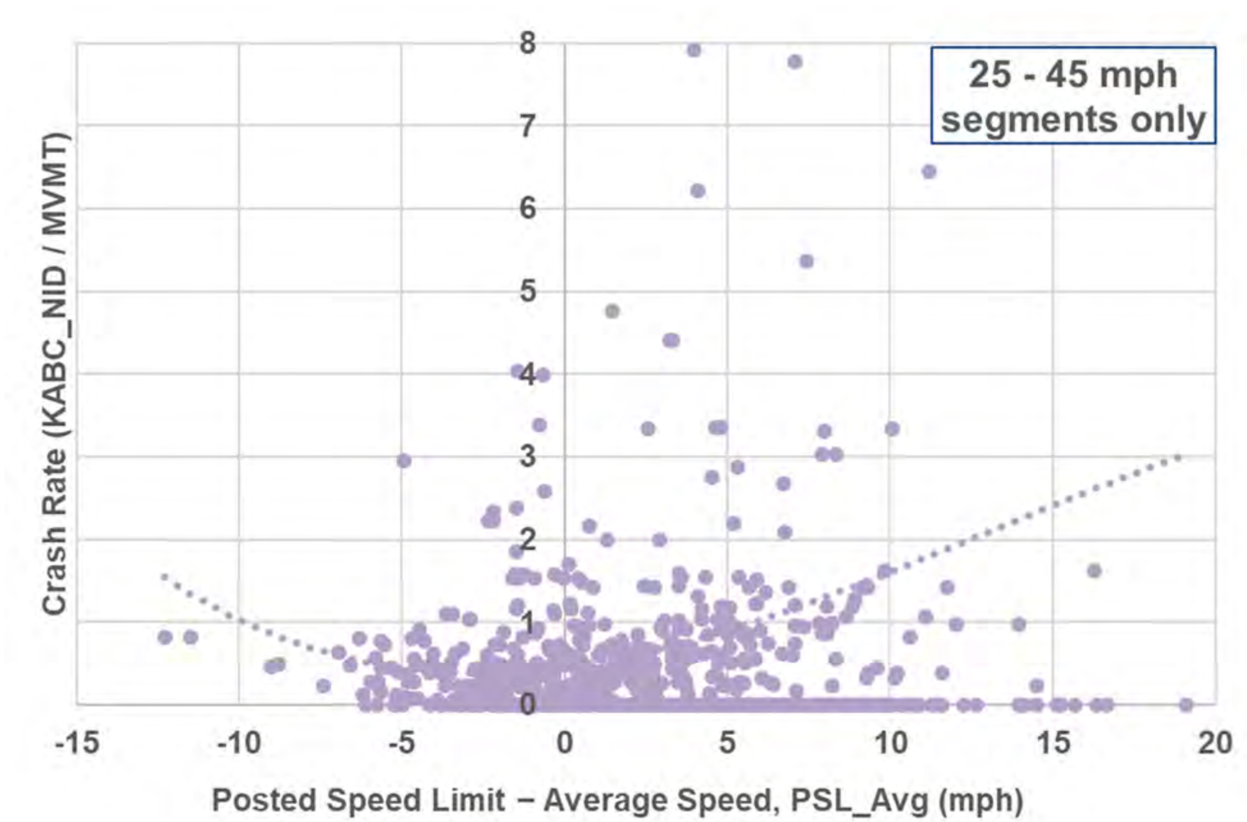


Figure 15. Comparison of crash rate to the difference between posted speed limit and average speed.

Results and Discussion

The estimated model coefficients for KABC crashes from the Round 3 path analysis are presented in Table 37. The table shows that the mediator variable Abs(PSL−Avg) was statistically significant at α=0.1, having a positive association with KABC crashes (i.e., as the values of Abs(PSL−Avg) increased, KABC crash frequency increased). Also, residential area and the presence of a raised median were associated with lower crash frequency. The number of signalized intersections, traffic volumes, and segment length were found to be positively correlated with crash frequency. As expected, higher PSL was associated with higher Abs(PSL−Avg), which implies that PSL has indirect effects on KABC crashes through its effect on Abs(PSL−Avg). Note that the presence of a bike lane, the presence of a school zone, and RU_F_rev=Local also had indirect effects on KABC crashes since they had statistically significant positive associations with Abs(PSL−Avg). ROADSURF had a statistically significant negative association with Abs(PSL−Avg), which also had an indirect effect on KABC crashes, subsequently. The relationship of the variables with either KABC_NID or Abs(PSL−Avg) is shown in Figure 16. Note that the standard errors of model coefficient estimates are provided in parentheses.

Table 37. Estimated regression coefficients for KABC_NID crashes by path analysis with mediator variable Abs(PSL−Avg) based on 649 sites.

Outcome Variable	Independent Variable	Mediator / Coefficient	Abs(PSL−Avg)
KABC_NID crashes	Intercept	β_0	−3.648
	Mediator	$\beta_{Mediator}$	0.044
	Dvelop2	$\beta_{Develop2}$	−0.483
	Median2	$\beta_{Median2}$	−0.618
	NSigInt	$\beta_{NSigInt}$	0.542
	LnVol	β_{LnVol}	0.599
	LnLen	β_{LnLen}	0.852
Speed	Intercept	α_0	−0.471
	PSL	α_{PSL}	0.327
	BIKE1YES	$\alpha_{BIKE1YES}$	1.123
	DEVELOP2	$\alpha_{Develop2}$	−0.870
	ROADSURF	$\alpha_{ROADSURF}$	−0.044
	SCZN1YES	$\alpha_{PedAuto}$	1.497
	RU_F_rev	$\alpha_{RU\_F\_rev}$	1.189
	LNVOL	α_{LNVOL}	−0.078
	LNLEN	α_{LNLEN}	−3.367
Model fit	BIC		5568.8

Notes: Cells are highlighted in light gray when the p-value is between 0.05 and 0.1. Cells are highlighted in dark gray when the p-value is less than 0.05.

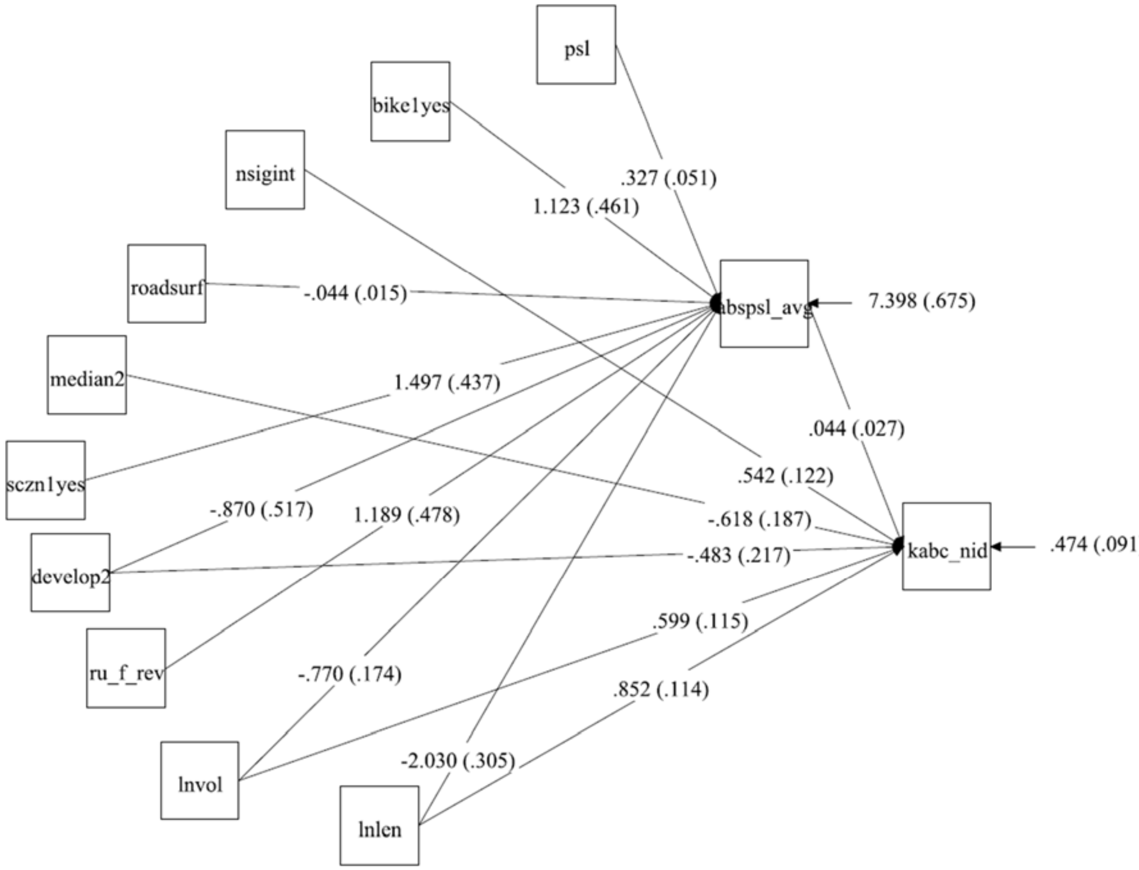


Figure 16. Path analysis findings for segments with posted speed limits of 20 to 45 mph.

FINDINGS' IMPACT ON SLS-TOOL

The findings from this effort support the following decision rules for the SLS-Tool:

- Inclusion of the following variables:
  - Number of signals or signal density.
  - On-street parking.
- Addition of the following variable:
  - Median type (raised medians were associated with fewer KABC crashes compared to no median or TWLTL, and TWLTLs were associated with more KABC crashes compared to no median).

The findings from the path analysis support the consideration of the 50th percentile speed in identifying a suggested speed limit.

APPENDIX E. RELATIONSHIP AMONG URBAN/SUBURBAN ROADWAY CHARACTERISTICS, POSTED SPEED LIMIT, AND CRASHES IN WASHTENAW COUNTY, MICHIGAN

OVERVIEW

In order to provide guidance for the setting of speed limits consistent with the stated objectives of NCHRP Project 17-76, a safety analysis was conducted specific to urban and suburban roadway segments located in Washtenaw County, Michigan (see Figure 17). This included the collection of historical traffic and crash data, in addition to the collection of other relevant roadway characteristics. Ultimately, the relative safety performance of urban and suburban non-freeway roadway segments was compared with the posted speed limit and other roadway features to provide additional qualitative guidance for practitioners.

Figure 17. Location of study roadway segments in Washtenaw County, Michigan.

DATABASE DEVELOPMENT

Initially, roadway inventory data for all public highways in Washtenaw County, including those under the jurisdiction of the Michigan DOT, Washtenaw County, and the City of Ann Arbor, were collected and merged with daily traffic volume estimates and posted speed limit data, where available, to develop a database of potential study highways. These data were then reduced to include only non-freeway and non-local roadways with urban designations where the posted speed limit ranged between 25 to 50 mph. These candidate roadways were then segmented such that each roadway segment's end points were intersections controlled via either signalization, stop control, a roundabout (yield control), or the route otherwise ending (such as the county line). A manual review of each segment was then conducted to determine additional roadway features (such as the presence of sidewalks, lane width, etc.). This process resulted in a total of 586 distinct roadway segments encompassing approximately 312 mi. The following subsections describe the process to develop the database for subsequent analysis.

Roadway Inventory Data

Roadway inventory data for Washtenaw County were collected via the Michigan Geographic Framework (MGF), which includes all public roadways in the state of Michigan (*216*). The MGF provides a linear referencing system that is used by several agencies in the state of Michigan and allows for merging data from other sources with these roadway inventory data (such as traffic crashes or the posted speed limit). Figure 18 shows a map of the approximately 2,954 mi of public roadways in Washtenaw County along with the adjusted census urban boundaries (ACUBs), as indicated by the pink shading. The major urban areas in Washtenaw County include the cities of Ann Arbor, Ypsilanti, Saline, and Chelsea.

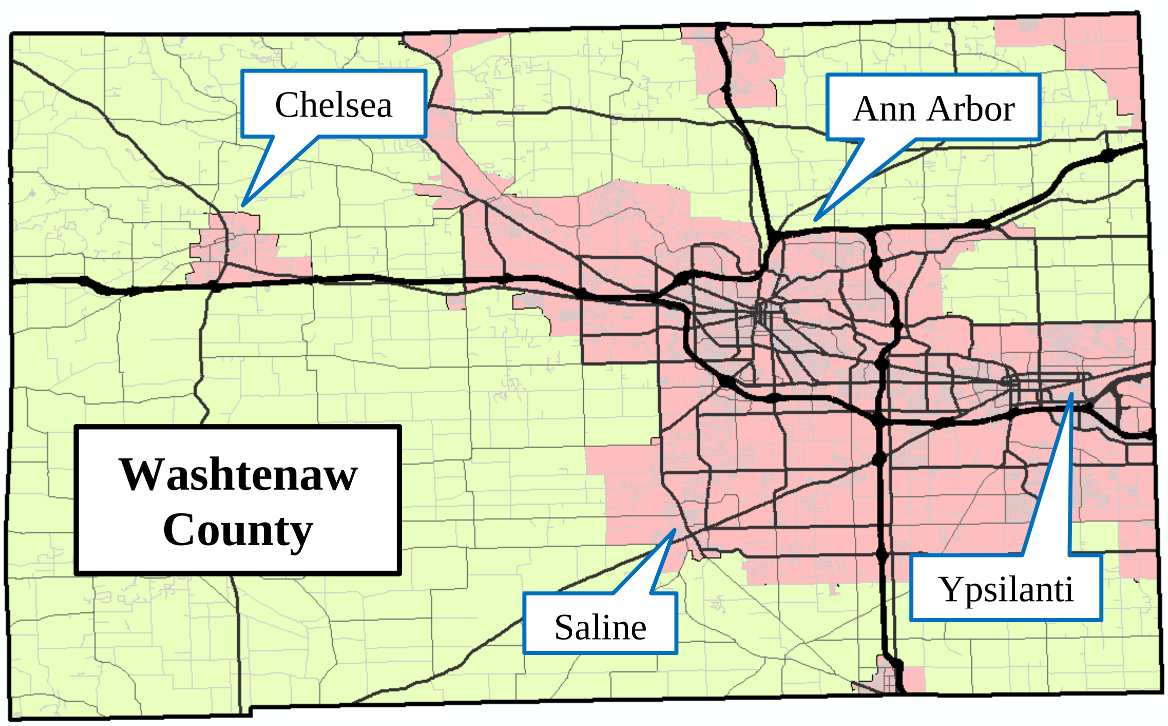


Figure 18. Washtenaw County roadway network and urban boundaries.

Identification of Study Roadway Segments

Given the roadway inventory data shown in Figure 18 for Washtenaw County, daily traffic volume estimates and posted speed limits for each roadway were assigned to each roadway via ArcGIS. AADT volume estimates were acquired from the FHWA Highway Performance Monitoring System (HPMS) shapefile as well as from the Southeast Michigan

Council of Government's (SEMCOG's) open data portal (*217, 218*). Posted speed limit data were also acquired from SEMCOG's open data portal. These data were used to identify all public roadways that met the criteria for inclusion as a potential study roadway, as shown in Table 38.

Table 38. Summary of criteria for inclusion as potential study roadway.

Characteristic	Criteria
Posted Speed Limit	25 to 50 mph per SEMCOG's open data portal
National Functional Class	Includes other principal arterial, minor arterial, major collector, minor collector Excludes interstates, other freeways, and local
Historical Traffic Volume	Must include recent AADT estimate from either HPMS or SEMCOG
Urban Boundary	Includes roadways that fall within or extend from ACUB per MGF

Segmentation of Roadway Data

Given these potential study roadways, a spatial analysis was performed in ArcGIS to identify the location of all public roadway intersections along these highways. The traffic control for each intersection (signal, all-way stop, minor route stop, or roundabout) was then determined via a manual review of satellite imagery. These data were then used to segment the roadway inventory data such that each roadway segment's end points were intersections controlled via either signalization, stop control, a roundabout (yield control), or the route otherwise ending (such as the county line). This ensured that there was no traffic control along the major route within the bounds of each segment. All segments less than 0.06 mi were excluded from further analysis. All segments that ranged from 0.06 to 0.10 mi in length were manually reviewed via satellite imagery to determine if the roadway inventory data were representative of actual field conditions, and atypical segments were screened from further analysis. An example of output from this segmentation process is shown in Figure 19.

Figure 19. Segmentation of study road segments in Washtenaw County, Michigan.

After the identification and segmentation process was complete, a total of 586 distinct study roadway segments encompassing approximately 312.7 mi were selected for further analysis. A map of the study roadway segments in Washtenaw County is provided in Figure 20.

A map of study segments by posted speed limit is presented in Figure 21, and a map of study segments by AADT is presented in Figure 22**.**

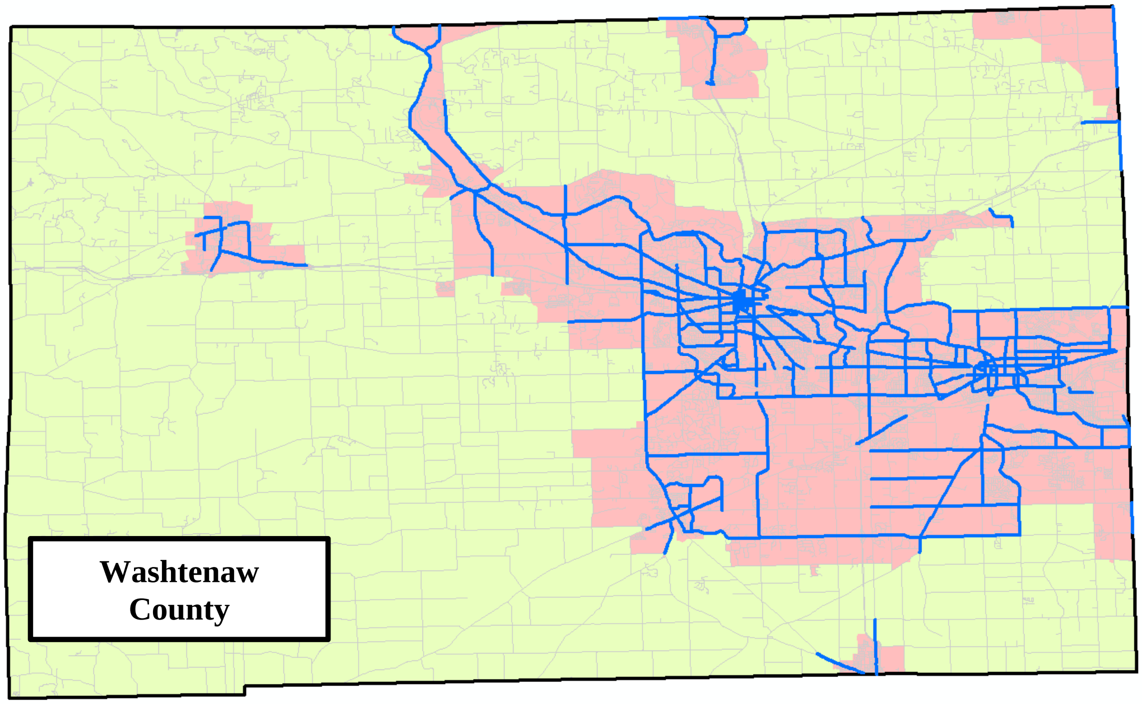


Figure 20. Map of study road segments in Washtenaw County, Michigan.

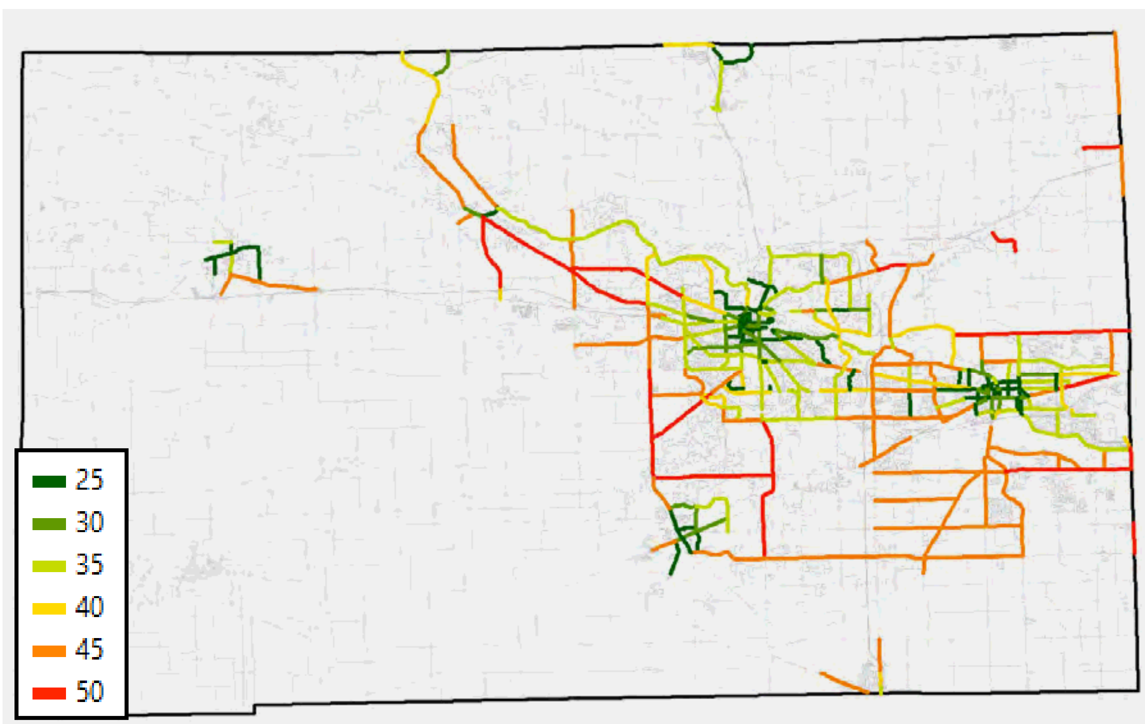


Figure 21. Study road segments by posted speed limit.

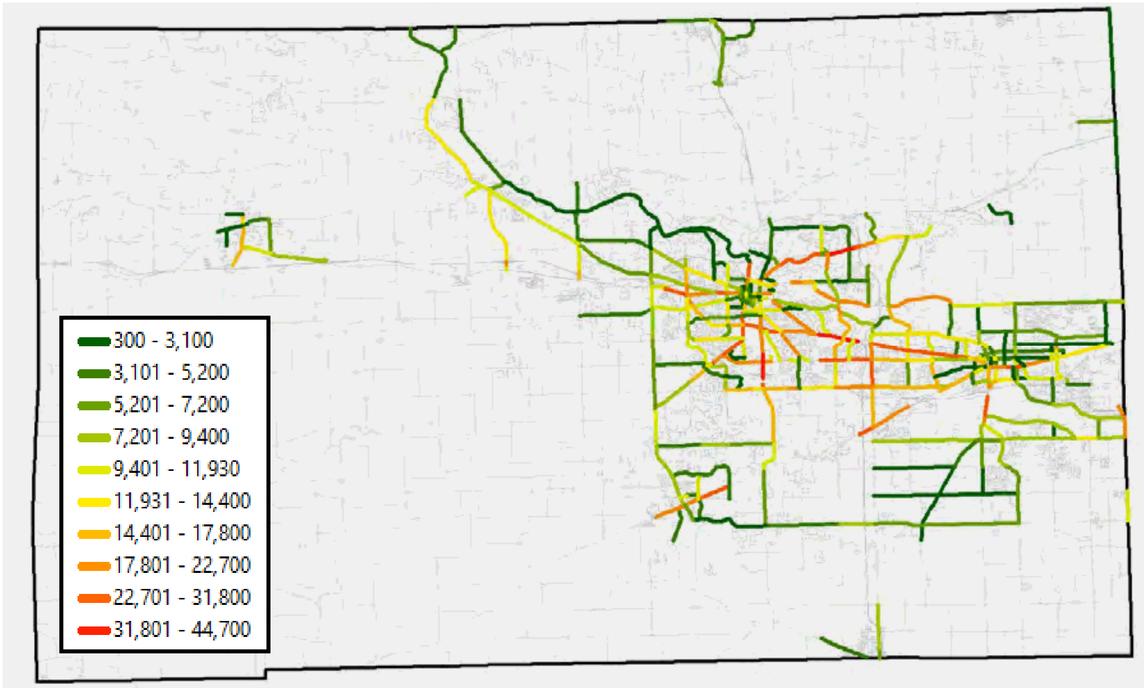


Figure 22. Study road segments by AADT estimate.

Historical Traffic Crash Data

Historical traffic crash data were collected from annual databases maintained by the Michigan State Police (MSP), including a 5-year period from 2013 to 2017. These data were assigned to each study segment based upon the location along the MGF associated with each crash record. Each crash was also determined to be intersection related if it occurred within 250 ft of an intersection at either end point of the segment. All remaining records were considered to be midblock segment crashes for the purposes of this evaluation. Only those crashes occurring on the subject roadway were counted, and crashes occurring on the side streets and driveways were excluded. This allocation scheme was used in order to be consistent with data collected in Austin, Texas, specific to NCHRP Project 17-76. Figure 23 shows an example of the crash data allocation process.

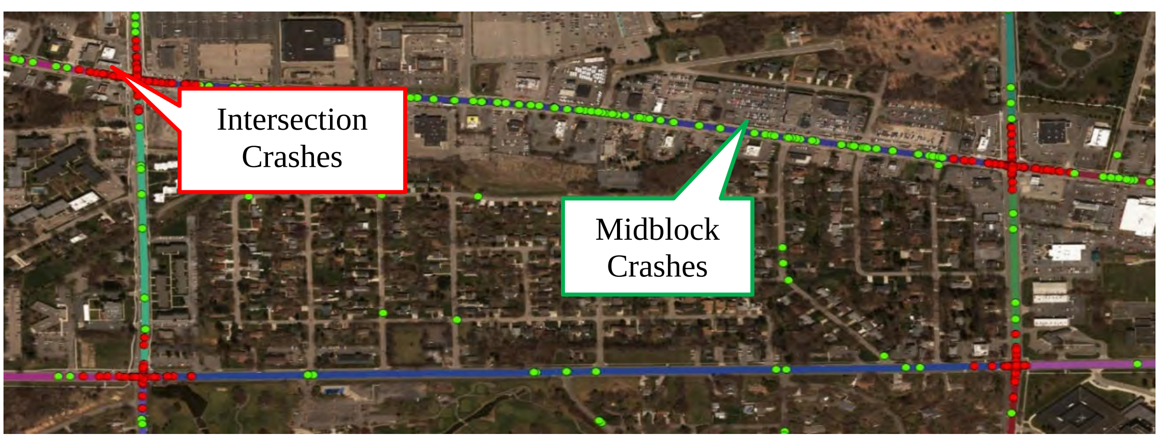


Figure 23. Example of traffic crash locations along study road segments (2013–2017).

Additional Geometric and Roadway Characteristics

After the identification of the study road segments, an additional manual review of satellite imagery was performed in order to collect a variety of geometric and other roadway characteristics specific to each segment. These characteristics are summarized in Table 39.

Table 39. Roadway and traffic control device variables for Washtenaw County, Michigan.

Column Heading	Description
AADTR	AADT estimate from FHWA HPMS or SEMCOG system-wide data rounded to nearest 10
AccessDen	Data for DrvUsigPerMileBoth regrouped into three levels: LT40=less than 40 driveways/unsignalized intersections per mile, 40to60=between 40 and 60 driveways/unsignalized intersections per mile, and GT60=greater than 60 driveways/unsignalized intersections per mile
Bike_Lane	Bike lane presence: 1=yes, 0=no
Bus	Bus stop presence collected via “Places” in Google Earth: 1=yes, 0=no
Crosswalk	Presence of a midblock crosswalk in between end points (do not include crosswalks located adjacent to end points): 1=yes, 0=no
Curb_1yes	Is curb present (for at least 50% of segment): yes=1, no=0
Develop	Development (revised to match Austin variable): Residential, RuralParks, or ComRetInd (for commercial, retail, or industrial)
DrvUsigPerMileBoth	Per mile rate for driveways (residential and commercial) and public intersections along the segment in both directions
FuncClass	Revised National Functional Class Code
Horz	Horizontal alignment: 0=straight, 1=some horizontal curvature
Int_Type1	Description of End Point #1: signal, all-way stop, stop, roundabout, or other break point
Int_Type2	Description of End Point #2: signal, all-way stop, stop, roundabout, or other break point
LnWdG	Lane width (ft) for the segment grouped into N=Narrow (7, 8, 9, or 10 ft), T=Typ (11 or 12 ft), W=Wide (13 ft or more)
Median	Median type: none (undivided), raised (also depressed), TWLTL (also delineated)
MedWidth	Median width (ft)
Miles	Total length in miles (accounts for divided roadways in two pieces)
Num_Lanes	Number of through lanes (not including exclusive turn lanes)
NumSigInt	Number of signalized intersections along segment, including any signals at the beginning or end of the segment
OnStreet_Parking	On-street parking: yes=1 or no=0
PedAuto	The typical or average distance between the sidewalk (or where the pedestrian could be walking) and the automobile lane for the corridor (ft)
POSTED_SPE	Posted speed limit per SEMCOG system-wide data
RoadSurf	Distance between the driving surface edges, including consideration of travel lanes, median width, on-street parking lane width, and bike lane width
School	School zone presence collected via “Places” in Google Earth: 1=yes, 0=no
Sidewalk	Sidewalk presence, 0=none, 1=one side, 2=both sides (based on majority of segment)

DATA ANALYSIS—METHODOLOGY

The research team compiled the dataset consisting of 530 sites to conduct the analysis. Table 40 provides the descriptive statistics for the variables considered in the analysis.

Table 40. Descriptive statistics of variables for Washtenaw County, Michigan.

Variable[a]	Variable Type[b]	Minimum	Maximum	Mean	Std. Dev.
AADTR	Numerical	800	44,700	11,726.83	7,964.25
DrvUsigPerMileBoth	Numerical	0	142.9	39.40	31.31
Miles	Numerical	0.06	6.839	0.57	0.63
PedAuto	Numerical	0	75	10.67	10.15
RoadSurf	Numerical	20	108	38.78	15.31
MedWidth	Numerical	0	60	4.72	7.97
Num_Lanes	Numerical	2	4	2.58	0.91
NumSigInt	Numerical	0	2	1.49	0.70
POSTED_SPE	Numerical	25	50	35.55	8.31
Crosswalk	Dichotomous	0	1	0.19	0.40
Curb_1yes	Dichotomous	0	1	0.75	0.44
Horz	Dichotomous	0	1	0.18	0.38
OnStreet_Parking	Dichotomous	0	1	0.17	0.38
School	Dichotomous	0	1	0.05	0.21
Bike_Lane	Dichotomous	0	1	0.22	0.42
Bus	Dichotomous	0	1	0.43	0.50
Sidewalk_1yes	Dichotomous	0	1	0.82	0.38
Develop	Polychotomous	ComRetInd (221), Residential (261), Rural/Parks (48)			
FuncClass	Polychotomous	Coll (164), MinArt (220), PrinArt (146)			
Int_Type1	Polychotomous	AllWay (81), Break (4), Roundabout (13), Signal (419), Stop (13)			
Int_Type2	Polychotomous	AllWay (49), Break (39), Roundabout (19), Signal (369), Stop (54)			
LnWdG	Polychotomous	N (46), T (460), W (24)			
Median	Polychotomous	Raised (16), TWLTL (183), None (331)			
Sidewalk	Polychotomous	None (94), One Side (89), Both Sides (347)			
AccessDen	Polychotomous	LT40 (327), 40to60 (78), GT60 (125)			

[a] Variable descriptions are in Table 39.
[b] For dichotomous variables, "1" indicates the presence of the feature, and "0" indicates its absence. For polychotomous variables, the numbers in parentheses represent frequencies of the corresponding categories.

Regression Model Overview

The research team applied NB regression models to the site-level data to investigate the relationship between crashes and posted speed limit while controlling for the effects of other variables including the natural logarithm of AADT and roadway geometry variables. The research team examined several NB regression models. The models included the log of segment length as an offset variable.

RESULTS AND DISCUSSION

Variable Relationships with Crashes

The investigation into the relationships among the roadway characteristics, posted speed limit, and traffic crashes focused on segment crashes rather than all crashes that included intersections. The research team considered both crashes with fatal and injuries (i.e., KABC) and all severity level crashes (i.e., KABCO).

Injury Segment Crashes (KABC Midblock)

Multiple models were developed to identify the model containing several variables that were significant at α=0.1 or smaller. Table 41 provides the significance per variable, while Table 42 provides the estimate along with the p-value for each variable/level combination for the selected model. Key observations include the following:

- As expected, more vehicle volume was associated with more crashes.
- Higher posted speed limits were associated with more crashes.
- Minor arterials and collectors, compared to principal arterials, were associated with fewer crashes.
- The presence of a midblock crosswalk was associated with more vehicle crashes.
- Contrary to what was found in Austin, the presence of a sidewalk was found to be associated with fewer crashes.
- A greater number of access points was associated with more crashes. For the model shown in Table 41 and Table 42, the access points were grouped into the levels used in USLIMITS2. Roads with more than 60 access points per mile had more crashes than roads with between 40 to 60 access points. Roads with between 40 and 60 access points had more crashes than roads with fewer than 40 access points.
- Greater distances between pedestrians and autos were associated with more crashes. The research team currently does not have a theory as to why pedestrians being a greater distance away would be associated with more vehicle crashes.

Table 41. Score statistics for model shown in Table 42.

Variable	DF	Chi-Square	Pr > ChiSq
LnVol	1	65.20	<.0001
POSTED_SPE	1	12.25	0.0005
FuncClass	2	12.91	0.0016
AccessDen	2	11.50	0.0032
Crosswalk	1	6.66	0.0099
PedAuto	1	4.96	0.0259
Sidewalk_1yes	1	4.09	0.0431

Note: LR statistics for Type 3 analysis. Variable descriptions are in Table 39. LnVol=Log(AADTR).

Table 42. Variables with significant effects on KABC segment crashes.

Variable	Level	DF	Estimate	Standard Error	Wald 95% Confidence Limits		Wald Chi-Square	Pr > ChiSq
Intercept		1	−4.9187	0.8432	−6.5713	−3.2660	34.03	<.0001
FuncClass	Coll	1	−0.5925	0.1736	−0.9328	−0.2522	11.65	0.0006
FuncClass	MinArt	1	−0.3516	0.1111	−0.5693	−0.1338	10.01	0.0016
FuncClass	PrinArt	0	0.0000	0.0000	0.0000	0.0000	.	.
Crosswalk		1	0.2588	0.1013	0.0602	0.4574	6.53	0.0106
PedAuto		1	0.0103	0.0047	0.0011	0.0195	4.85	0.0276
POSTED_SPE		1	0.0227	0.0065	0.0100	0.0354	12.22	0.0005
Sidewalk_1yes		1	−0.2930	0.1453	−0.5778	−0.0081	4.06	0.0439
AccessDen	LT40	0	0.0000	0.0000	0.0000	0.0000	.	.
AccessDen	40to60	1	0.2009	0.1164	−0.0272	0.4291	2.98	0.0843
AccessDen	GT60	1	0.3669	0.1109	0.1496	0.5843	10.95	0.0009
LnVol		1	0.6812	0.0805	0.5234	0.8389	71.65	<.0001
Dispersion		1	0.3813	0.0487	0.2969	0.4897	NR	NR

Notes: Analysis of maximum likelihood parameter estimates. Variable descriptions are in Table 39.
LnVol=Log(AADTR).
. = value is not relevant since this level is the base for the variable.
{blank} = value not relevant because the variable is not a multicategory variable.
NR = value not relevant for the dispersion variable.

All Segment Crashes (KABCO Midblock)

Similar to the effort for midblock injury crashes, the research team developed several NB regression models to understand the relationship between all segment crashes and roadway characteristics. Table 43 provides the significance per variable, while Table 44 provides the estimate along with the p-value for each variable/level combination for the selected model. The following observations are similar to the findings for midblock injury crashes:

- As expected, more vehicle volume was associated with more crashes.
- Minor arterials and collectors, compared to principal arterials, were associated with fewer crashes.
- A greater number of access points was associated with more crashes.
- Contrary to what was found in Austin, the presence of a sidewalk was found to be associated with fewer crashes.
- Greater distances between pedestrians and autos were associated with more crashes. The research team currently does not have a theory as to why pedestrians being a greater distance away would be associated with more vehicle crashes.

Findings that were either not present or were different from those found with KABC midblock include the following:

- Wider median widths were found to be associated with more crashes, which is contrary to the finding for the Austin data.
- More signals were associated with more crashes, which agrees with the finding from Austin, but the relationship was not present when examining Washtenaw's injury crashes.
- Posted speed limit was significant for injury crashes (see Table 41) but not all crashes.

- Median type was significant for all severity level crashes, with the presence of a raised median being associated with fewer crashes than either a TWLTL or no median, which is consistent with the findings for data from Austin. The presence of a TWLTL was also associated with fewer crashes when compared to no median, a finding that is contradictory in this case to the KABC NID crash data from Austin.

Table 43. Score statistics for model shown in Table 46.

Variable	DF	Chi-Square	Pr > ChiSq
Sidewalk_1yes	1	17.14	<.0001
LnVol	1	67.92	<.0001
Crosswalk	1	12.22	0.0005
FuncClass	2	14.89	0.0006
MedWidth	1	11.16	0.0008
NumSigInt	1	7.43	0.0064
Median	2	10.00	0.0067
PedAuto	1	7.11	0.0077
AccessDen	2	7.71	0.0211

Notes: LR statistics for Type 3 analysis. Variable descriptions are in Table 39.
LnVol=Log(AADTR).

Table 44. Variables with significant effects on KABCO segment crashes.

Variable	Level	DF	Estimate	Standard Error	Wald 95% Confidence Limits		Wald Chi-Square	Pr > ChiSq
Intercept		1	−2.2141	0.6991	−3.5844	−0.8439	10.03	0.0015
FuncClass	Coll	1	−0.5590	0.1462	−0.8455	−0.2725	14.63	0.0001
FuncClass	MinArt	1	−0.3256	0.1027	−0.5268	−0.1243	10.05	0.0015
FuncClass		0	0.0000	0.0000	0.0000	0.0000	.	.
Crosswalk		1	0.3108	0.0903	0.1338	0.4879	11.84	0.0006
Median	Raised	1	−1.3487	0.4191	−2.1701	−0.5272	10.35	0.0013
Median	TWLTL	1	−0.2722	0.1410	−0.5485	0.0041	3.73	0.0535
Median	None	0	0.0000	0.0000	0.0000	0.0000	.	.
MedWidth		1	0.0330	0.0101	0.0132	0.0529	10.63	0.0011
PedAuto		1	0.0112	0.0043	0.0028	0.0196	6.80	0.0091
Sidewalk_1yes		1	−0.5020	0.1223	−0.7418	−0.2622	16.84	<.0001
NumSigInt		1	0.1844	0.0671	0.0529	0.3159	7.56	0.0060
AccessDen	LT40	0	0.0000	0.0000	0.0000	0.0000	.	.
AccessDen	40to60	1	0.1879	0.1046	−0.0171	0.3928	3.23	0.0725
AccessDen	GT60	1	0.2376	0.0939	0.0535	0.4217	6.40	0.0114
LnVol		1	0.6337	0.0729	0.4908	0.7766	75.56	<.0001
Dispersion		1	0.5145	0.0421	0.4382	0.6040	NR	NR

Notes: Analysis of maximum likelihood parameter estimates. Variable descriptions are in Table 39.
LnVol=Log(AADTR).
. = value is not relevant since this level is the base for the variable.
{blank} = value not relevant because the variable is not a multicategory variable.
NR = value not relevant for the dispersion variable.

Variable Relationships with Posted Speed Limit

A better understanding of relationships between roadway characteristics and the posted speed limit may assist with identifying how the look and feel of a road could help to communicate the appropriate operating speed along with the posted speed for the facility. Table 45 provides a summary of three models that explore the significance for several variables with posted speed limit. These results illustrate how certain roadway characteristics tend to be associated with different posted speed limits.

Key observations include the following:

- Certain variables were always significant at a 0.05 level or better regardless of the method used to select the variables. The variables with a strong association with posted speed limit included:
  - Number of driveways/unsignalized intersections per mile.
  - Functional classification.
  - Presence of horizontal curvature within the segment.
  - Presence of median.
  - Presence of on-street parking.
  - Distance between vehicles and pedestrians (PedAuto).
- Variables that were not significant at the 0.05 level included:
  - Develop, which indicates that a range of posted speed limits exist for the three development levels used: residential; commercial, retail, or industrial; and rural/parks.
  - Lane width for the segment.
  - Number of signalized intersections. While the number of signalized intersections was found to not be significant with respect to posted speed limit, it was with respect to crashes.
  - Road surface width.
  - Presence of school.

FINDINGS' IMPACT ON SLS-TOOL

The findings from this effort support the following decision rules for the SLS-Tool:

- Inclusion of the following variables:
  - Signal density (represented by the variable NumSigInt in the models).
  - Access density, along with the break points at 40 and 60 access points per mile.
- Addition of the following variable:
  - Median type (raised medians were associated with fewer KABCO crashes compared to none or TWLTL, and TWLTLs were associated with fewer KABCO crashes compared to no median).

Table 45. Models exploring the significance of variables for posted speed limit.

Variable	DF	Model 1 Chi-Square	Model 1 Pr > ChiSq	Model 2 Chi-Square	Model 2 Pr > ChiSq	Model 3 Chi-Square	Model 3 Pr > ChiSq
AADTR	1	3.6	0.0579	3.54	0.0598	8.15	0.0043
Crosswalk	1	3.73	0.0534	3.17	0.075	20.11	<.0001
Curb_1yes	1	18.18	<.0001	23.27	<.0001	3.52	0.1717
Develop	2	4.28	0.1176	NI	NI	NI	NI
DrvUsigPerMileBoth	1	11	0.0009	10.88	0.001	11.89	0.0006
FuncClass	2	28.38	<.0001	41.1	<.0001	31.85	<.0001
Horz	1	6.32	0.0119	6.86	0.0088	8.19	0.0042
LnWdG	2	4.24	0.1202	NI	NI	5.28	0.0715
Median	2	39.69	<.0001	44.19	<.0001	47.61	<.0001
Miles	1	35.91	<.0001	39.43	<.0001	35	<.0001
Num_Lanes	1	5.16	0.0232	6.75	0.0094	NI	NI
NumSigInt	1	1.85	0.1736	NI	NI	NI	NI
OnStreet_Parking	1	6.51	0.0107	6.02	0.0141	20.73	<.0001
PedAuto	1	28.04	<.0001	30.26	<.0001	24.13	<.0001
RoadSurf	1	0.87	0.3515	1.41	0.2355	NI	NI
School	1	1.43	0.2325	NI	NI	NI	NI
Sidewalk_1yes	1	23.9	<.0001	24.88	<.0001	23.11	<.0001

Note: LR statistics for Type 3 analysis. Variable descriptions are in Table 39. Model 1: Variables selected based on P-value threshold (probability to enter: 0.25, probability to leave: 0.1). Model 2: Variables selected based on AIC. Model 3: Variables selected based on BIC. NI = variable not included in the model.

APPENDIX F. DECISION RULE DEVELOPMENT

SLSG = LIMITED ACCESS

Overview

This section provides an overview of the decision rules selected for the SLSG of Limited Access. The research team considered the following sources in creating the decision rules for limited-access roadways:

- Rules used in USLIMITS2 (*11*).
- Information included in the updated *User Guide for USLIMITS2* (*15*).
- Findings from the literature, particularly the final report from NCHRP Project 17-45 (*219*) and *NCHRP Report 783* (*158*).
- Guidance from the *Green Book* (*17*) and the HSM (*16*).
- Research team expert opinions.
- Feedback from experts, including the project panel.

Decision Rule Development

The research team reviewed several options and decided to start with the rules used within USLIMITS2 and then refine or add to those rules based on findings in the literature. For roadways within the Limited-Access SLSG, measured operating speeds are used to identify the suggested posted speed limit. In general, the relationship of a variable with crashes is used to suggest whether the suggested posted speed limit should reflect:

- The 85th percentile speed rounded to the closest 5-mph increment (C85).
- The 85th percentile speed rounded down to the nearest 5-mph increment (RD85).
- The 50th percentile speed rounded to the closest 5-mph increment (C50).

When the roadway conditions are optimal, the suggested speed limit should reflect the 85th percentile speed. When roadway conditions are not favorable to all users or when crashes are a significant concern, then the suggested speed limit should reflect the 50th percentile speed. An RD85 speed limit is suggested when conditions are between those extremes. In rare cases, the RD85 will be less than the C50 due to rounding. As an example, if the 50th percentile speed were 58 mph and the 85th percentile speed were 59 mph, then the C50 would equal 60 mph and the RD85 would equal 55 mph. This situation only occurs when the 85th and 50th percentile speeds are within 1 mph of each other.

Variables Included in SLS-Tool

Table 46 provides an overview of the variables along with the variable value that would trigger using C85, RD85, or C50. Following is a justification for selecting those variables and break points.

Table 46. Overview of decision rules for SLSG = Limited Access.

Variable	Basis for Suggested Posted Speed Limit		
	Closest 50th (C50)	**Rounded Down 85th (RD85)**	**Closest 85th (C85)**
Interchange spacing (length/number of interchanges) in miles and AADT (two-way total) in vehicles per day	Inter_spac ≤ 0.5 mi and AADT ≥ 180,000 veh/d	0.5 mi < Inter_spac ≤ 1 mi and AADT ≥ 180,000 veh/d	All other cases
Grade in percent and design speed in miles per hour	{Not applicable, see criteria in other cells}	• Design speed ≥ 60 mph and grade > 4% • Design speed ≤ 55 mph and grade > 5%	All other cases
Outside shoulder width (SW) in feet	{Not applicable, see criteria in other cells}	SW < 8 ft	SW ≥ 8 ft
Inside shoulder width (ISW) in feet, number of lanes (N), and directional design-hour truck volume in trucks per hour	{Not applicable, see criteria in other cells}	• Truck_vol > 250 trk/hr and ISW < 12 ft • Truck_vol ≤ 250 trk/hr, N ≥ 6, and ISW < 10 • Truck_vol ≤ 250 trk/hr, N < 6, and ISW < 4	All other cases
All (KABCO) crash rate • High: Crash_rate > critical crash rate • Medium: Crash_rate > 1.3 average crash rate • Low: neither of the above is true	High	Medium	Low
Fatal and Injury (F&I) (KABC) crash rate • High: F&I_rate > critical crash rate • Medium: F&I_rate > 1.3 average crash rate • Low: neither of the above is true	High	Medium	Low

Interchange Spacing

USLIMITS2 includes the variable “interchange spacing” with the break points shown in Table 46. The analyst enters the section length, number of interchanges, and AADT in vehicles per day. The program computes interchange spacing as length per interchange and calls for lower posted speed limits for the specified levels of interchange spacing if the AADT equals or exceeds 180,000 veh/d. The research team suggests retaining this approach.

Grade and Design Speed

USLIMITS2 calls for the analyst to enter the terrain type and caps the posted speed limit at 70 mph if the terrain type is mountainous. The research team suggests a similar special consideration for mountainous terrain based on the *Green Book* guidance for maximum grade and design speed of limited-access facilities (*17*, Table 8-1). The guidance is synthesized as follows:

- If design speed is 60 mph or greater and maximum grade exceeds 4 percent, use rounded-down 85th percentile speed.
- If design speed is 55 mph or less and maximum grade exceeds 5 percent, use rounded-down 85th percentile speed.
- In all other cases, set the posted speed limit as the closest 85th percentile.

The first two conditions are based on the break points between maximum grades for rolling and mountainous terrain specified by the *Green Book*.

Outside Shoulder Width

For limited-access facilities, the *Green Book* (*17*, Chapter 8) calls for outside shoulder widths of at least 12 ft if the truck volume exceeds 250 trucks per hour (trk/hr), and at least 10 ft otherwise. Examination of the outside shoulder width CMF for limited-access facilities in the HSM (*16*) shows that outside shoulder width can be reduced slightly without a significant increase in crash frequency. The CMF value computes as 1.21 for outside shoulder width of 7 ft and 1.14 for outside shoulder width of 8 ft. In other words, when the outside shoulder width (rounded down to the nearest foot) is less than 8 ft, crash frequency is expected to increase by about 21 percent. Thus, based on safety considerations, the research team suggests setting the posted speed limit based on the rounded-down 85th percentile if outside shoulder width is less than 8 ft, or the closest 85th percentile otherwise.

Inside Shoulder Width, Number of Lanes, and Hourly Truck Volume

For limited-access facilities, the *Green Book* (*17*, Chapter 8) calls for the following minimum ISW:

- If directional design-hour truck volume ≤ 250 trk/hr and number of through lanes (two-way total) < 6, then ISW ≥ 4 ft.
- If directional design-hour truck volume ≤ 250 trk/hr and number of through lanes ≥ 6, then ISW ≥ 10 ft.
- If directional design-hour truck volume > 250 trk/hr, then ISW ≥ 12 ft.

Examination of the inside shoulder width CMF for limited-access facilities in the HSM (*16*) shows that inside shoulder width has a minor effect on crash frequency. The CMF value computes as 1.07 for inside shoulder width of 2 ft. Thus, the research team suggests setting the posted speed limit based on the *Green Book* criteria. If the criteria are met, set the posted speed limit based on the closest 85th percentile. If the criteria are not met, set the posted speed limit based on the rounded-down 85th percentile.

Crash Level

USLIMITS2 can produce a suggested posted speed limit when crash data are and are not available. USLIMITS2 requests the following to be able to conduct an analysis of the crash data:

- Length of the study period in years and months (at least 3 years of crash data is recommended; if less than 1 year of data are input, the program suggests that additional data should be collected and the process repeated).
- Total number of crashes (KABCO) in the section.
- Total number of injury and fatal crashes (KABC) in the section.

- Average AADT (two-way total) for the study period.
- Average rate of total crashes and average rate of injury and fatal crashes (100 million vehicle miles [MVM]) for similar road sections in a jurisdiction. To determine the average crash/injury rate for similar sections, users should select a group of sections that have the same or similar geometry (i.e., number of lanes, median type, etc.) and similar traffic volumes and area type.

The length of study, number of crashes, and average AADT are used to calculate the section crash rate for total crashes and for injury and fatal crashes per 100 MVM. If the user does not provide average rates, default values from the HSIS are used (see Table 47 and Table 48). The critical crash rate is calculated from:

$$R_c = R_a + K\sqrt{\frac{R_a}{M}} + \frac{1}{2M}$$

Where:

R_c = Critical crash rate for a given road type.

R_a = Average crash rate for a given road type, provided by the user or obtained from Table 47 or Table 48.

K = Constant associated with the confidence level (1.645 for 95 percent confidence).

M = Exposure (100 MVM).

When crash data are available, the program compares crash rate—both all and injury—for the section to critical crash rate and average crash rate and uses the worst-case scenario.

- High: section crash_rate > critical crash rate.
- Medium: section crash_rate > 1.3 average crash rate.
- Low: neither of the above is true.

USLIMITS permits the use of “low,” even if crash level is medium or high, when the user indicates that “traffic control and/or geometric treatments reduce crash/injury rate in this section.”

The research team suggests retaining this approach.

Table 47. Average KABCO crash rate per 100 MVM for Limited Access SLSG.

AADT Category—Min	AADT Category—Max	Urban Limited-Access Facilities (Inter_spac > 1 mi)	Rural Limited-Access Facilities (Inter_spac > 1 mi)
0	24,999	92.83	49.20
25,000	49,999	79.80	51.23
50,000	74,999	76.96	44.16
75,000	99,999	88.34	
100,000	149,999	91.16	
150,000	199,999	91.60	
200,000	{no limit}	104.51	

Note: Crash rates and injury rates were calculated using the latest 3 years of data that were available: California (2009–11), Minnesota (2010–12), North Carolina (2011–13), Ohio (2010–12), and Washington (2010–12).

Source: Adapted from the 2017 version of the *User Guide for* USLIMITS2 (15), Table 1. Transportation Research Board. 2006. Expert System for Recommending Speed Limits in Speed Zones: NCHRP 03-67. Adapted and Reproduced with permission from the National Academy of Sciences, Washington, DC.

Table 48. Average KABC crash rate per 100 MVM for Limited Access SLSG.

AADT Category—Min	AADT Category—Max	Urban Limited-Access Facilities (Inter_spac > 1 mi)	Rural Limited-Access Facilities (Inter_spac > 1 mi)
0	24,999	24.74	13.39
25,000	49,999	21.24	12.92
50,000	74,999	21.37	14.41
75,000	99,999	25.15	
100,000	149,999	27.69	
150,000	199,999	29.25	
200,000	{no limit}	30.75	

Note: Crash rates and injury rates were calculated using the latest 3 years of data that were available: California (2009–11), Minnesota (2010–12), North Carolina (2011–13), Ohio (2010–12), and Washington (2010–12).
Source: Adapted from the 2017 version of the *User Guide for USLIMITS2* (*15*), Table 1. Transportation Research Board. 2006. Expert System for Recommending Speed Limits in Speed Zones: NCHRP 03-67. Adapted and Reproduced with permission from the National Academy of Sciences, Washington, DC.

Variables Considered but Not Included in SLS-Tool

The research team considered the following variables but did not select them for the SLS-Tool:

- **Terrain.** USLIMITS2 calls for the analyst to enter terrain type (mountainous, rolling, or level) and caps the posted speed limit at 70 mph for mountainous terrain. The research team suggests an alternate approach that accounts for terrain through consideration of grade and design speed. This approach provides the analyst with a more quantitative method to account for the terrain.
- **Illumination.** Research has not consistently shown under what conditions illumination is needed on limited-access facilities for safety purposes or whether the presence of illumination notably affects vehicle speeds.
- **Lane width**. Examination of the lane width CMF for limited-access facilities in the HSM (*16*) shows that lane width has a minor effect on crash frequency. The CMF value is only 1.06 for a lane width of 10.5 ft, and lanes more narrow than 10.5 ft are rare in practice.
- **Horizontal alignment**. The tool should continue to provide a warning when the user indicates that an adverse alignment is present, but this variable should not form the basis for adjusting the posted speed limit.
- **Number of high-volume or congested hours per day**. While a notable volume of research exists to suggest implementing variable speed limits by time of day based on hourly volumes or onset of congestion, this variable should not form the basis for adjusting the base posted speed limit. Variable speed limits are outside the scope of this research project.
- **Presence of HOV or managed lanes (and type of separation from mixed-flow lanes)**. This variable is outside the scope of this research project.
- **Longitudinal barrier presence (median or roadside).** This variable significantly affects safety performance but does not have a direct bearing on vehicle speeds. Thus, a longitudinal barrier presence should be considered in the analysis of crash rates. Additionally, the amount of effort needed to describe longitudinal barrier presence

(both length and offset are required) is greater than desired for analysis of the posted speed limit.
- **Clear zone width.** The safety effect of this variable is minor compared to that of outside shoulder width.

Input Variables

The user is asked to provide the following variables:
- Maximum speed limit (mph).
- 85th percentile speed (mph).
- 50th percentile speed (mph).
- Section length (mi).
- Number of lanes (two-way total).
- Average annual daily traffic (veh/d).
- Directional design-hour truck volume (trk/hr).
- Design speed (mph).
- Number of interchanges in the section.
- Roadway grade (percent).
- Outside (right) shoulder width (ft).
- Inside (left) shoulder width (ft).
- Is there adverse alignment (yes/no)?
- Are crash data available (yes/no)?
- If crash data are available, provide:
  - Number of years of crash data.
  - Average AADT for crash data period (veh/d).
  - Number of all (KABCO) crashes for crash data period.
  - Number of fatal and injury (KABC) crashes for crash data period.
  - Average KABCO crash rate (per 100 million vehicle miles traveled [VMT]) for similar sections during the same time period. If not provided, average KABCO rate from HSIS is used.
  - Average KABC crash rate (per 100 million VMT) for similar sections during the same time period. If not provided, average KABC rate from HSIS is used.

Warning Messages

USLIMITS2 checks for several conditions and issues warnings as needed. The NCHRP Project 17-76 SLS-Tool also issues warnings. The guide discusses the warning messages included in the SLS-Tool. The suggested minimum section length used in the warning message is from USLIMITS2, which notes that the minimum length values are the same as used in the USLIMITS1.0 and Australian XLIMITS expert systems (see Table 49).

Table 49. Minimum section length for a particular speed limit.

Speed Limit (mph)	Minimum Length (mi)
30	0.30
35	0.35
40	0.40
45	0.45
50	0.50
55	0.55
60	1.20
65	3.00
70	6.20
75	6.20

Source: Adapted from the 2017 version of the User Guide for USLIMITS2 (15) Table 2. Transportation Research Board. 2006. Expert System for Recommending Speed Limits in Speed Zones: NCHRP 03-67. Adapted and Reproduced with permission from the National Academy of Sciences, Washington, DC.

SLSG = UNDEVELOPED

Overview

This section provides an overview of the decision rules selected for the SLSG of Undeveloped. The research team considered the following sources when creating the decision rules:

- Findings from the literature review, particularly Stapleton et al. (*220*), Gates et al. (*221*), Das et al. (*222*), and Gates et al. (*223*).
- Rules used in USLIMITS2 (*11*).
- Information included in the updated *User Guide for USLIMITS2* (*15*).
- Expert opinions from members of the research team.
- Feedback from the project panel.

Decision Rule Development

The research team reviewed several options before deciding to start with the rules used within USLIMITS2 (*11*) and then refine or add to those rules based on findings from the literature. For roadways within the undeveloped group, the research team used measured operating speeds to identify the suggested posted speed limit. In general, the relationship of a variable with crashes is used to determine whether the suggested posted speed limit should reflect:

- The 85th percentile speed rounded to the closest 5 mph increment (C85).
- The 85th percentile speed rounded down to the nearest 5 mph increment (RD85).
- The 50th percentile speed rounded to the closest 5 mph increment (C50).

When the roadway conditions are optimal, the suggested speed limit should reflect the 85th percentile speed. When roadway conditions are not favorable to all users or when crashes are a significant concern, then the suggested speed limit should reflect the 50th percentile speed. An RD85 speed limit is suggested when conditions are between those extremes. In rare cases, the RD85 will be less than the C50 due to rounding. As an example, if the 50th percentile speed were 33 mph and the 85th percentile speed were 34 mph, then the C50 would equal 35 mph and the RD85 would equal 30 mph. This situation only occurs when the 85th and 50th percentile speeds are within 1 mph of each other.

Variables Included in SLS-Tool

Table 50 provides an overview of the variables along with the variable value that would trigger using either C85, RD85, or C50. Following the table is a justification for selecting those variables and break points.

Access Points

Previous studies have shown that roadway safety decreases as the number of access points increases (*220, 221*). The guidance for access points is synthesized as follows:

- If the number of access points is greater than or equal to 40 per mile on undeveloped divided roadways or if the number of access points is greater than or equal to 30 per mile on undeveloped undivided roadways, then the posted speed limit should be set at the lower of the closest increment to the 50th percentile (C50) or rounded down to the closest increment to the 85th percentile (RD85).
- If the number of access points is greater than 20 and less than 40 per mile on undeveloped divided roadways or if the number of access points is greater than 15 or smaller than 30 per mile on undeveloped undivided roadways, then the posted speed limit should be set at the closest 5-mph increment to the rounded-down 85th percentile (RD85).
- If the number of access points is less than or equal to 20 per mile on undeveloped divided roadways or if the number of access points is less than or equal to 15 per mile on undeveloped undivided roadways, then the posted speed limit should be set at the closest increment to the 85th percentile (C85).

Number of Lanes/Median Type (Divided or Undivided) Combinations

Das et al. (*222*) found that undeveloped undivided four-lane roadways had a greater speed variability than undeveloped undivided two-lane roadways.

A review of the HSM showed that the crash prediction for undivided four-lane roadways is greater than for divided four-lane roadways (see Figure 24). The figure uses the SPFs in the HSM. The SPFs for undivided roadway segments on rural multilane highways (4U) are applicable to the AADT range from 0 to 33,200 veh/d (HSM, pages 11–15). The SPFs for divided roadway segments on rural multilane highways (4D) are applicable to the AADT range from 0 to 89,300 veh/d (HSM, pages 11–18).

Table 50. Overview of decision rules for SLSG = Undeveloped.

Variable	Basis for Suggested Posted Speed Limit		
	Closest 50th (C50)	**Rounded-Down 85th (RD85)**	**Closest 85th (C85)**
Access points (non-residential driveways and intersections per mile)	• > 40 access points per mile (divided) • > 30 access points per mile (undivided)	• > 20 and ≤ 40 access points per mile (divided) • > 15 and ≤ 30 access points per mile (undivided)	• ≤ 20 access points per mile (divided) • ≤ 15 access points per mile (undivided)
Number of lanes, median type, AADT (two-way total) combination	{Not applicable, see criteria in other cells}	• Four or more lanes with no median (undivided) and AADT > 2000 veh/d	• Four or more lanes with divided median • Two lanes with any median type • Four or more lanes with no median (undivided) and AADT ≤ 2000 veh/d • Any number of lanes/median type combination when AADT ≤ 2000 veh/d
Lane width (LW) and AADT (two-way total)	• LW ≤ 9 ft and AADT > 2000 veh/d	• 9 ft < LW < 11 ft and AADT > 2000 veh/d	• LW ≥ 11 ft and AADT > 2000 veh/d • Any lane width when AADT ≤ 2000
SW and AADT (two-way total)	• SW < 2 ft and AADT > 2000 veh/d	• 2 ft ≤ SW < 6 ft and AADT > 2000 veh/d	• SW ≥ 6 ft and AADT > 2000 veh/d • Any shoulder width when AADT ≤ 2000 veh/d
All (KABCO) crash rate • High: crash_rate > critical crash rate • Medium: crash_rate > 1.3 average crash rate • Low: neither of the above is true	High	Medium	Low
F&I (KABC) crash rate • High: F&I_rate > critical crash rate • Medium: F&I_rate > 1.3 average crash rate • Low: neither of the above is true	High	Medium	Low

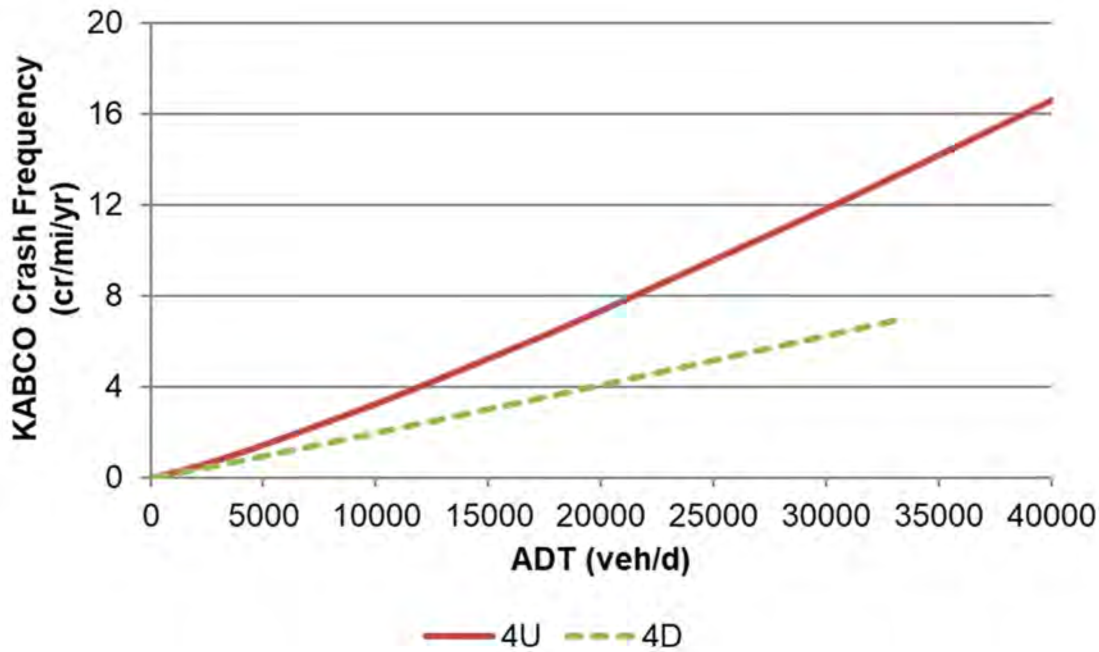


Figure 24. Crash prediction using HSM equations for four-lane undivided and divided roadways.

Four-lane undivided roads with AADT of 2,000 have about 35 percent more crashes compared to four-lane divided roads with the same AADT. The percent is smaller for roads with AADT less than 2,000 and more for AADT greater than 2,000. As will be discussed in the lane width and shoulder width sections below, the research team considered a CMF of more than 1.30 sufficient to justify using the rounded-down 85th percentile speed rather than the closest 85th percentile speed for that condition. Therefore, the research team suggests that the rounded-down 85th percentile speed be used when the road has four lanes, is undivided, and has 2,000 or more AADT. Other cases, such as two lanes, or AADT less than 2,000 would use the closest 85th percentile speed.

Additional justification for using 2,000 veh/d is provided with the recent publication of the second edition of AASHTO's low-volume road guidance (*224*). That document includes 2,000 veh/d or less as the threshold of traffic volume for low-volume roadways. The cut off between high-volume and low-volume roadways previously depended on context including roadway functional classification. AASHTO's first edition of *Guidelines for Geometric Design of Very Low-Volume Local Roads,* published in 2001, considered 400 veh/d or less as the threshold of traffic volume for low-volume roadways (*16*). *NCHRP Report 362* (*Roadway Widths for Low-Traffic-Volume Roads*) considered roadways with 2,000 veh/d or less as low-volume roadways (*225*). According to the sixth edition (in 2011) of AASHTO's *Green Book*, "It may not be cost-effective to design local roads and streets that carry less than 400 vehicles per day using the same criteria applicable to higher volume roads or to make extensive traffic operational or safety improvements to such very low-volume roads" (*226*). The 2018 version of the AASHTO *Green Book* revised that sentence to use the 2,000 veh/d number:

> It may not be cost-effective to design local roads and streets that carry less than 2,000 vehicles per day using the same criteria applicable to higher volume roads or to make extensive improvements to such very low-volume roads. Alternate

> design criteria may be considered for local and minor collector roads and streets that carry 2,000 vehicles per day or less in accordance with the AASHTO *Guidelines for Geometric Design of Very Low-Volume Local Roads.* (*17*, page 5-2)

The guidance for number of lanes/median type combination is synthesized as follows: if the undeveloped roadway has > 2,000 AADT, is four or more lanes, and is undivided, the posted speed limit should be set using the rounded-down 85th percentile speed (RD85). For other cases, such as when the roadway is divided, the closest 85th percentile speed is used. Roads with raised, depressed, or grass medians would be considered divided.

Lane Width

Examination of the lane width CMF for undeveloped facilities in the HSM (*16*) shows that a 12-ft lane width is assigned a CMF of 1.00 (see Table 10.8, Table 11.11, and Table 11.16 in the HSM). The CMF value computes as 1.05 for 11-ft and 1.30 for 10-ft lane width for two-lane roadways. For multilane undivided roadways, these values are 1.04 and 1.23 for 11-ft and 10-ft roadways, respectively. Stapleton et al. (*220*) found that rural two-lane roadway lane widths greater than 12 ft were found to have fewer F&I crashes. The guidance for lane width is synthesized as follows:

- If lane width is less than 10 ft, the suggested posted speed limit should use the closest increment to the 50th percentile speed (C50).
- If lane width is greater than 9 ft and less than 11 ft, the posted speed limit should be set using the rounded-down 85th percentile (RD85).
- If lane width is equal to or greater than 11 ft, the posted speed limit should be set at the closest increment to the 85th percentile (C85).

Shoulder Width

Studies have consistently found that wider paved shoulders on undeveloped roadways result in fewer crashes (*227*, *228*). Examination of the shoulder width CMF for undeveloped facilities in the HSM shows that a 6-ft shoulder width is assigned a CMF of 1.00 (see Table 10.9, Table 11.12, and Table 11.16 in the HSM). The CMF value computes as 1.15 for 4-ft and 1.30 for 2-ft shoulder width for two-lane roadways. For multilane undivided roadways, these values are 1.15 and 1.30 for 4-ft and 2-ft shoulder width, respectively. For multilane divided roadways, an 8-ft right shoulder width is assigned a CMF of 1.00 (see Table 11-17 in the HSM). The guidance for shoulder width is synthesized as follows:

- If the shoulder width is less than 2 ft in undeveloped roadways with AADT > 2,000 veh/d, the suggested posted speed limit should use the 50th percentile speed (C50).
- If the shoulder width is greater than or equal to 2 ft and less than 6 ft in undeveloped roadways (AADT > 2,000 veh/d), the posted speed limit should be set using the rounded-down 85th percentile (RD85).
- If the shoulder width is greater than or equal to 6 ft in undeveloped roadways (AADT > 2,000 veh/d), the posted speed limit should be set at the closest increment to the 85th percentile (C85).

Crash Level

USLIMITS2 can produce a suggested posted speed limit whether crash data are available or not (*11*). USLIMITS2 requests the following information in order to conduct an analysis of the crash data:

- Length of the study period in years and months (at least 3 years of crash data is recommended; if less than 1 year of data are input, the program suggests that additional data should be collected and the process repeated).
- Total number of crashes (KABCO) in the section.
- Total number of F&I crashes (KABC) in the section.
- Average AADT for the study period.
- Average rate of total crashes and average rate of F&I crashes (100 MVM) for similar road sections in a jurisdiction. To determine the average crash/F&I rate for similar sections, users should select a group of sections that have the same or similar geometry (i.e., number of lanes, median type, etc.) and similar traffic volumes and area type.

The length of study, number of crashes, and average AADT are used to calculate the section crash rate for total crashes and for F&I crashes per 100 MVM. If the user does not provide average rates, default values from the HSIS are used (see Table 51 and Table 52). The critical crash rate is calculated from:

$$R_c = R_a + K\sqrt{\frac{R_a}{M}} + \frac{1}{2M}$$

Where:

R_c = Critical crash rate for a given road type.

R_a = Average crash rate for a given road type, provided by the user or obtained from Table 51 or Table 52.

K = Constant associated with the confidence level (1.645 for 95 percent confidence).

M = Exposure (100 MVM).

Table 51. Average crash rate per 100 MVM for Undeveloped SLSG (i.e., context = rural with roadway types of principal arterial, minor arterial, collector, or local).

AADT Category—Min	AADT Category—Max	Two-Lane Roads	Multilane Divided	Multilane Undivided
0	1,249	206.56	102.55	153.35
1,250	2,499	166.00	102.55	153.35
2,500	3,749	147.23	102.55	153.35
3,750	4,999	133.96	102.55	153.35
5,000	6,249	128.57	76.77	145.63
6,250	7,499	121.91	76.77	145.63
7,500	8,749	125.70	76.77	145.63
8,750	9,999	123.35	76.77	145.63
10,000	14,999	98.16	73.90	124.54
15,000	19,999	98.16	70.83	124.54
20,000	24,999	98.16	70.59	124.54
25,000	{no limit}	98.16	65.56	124.54

Note: Crash rates and injury rates were calculated using the latest 3 years of data that were available: California (2009–11), Minnesota (2010–12), North Carolina (2011–13), Ohio (2010–12), and Washington (2010–12).
Source: Adapted from the 2017 version of the *User Guide for USLIMITS2* (*15*), Table 1. Transportation Research Board. 2006. Expert System for Recommending Speed Limits in Speed Zones: NCHRP 03-67. Adapted and Reproduced with permission from the National Academy of Sciences, Washington, DC.

When crash data are available, the program compares crash rate—both total and F&I—for the section to critical crash rate and average crash rate and uses the worst-case scenario.

- High: section observed crash_rate > critical crash rate.
- Medium: section observed crash_rate > 1.3 average crash rate.
- Low: neither of the above is true.

USLIMITS2 (*11*) permits the use of "low," even if the crash level is medium or high, when the user indicates that "traffic control and/or geometric treatments reduce crash/F&I rate in this section."

The research team suggests retaining this approach.

Table 52. Average F&I crash rate per 100 MVM for Undeveloped SLSG (i.e., context = rural with roadway types of principal arterial, minor arterial, collector, or local).

AADT Category—Min	AADT Category—Max	Two-Lane Roads	Multilane Divided	Multilane Undivided
0	1,249	65.21	28.93	50.00
1,250	2,499	54.01	28.93	50.00
2,500	3,749	47.73	28.93	50.00
3,750	4,999	43.89	28.93	50.00
5,000	6,249	43.29	22.14	42.08
6,250	7,499	41.46	22.14	42.08
7,500	8,749	44.14	22.14	42.08
8,750	9,999	43.46	22.14	42.08
10,000	14,999	35.60	20.77	41.14
15,000	19,999	35.60	20.79	41.14
20,000	24,999	35.60	23.11	41.14
25,000	{no limit}	35.60	21.28	41.14

Note: Crash rates and injury rates were calculated using the latest 3 years of data that were available: California (2009–11), Minnesota (2010–12), North Carolina (2011–13), Ohio (2010–12), and Washington (2010–12).
Source: Adapted from the 2017 version of the *User Guide for USLIMITS2* (*15*), Table 1. Transportation Research Board. 2006. Expert System for Recommending Speed Limits in Speed Zones: NCHRP 03-67. Adapted and Reproduced with permission from the National Academy of Sciences, Washington, DC.

Variables Considered but Not Included in SLS-Tool

The research team considered the following variables but did not select them for the SLS-Tool:

- **Roadside hazard rating.** USLIMITS2 (*11*) calls for the analyst to enter roadside hazard rating (RHR) as shown in Table 53. RHR is ranked on a 7-point categorical scale from 1 (best) to 7 (worst). Since these ratings are subjective in nature and vary based on the analyst's perception, the research team excluded RHR in developing the decision rules.
- **Illumination.** The HSM (*16*) has developed a CMF for roadway lighting of undeveloped roadways (see Table 11-19 in the HSM). However, the effect of lighting on undeveloped roadway safety is not consistent.
- **Horizontal alignment**. The tool should continue to provide a warning when the user indicates that an adverse alignment is present, but this variable should not form the basis for adjusting the posted speed limit.
- **Median width.** The HSM has included several CMFs for median width of undeveloped roadways. For example, a 30-ft median for an undeveloped multilane divided roadway has a CMF of 1. The CMF is reduced to 0.97 if the median width increases by 20 ft, but this value has a minimal effect on safety improvement. Instead, the research team used divided/undivided criteria for the decision rule for highways with four lanes.
- **Clear zone width.** The safety effect of this variable is minor compared to that of shoulder width.
- **Horizontal alignment on two-lane highways (horizontal curves).** Gates et al. (*223*) conducted a study on Michigan federal-aid two-lane highways that found horizontal

curvature to significantly affect crash occurrence. These data were reanalyzed for purposes of guideline development here. The findings are:

- For county federal-aid rural two-lane 55-mph roadways, total and F&I segment crash frequency (non-deer) increased when the frequency of horizontal curves with design speeds below 60 mph exceeded 0.5 per mile (one curve every 2 mi).
- For state-owned rural two-lane 55-mph roadways, total and F&I segment crash frequency (non-deer) increased when the frequency of horizontal curves with design speeds below 55 mph exceeded 0.5 per mile (one curve every 2 mi).

Since undeveloped roadways have a variety of design speeds, it would be necessary to generalize the research findings when developing guidance for such roadways. Therefore, the decision was to not include this criterion as a factor in identifying a suggested speed limit. Rather, the tool includes a warning message when the user indicates that adverse alignment is present.

Input Variables

The user is asked to input the following variables:

- Maximum speed limit (mph).
- 85th percentile speed (mph).
- 50th percentile speed (mph).
- Section length (mi).
- Two-way vehicle volume, AADT (veh/d).
- Number of lanes (two-way total).
- Median type (undivided or divided).
- Number of access points (non-residential driveways and unsignalized intersections).
- Lane width (ft).
- Shoulder width (ft).
- Is there adverse alignment (yes/no)?
- Are crash data available (yes/no)?
- If crash data are available, provide:
    - Number of years of crash data.
    - Average AADT for crash data period (veh/d).
    - Number of all (KABCO) crashes for crash data period.
    - Number of fatal and injury (KABC) crashes for crash data period.
    - Average KABCO crash rate (per 100 million VMT) for similar sections during the same time period. If not provided, average KABCO rate from HSIS is used.
    - Average KABC crash rate (per 100 million VMT) for similar sections during the same time period. If not provided, average KABC rate from HSIS is used.

Table 53. RHR for undeveloped roadways.

RHR	Description
1	• Wide clear zones free from obstacles greater than or equal to 9 m (30 ft) from the pavement edgeline. • Sideslope flatter than 1:4. • Recoverable in a run-off-road situation.
2	• Clear zone free from obstacles between 6 and 7.5 m (20 and 25 ft) from pavement edgeline. • Sideslope about 1:4. • Recoverable in a run-off-road situation.
3	• Clear zone free from obstacles about 3 m (10 ft) from pavement edgeline. • Sideslope about 1:3 or 1:4. • Rough roadside surface. • Marginally recoverable in a run-off-road situation.
4	• Clear zone free from obstacles between 1.5 and 3 m (5 to 10 ft) from pavement edgeline. • Sideslope about 1:3 or 1:4. • May have guardrail (1.5 to 2 m [5 to 6.5 ft] from pavement edgeline). • May have exposed trees, poles, or other objects (about 3 m or 10 ft from pavement edgeline). • Marginally forgiving in a run-off-road situation, but increased chance of a reportable roadside collision.
5	• Clear zone free from obstacles between 1.5 and 3 m (5 to 10 ft) from pavement edgeline. • Sideslope about 1:3. • May have guardrail (0 to 1.5 m [0 to 5 ft] from pavement edgeline). • May have rigid obstacles or embankment within 2 to 3 m (6.5 to 10 ft) of pavement edgeline. • Virtually non-recoverable in a run-off-road situation.
6	• Clear zone free from obstacles less than or equal to 1.5 m (5 ft). • Sideslope about 1:2. • No guardrail. • Exposed rigid obstacles within 0 to 2 m (0 to 6.5 ft) of the pavement edgeline. • Non-recoverable in a run-off-road situation.
7	• Clear zone free from obstacles less than or equal to 1.5 m (5 ft). • Sideslope 1:2 or steeper. • Cliff or vertical rock cut. • No guardrail. • Non-recoverable in a run-off-road situation with a high likelihood of severe injuries from roadside collision.

Source: Adapted from the 2017 version of the *User Guide for USLIMITS2* (*15*), pages 23–24. Transportation Research Board. 2006. Expert System for Recommending Speed Limits in Speed Zones: NCHRP 03-67. Adapted and Reproduced with permission from the National Academy of Sciences, Washington, DC.

Warning Messages

USLIMITS2 (*11*) checks for several conditions and issues warnings as needed. The NCHRP Project 17-76 SLS-Tool also issues warnings. The guide discusses the warning messages included in the SLS-Tool. The suggested minimum section length used in the warning message is from USLIMITS2, which notes that the minimum length values are the same as used in the USLIMITS1.0 and Australian XLIMITS expert systems (see Table 49).

SLSG = DEVELOPED

Overview

This section provides an overview of the decision rules selected for the SLSG of Developed. The research team considered the following sources in creating the decision rules for developed roadways:

- Rules used in USLIMITS2 (*11*).
- Information included in the updated *User Guide for USLIMITS2* (*15*).
- Findings from the literature.
- Findings from the analyses conducted using data from Austin, Texas (see Appendix D) and Washtenaw County, Michigan (see Appendix E).
- Research team expert opinions.
- Feedback from experts, including the project panel.

Decision Rule Development

After review of several potential options, the research team decided to use the rules of USLIMITS2 as a basis, with further refinement to those rules made based on findings in the literature or findings from the safety analyses conducted as part of NCHRP Project 17-76 (see Appendix D on Austin, Texas, and Appendix E on Washtenaw, Michigan). For roadways within the Developed SLSG, measured operating speeds are used to identify the suggested posted speed limit. In general, the relationship of a variable with roadway safety is used to determine whether the suggested posted speed limit should reflect:

- The 85th percentile speed rounded to the closest 5 mph increment (C85).
- The 85th percentile speed rounded down to the nearest 5 mph increment (RD85).
- The 50th percentile speed rounded to the closest 5 mph increment (C50).

When the roadway conditions are optimal, the suggested speed limit should reflect the 85th percentile speed. When roadway conditions are not favorable to all users or when crashes are a significant concern, then the suggested speed limit should reflect the 50th percentile speed. An RD85 speed limit is suggested when conditions are between those extremes. In rare cases, the RD85 will be less than the C50 due to rounding. As an example, if the 50th percentile speed were 33 mph and the 85th percentile speed were 34 mph, then the C50 would equal 35 mph and the RD85 would equal 30 mph. This situation only occurs when the 85th and 50th percentile speeds are within 1 mph of each other.

Variables Included in SLS-Tool

Table 54 provides an overview of the variables along with the variable value that would trigger using C85, RD85, or C50. Table 55 shows the combinations of pedestrian treatments and pedestrian activity that would trigger the different speed percentage levels. The following sections provide justification for selecting those variables and the values provided for each.

Table 54. Overview of decision rules for SLSG = Developed.

Variable	**Closest 50th (C50)**	**Rounded-Down 85th (RD85)**	**Closest 85th (C85)**
Signal density	> 4 signals/mile	> 3 signals/mile	≤ 3 signals/mile
Access density	> 60 driveways/ unsignalized intersections per mile	> 40 and <= 60 driveways/ unsignalized intersections per mile	<= 40 driveways/ unsignalized intersections per mile
Number of lanes/median type (undivided, TWLTL, divided)	{Not applicable, see criteria in other cells}	Four or more lanes with undivided median	• Four or more lanes with divided or TWLTL median • Fewer than four lanes with any median type
Bicyclist activity—in motor vehicle lane, shoulder, or non-separated bike lane	High	{Not applicable, see criteria in other cells}	Not high
Bicyclist activity—in separated bike lane	{Not applicable, see criteria in other cells}	High	Not high
Sidewalk presence/width (none, narrow, adequate, wide), sidewalk buffer (present, not present), and pedestrian activity (high, some, negligible)	See Table 55	See Table 55	See Table 55
On-street parking activity	High	{Not applicable, see criteria in other cells}	Not high
On-street parking type	Angle parking present for 40 percent or more of section	• Parallel parking permitted • Angle parking present for less than 40 percent of section	None
All (KABCO) crash rate • High: crash_rate > critical crash rate • Medium: crash_rate > 1.3 average crash rate • Low: neither of the above is true	High	Medium	Low
F&I (KABC) crash rate • High: F&I_rate > critical crash rate • Medium: F&I_rate > 1.3 average crash rate • Low: neither of the above is true	High	Medium	Low

Table 55. Decision matrix for sidewalk presence/width, sidewalk buffer, and pedestrian activity combinations for Developed SLSG.

Pedestrian Activity	Sidewalk Presence/Width	Sidewalk Buffer	Speed%
High	Adequate	Not present	RD85
High	Adequate	Present	C85
High	Narrow	Not present	C50
High	Narrow	Present	RD85
High	None	Not applicable	C50
High	Wide	Not present	C85
High	Wide	Present	C85
Some	Adequate	Not present	C85
Some	Adequate	Present	C85
Some	Narrow	Not present	C50
Some	Narrow	Present	C85
Some	None	Not applicable	C50
Some	Wide	Not present	C85
Some	Wide	Present	C85
Negligible	Adequate	Not present	C85
Negligible	Adequate	Present	C85
Negligible	Narrow	Not present	C85
Negligible	Narrow	Present	C85
Negligible	None	Not applicable	RD85
Negligible	Wide	Not present	C85
Negligible	Wide	Present	C85

Note: See text for additional discussion on sidewalk presence/width and sidewalk buffer characteristics.

Signal Density

USLIMITS2 includes the variable "signals per mile" with the break points shown in Table 46. The findings from the analyses conducted using City of Austin, Texas, data (see Appendix D) and Washtenaw County, Michigan, data (see Appendix E) support the inclusion of this variable. Those analyses also appear to support the break points of 3 and 4 signals per mile; however, additional research may be needed to refine those values. The segments used in the 17-76 analyses were created when a signal was present; in other words, the segments began and ended with a signalized intersection or with a control that would have resulted in a change of speed (e.g., four-way stop or end of road). The user provides the number of signals within the section, and the program calculates the signals density (signals/section length).

Access Density

USLIMITS2 includes the variable "driveways per mile." The research team renamed the variable "access density" to avoid the question of whether the driveways per mile variable should include unsignalized intersections (which it should). The findings from NCHRP Project 17-76 support the break points used in USLIMITS2. All types of non-single-family driveways (e.g., multifamily residential, commercial, etc.) along with unsignalized intersections should be counted. The user is asked to provide the number of driveways and unsignalized intersections within the section, and the tool calculates the access density.

Number of Lanes/Median Type (Undivided, TWLTL, Divided) Combinations

The safety analyses conducted as part of NCHRP Project 17-76 (see Appendix D on Austin, Texas, and Appendix E on Washtenaw, Michigan) found fewer crashes for a raised (divided) median compared to a TWLTL or no median. A review of the literature found studies that documented reduction in crashes when a TWLTL was added to a four-lane undivided roadway (*70*, *71*).

The research team recommends that the presence of a divided (raised or depressed) median or a TWLTL on a road with four lanes or more be considered the baseline condition, and for undivided four-lane roads, be associated with suggested posted speed limits that reflect the rounding down of the 85th percentile speed.

Because the type of median may vary within a section, the user is asked for the type of median treatment that is predominant within the section.

Pedestrian Activity

In USLIMITS2, the user is asked to select between “high” and “not high” for pedestrian activity. USLIMITS2 provides the following examples for high pedestrian activity:

- Residential developments with four or more housing units per acre interspersed with multifamily dwellings.
- Hotels located with ½ mi of other attractions such as retail stores, recreation areas, or senior centers.
- Downtown or CBD areas.
- Areas that usually have paved sidewalks, marked crosswalks, and pedestrian signals.

The research team recommends that an appreciation for the pedestrian activity level be retained within the SLS-Tool. The examples for high pedestrian activity used in USLIMITS2 should be refined to reflect the use of the Expanded Functional Classification System in that downtown or CBD areas now fit within the urban core context.

The suggested examples for when pedestrian activity is high are:

- Residential developments with four or more housing units per acre interspersed with multifamily dwellings.
- Hotels located with ½ mi of other attractions such as retail stores, recreation areas, or senior centers.
- Areas with paved sidewalks, marked crosswalks, and pedestrian signals.
- Areas with multiple transit stops within the section.

The level of pedestrian activity ties into the decision rule that considers pedestrian facilities such as sidewalk presence/width and sidewalk buffer.

Bicyclist Activity

In USLIMITS2, the user is asked to select between “high” and “not high” for pedestrian and bicycle activity. USLIMITS2 provides the following examples for high activity:

- Residential developments with four or more housing units per acre interspersed with multifamily dwellings.
- Hotels located with ½ mi of other attractions such as retail stores, recreation areas, or senior centers.
- Downtown or CBD areas.
- Areas that usually have paved sidewalks, marked crosswalks, and pedestrian signals.

The research team recommends that an appreciation for the bicycle activity level be retained within the SLS-Tool but separated from pedestrian activity. The examples for high bicyclist activity used in USLIMITS2 should be refined to reflect the use of the Expanded Functional Classification System in that downtown or CBD areas now fit within the urban core context.

The suggested examples for when bicyclist activity is high are:

- Residential developments with four or more housing units per acre interspersed with multifamily dwellings.
- Areas with bicycle treatments including marked bike lanes, bike boxes, etc.
- Areas with multiple transit stops within the section.

Based on feedback from the panel, the research team subdivided bicyclist activity for when a separated bike lane is present. When bicycle activity is high and bicyclists are with, or not separated from, motor vehicles (i.e., the bicyclists are in the travel lane or shoulder, or the bike lane does not have vertical separations), the suggested speed limit is lower than when the bicyclists are within a separated bike lane.

Sidewalk Presence/Width, Sidewalk Buffer (Separation Distance between Pedestrian and Vehicles), and Pedestrian Activity Combination

When there is a reasonable expectation of pedestrians on or very near a roadway, selection of a lower operating speed can be justified (i.e., the analyst selects high or some as the level of pedestrian activity) depending upon the quality of the pedestrian facility present. The following conditions were assigned to rounding the operating speed to the 5-mph increment that is nearest the 50th percentile: narrow sidewalk that has no buffer between the sidewalk and the road or when there is a reasonable expectation of a pedestrian and no sidewalk is present. These conditions place the pedestrian very close to the moving vehicles. When wide sidewalks are present, pedestrians can shift away from the moving traffic; thus, that condition was assigned to the closest 85th percentile operating speed. Those cases when a sidewalk is not present and there is minimal expectation of a pedestrian were assigned to the rounding down of the 85th percentile speed. When there could be an expectation of <u>some</u> pedestrians but not a high number of pedestrians and a sidewalk facility exists but may be considered poor, the recommendation is C85. When there is a <u>high</u> level of pedestrians present and the sidewalk facility is poor, then the suggest speed limit reflects the 5-mph increment associated with RD85.

The FHWA Course on Bicycle and Pedestrian Transportation (*229*, page 13-1) states that "sidewalks require a minimum width of 5.0 feet if set back from the curb or 6.0 feet if at the curb face. Any width less than this does not meet the minimum requirements for people with disabilities."

Because the sidewalk characteristics may vary within a section, the user is asked for the sidewalk characteristics that are predominant within the section. The user is asked:

- What is the predominate width of the sidewalk within the section?
    - No sidewalk (<u>none</u>) is present on either side of the street.
    - A <u>narrow</u> sidewalk is present (sidewalk that is < 5 ft if set back from curb or 6 ft if at the curb face).
    - An <u>adequate</u> sidewalk is present (sidewalk is between 5 ft and 8 ft if set back from curb or between 6 ft and 8 ft if at curb face).
    - A <u>wide</u> sidewalk is present (sidewalk is 8 ft or greater).

- Is a sidewalk separation (or buffer) present or not present between road (face of curb when curb and gutter are present or edge of travel lane when a shoulder is present) and sidewalk? A buffer could include a nature strip, a bike lane, or on-street parking.
- What is the level of pedestrian activity (negligible, some, high)? See previous section discussion for advice regarding these levels.

On-Street Parking Activity and On-Street Parking Type

In USLIMITS2, the user is asked to select between “high” and “not high” for parking activity. USLIMITS2 notes that high parking activity typically occurs in high-turnover areas often found in downtown and/or CBD areas. In addition, these areas usually have parking on both sides of the road with parking time limits that do not exceed 60 minutes, with at least 30 percent of parking spaces occupied during weekdays.

USLIMITS2 says the high level of on-street parking activity should result in using C50. The findings from NCHRP Project 17-76 (see Appendix D and Appendix E) along with other studies—see Greibe (*20*) and Islam and El-Basyouny (*36*)—support this variable and consideration of a variable that reflects the characteristics of the on-street parking. For example, the findings from NCHRP Project 17-76 indicate that the parking width available has a relationship to number of crashes, with more narrow widths associated with more crashes.

A study by Bonneson et al. (*230*) synthesized several prior studies to formulate a curb parking CMF. The curb parking CMF was dependent on type of parking (angle versus parallel), type of adjacent land use, type of cross-section, and proportion of segment length with parking. Based on a review of those findings, the research team suggests the following with regards to angle parking:

- If angle parking is present for 40 percent or more of the section, use the closest 50th percentile speed. Angle parking results in a much larger increase in crash frequency than parallel parking.
- If angle parking is present for less than 40 percent of the section, use the rounded-down 85th percentile speed.

Because the on-street parking characteristics may vary within a section, the user is asked for the on-street parking characteristics that are predominant within the section. The user is asked:

- Is on-street parking activity “high” or “not high”? A high level of on-street parking can be characterized as having parking on both sides of the road with parking time limits.
- Is angle parking present for at least 40 percent of the section?
- Is parallel parking (marked or unmarked) permitted in the section?

Crash Level

USLIMITS2 can produce a suggested posted speed limit when crash data are and are not available. USLIMITS2 requests the following to be able to conduct an analysis of the crash data:

- Length of the study period in years and months (at least 3 years of crash data is recommended; if less than 1 year of data are input, the program suggests that additional data should be collected and the process repeated).
- Total number of crashes in the section.
- Total number of injury and fatal crashes in the section.

- Average AADT for the study period.
- Average rate of total crashes and average rate of injury and fatal crashes (per 100 MVM) for similar road sections in a jurisdiction. To determine the average crash/injury rate for similar sections, users should select a group of sections that have the same or similar geometry (i.e., number of lanes, median type, etc.) and similar traffic volumes and area type.

The length of study, number of crashes, and average AADT are used to calculate the section crash rate for total crashes and for injury and fatal crashes per 100 MVM. If the user does not provide average rates, default values from the HSIS are used (see Table 56 and Table 57). The critical crash rate is calculated from:

$$R_c = R_a + K\sqrt{\frac{R_a}{M}} + \frac{1}{2M}$$

Where:

R_c = Critical crash rate for a given road type.

R_a = Average crash rate for a given road type, provided by the user or obtained from Table 56 and Table 57.

K = Constant associated with the confidence level (1.645 for 95 percent confidence).

M = Exposure (100 MVM).

When crash data are available, the program compares crash rate—both all and fatal/injury—for the section to critical crash rate and average crash rate and uses the worst-case scenario.

- High: section crash_rate > critical crash rate.
- Med: section crash_rate > 1.3 average crash rate.
- Low: neither of the above is true.

USLIMITS permits the use of “low,” even if crash level is medium or high, when the user indicates that “traffic control and/or geometric treatments reduce crash/injury rate in this section.”

No changes are suggested to this approach.

Table 56. Average KABCO crash rate per 100 MVM from USLIMITS2 for Developed SLSG (i.e., context = urban, suburban, or rural town with roadway types of principal arterial, minor arterial, or collector).

AADT Category—Min	AADT Category—Max	Two-Lane Roads	Multilane Divided	Multilane Undivided	One-Way Streets
0	2,499	263.17	226.43	452.14	245.12
2,500	4,999	209.14	226.43	452.14	245.12
5,000	7,499	205.37	226.43	452.14	139.27
7,500	9,999	229.55	226.43	452.14	139.27
10,000	14,999	246.62	202.46	452.26	72.18
15,000	19,999	253.25	202.46	452.26	58.31
20,000	24,999	225.17	228.69	431.09	57.36
25,000	29,999	225.17	228.69	431.09	63.87
30,000	34,999	225.17	228.37	431.25	54.63
35,000	39,999	225.17	228.37	431.25	54.63
40,000	49,999	225.17	205.73	431.25	54.63
50,000	No limit	225.17	158.17	431.25	54.63

Note: Crash rates and injury rates were calculated using the latest 3 years of data that were available: California (2009–11), Minnesota (2010–12), North Carolina (2011–13), Ohio (2010–12), and Washington (2010–12).
Source: Adapted from the 2017 version of the *User Guide for USLIMITS2* (*15*), Table 1. Transportation Research Board. 2006. Expert System for Recommending Speed Limits in Speed Zones: NCHRP 03-67. Adapted and Reproduced with permission from the National Academy of Sciences, Washington, DC.

Table 57. Average KABC crash rate per 100 MVM from USLIMITS2 for Developed SLSG (i.e., context = urban, suburban, or rural town with roadway types of principal arterial, minor arterial, or collector).

AADT Category—Min	AADT Category—Max	Two-Lane Roads	Multilane Divided	Multilane Undivided	One-Way Streets
0	2,499	67.32	72.02	131.02	60.21
2,500	4,999	64.31	72.02	131.02	60.21
5,000	7,499	63.75	72.02	131.02	37.29
7,500	9,999	70.26	72.02	131.02	37.29
10,000	14,999	73.14	66.16	131.98	22.79
15,000	19,999	78.14	66.16	131.98	18.19
20,000	24,999	71.82	75.37	129.00	17.72
25,000	29,999	71.82	75.37	129.00	20.07
30,000	34,999	71.82	74.01	131.10	15.03
35,000	39,999	71.82	74.01	131.10	15.03
40,000	49,999	71.82	70.84	131.10	15.03
50,000	No limit	71.82	56.32	131.10	15.03

Note: Crash rates and injury rates were calculated using the latest 3 years of data that were available: California (2009–11), Minnesota (2010–12), North Carolina (2011–13), Ohio (2010–12), and Washington (2010–12).
Source: Adapted from the 2017 version of the *User Guide for USLIMITS2* (*15*), Table 1. Transportation Research Board. 2006. Expert System for Recommending Speed Limits in Speed Zones: NCHRP 03-67. Adapted and Reproduced with permission from the National Academy of Sciences, Washington, DC.

Variables Considered but Not Included in SLS-Tool

The research team considered the following variables but did not select them for the SLS-Tool:

- **Presence of a midblock crosswalk.** Whether the presence of a single midblock crossing warrants a speed reduction would need to consider whether additional supplemental treatments are present, such as a rectangular rapid flashing beacon or pedestrian hybrid beacon. Research studies on the safety relationship of these devices have indicated reduced crashes for both pedestrians and vehicles (*231*, *232*).
- **Presence of school or school crossings.** The SLS-Tool developed in NCHRP Project 17-76 does not apply to school zones.
- **Horizontal alignment.** The tool should continue to provide a warning when the user indicates that an adverse alignment is present.
- **Bus stops.** Pedestrian activity level associated with bus stops should be considered with the pedestrian activity variable.
- **Number of lanes or roadway surface width.**
- **Roadside.** Consideration of sidewalks is included.
- **Area type (residential collector, residential subdivision, commercial, large complexes).** USLIMITS2 asks for the area type (residential collector, residential subdivision, commercial, or large complexes). The information is one of the variables used to determine if the suggested speed limit should be RD85 or C85. Because of the new Extended Functional Class System, area type is now handled within the SLSG.

Input Variables

The user is asked to provide the following:

- Maximum speed limit (mph).
- 85th percentile speed (mph).
- 50th percentile speed (mph).
- Section length (mi).
- Number of lanes.
- Predominant median type for the section (undivided, TWLTL, divided).
- Number of traffic signals in the section.
- Number of access points (i.e., driveways and unsignalized intersections) in the section.
- Bicyclist activity (high or not high).
- What is the predominate width of the sidewalk within the section?
  - <u>None</u>, no sidewalk is present on either side of the street.
  - A <u>narrow</u> sidewalk is present (sidewalk that is < 5 ft if set back from curb or 6 ft if at the curb face).
  - An <u>adequate</u> sidewalk is present (sidewalk is between 5 ft and 8 ft if set back from curb or between 6 ft and 8 ft if at curb face).
  - A <u>wide</u> sidewalk is present (sidewalk is 8 ft or greater).
- Is a sidewalk separation (or buffer) present between road (face of curb when curb and gutter are present or edge of travel lane when a shoulder is present) and sidewalk (present or not present)? A buffer could include a nature strip, a bike lane, or on-street parking.

- Pedestrian activity (high, some, or negligible).
- Is on-street parking activity “high” or “not high”? A high level of on-street parking can be characterized as having parking on both sides of the road with parking time limits.
- Is parallel parking (marked or unmarked) permitted in the section?
- Is angle parking present for at least 40 percent of the section?
- Is there adverse alignment (yes/no)?
- Are crash data available (yes/no)?
- If crash data are available, provide:
  - Number of years of crash data.
  - Average AADT for crash data period (veh/d).
  - Number of all (KABCO) crashes for crash data period.
  - Number of fatal and injury (KABC) crashes for crash data period.
  - Is the segment a one-way street?
  - Average KABCO crash rate (per 100 million VMT) for similar sections during the same time period. If not provided, average KABCO rate from HSIS is used.
  - Average KABC crash rate (per 100 million VMT) for similar sections during the same time period. If not provided, average KABC rate from HSIS is used.

Warning Messages

USLIMITS2 checks for several conditions and issues warnings as needed. The NCHRP Project 17-76 SLS-Tool also issues warnings. The guide discusses the warning messages included in the SLS-Tool. The suggested minimum section length used in the warning message is from USLIMITS2, which notes that the minimum length values are the same as used in the USLIMITS1.0 and Australian XLIMITS expert systems (see Table 49).

SLSG = FULL ACCESS

Overview

This section provides an overview of the decision rules selected for the SLSG of Full Access. The research team considered the following sources in creating the decision rules:

- Rules used in USLIMITS2 (*11*).
- Information included in the updated *User Guide for USLIMITS2* (*15*).
- Findings from the literature.
- Findings from the analyses conducted using data from Austin, Texas (see Appendix D) and Washtenaw County, Michigan (see Appendix E).
- Research team expert opinions.
- Feedback from experts, including the project panel.

Decision Rule Development

After review of several potential options, the research team decided to use the rules for the SLSG of Developed as a basis, which were based on findings in the literature or findings from the safety analyses conducted as part of NCHRP Project 17-76 (see Appendix D on Austin, Texas, and Appendix E on Washtenaw, Michigan). Further refinements to those rules were made based on the research team and project panel’s expert opinions.

For roadways within the Full-Access SLSG, measured operating speeds are used to identify the suggested posted speed limit within the following two methods:

- The 50th percentile speed rounded to the closest 5-mph increment (C50).
- The 50th percentile speed rounded down to the nearest 5-mph increment (RD50).

Variables Included in SLS-Tool

Table 58 provides an overview of the variables along with the variable value that would trigger using C50 or RD50. The following is a justification for selecting those variables and the values provided for each.

Table 58. Overview of decision rules for SLSG = Full Access.

Variable	Rounded-Down 50th (RD50)	Closest 50th (C50)
Signal density	> 8 signals/mile	≤ 8 signals/mile
Access density	> 60 driveways/unsignalized intersections per mile	≤ 60 driveways/unsignalized intersections per mile
Bicyclist activity—in motor vehicle lane, shoulder, or non-separated bike lane	High	Not high
Bicyclist activity—in separated bike lane	High	Not high
Sidewalk presence/width (none, narrow, adequate, wide), sidewalk buffer (present, not present), and expectation of pedestrian activity (high, some, negligible)	See Table 59	See Table 59
On-street parking activity	High	Not high
On-street parking type	Angle parking present for 40 percent or more of section	No parking present Angle parking present for less than 40 percent of section
All (KABCO) crash rate • High: crash_rate > critical crash rate • Medium: crash_rate > 1.3 average crash rate • Low: neither of the above is true	High or Med	Low
F&I (KABC) crash rate • High: F&I_rate > critical crash rate • Medium: F&I_rate > 1.3 average crash rate • Low: neither of the above is true	High or Med	Low

Signal Density

USLIMITS2 includes the variable "signals per mile," and the variable was included in the Developed SLSG with break points at 3 and 4 signals per mile. These break points were supported by the findings from the analyses conducted using City of Austin, Texas, data (see Appendix D) and Washtenaw County, Michigan, data (see Appendix E). A revised break point was needed for use in the Full-Access SLSG, and the value of 8 signals/mile was selected based on feedback from the panel.

The user provides the number of signals within the section, and the program calculates the signal density.

Table 59. Decision matrix for sidewalk presence/width, sidewalk buffer, and pedestrian activity combinations for Full-Access SLSG.

Pedestrian Activity	Sidewalk Presence/Width	Sidewalk Buffer	Speed%
High	Adequate	Not present	RD50
High	Adequate	Present	C50
High	Narrow	Not present	RD50
High	Narrow	Present	RD50
High	None	Not applicable	RD50
High	Wide	Not present	C50
High	Wide	Present	C50
Some	Adequate	Not present	C50
Some	Adequate	Present	C50
Some	Narrow	Not present	RD50
Some	Narrow	Present	C50
Some	None	Not applicable	RD50
Some	Wide	Not present	C50
Some	Wide	Present	C50
Negligible	Adequate	Not present	C50
Negligible	Adequate	Present	C50
Negligible	Narrow	Not present	C50
Negligible	Narrow	Present	C50
Negligible	None	Not applicable	C50
Negligible	Wide	Not present	C50
Negligible	Wide	Present	C50

Note: See text for additional discussion on sidewalk presence/width and sidewalk buffer characteristics.

Access Density

USLIMITS2 includes the variable "driveways per mile." The research team renamed the variable "access density" to avoid the question of whether the driveways per mile variable should include unsignalized intersections (which it should). The findings from NCHRP Project 17-76 support the break points used in USLIMITS2. All types of non-single-family home driveways (e.g., multifamily residential, commercial, etc.) along with unsignalized intersections should be counted. The user is asked to provide the number of non-single-family residential driveways and unsignalized intersections within the section, and the tool calculates the access density.

Bicyclist Activity

Like the Developed SLSG, the suggested posted speed for a corridor within the Full-Access SLSG is a function of the level of bicyclist activity and the presence of a separated bike lane.

Sidewalk Presence/Width, Sidewalk Buffer (Separation Distance between Pedestrian and Vehicles), and Pedestrian Activity Combination

Like the Developed SLSG, the suggested posted speed is a function of the quality of pedestrian facility. When there is a reasonable expectation of a high number of pedestrians on or very near a roadway, selection of a lower operating speed can be justified. See additional discussion on these variables in the Developed SLSG section.

On-Street Parking Activity and On-Street Parking Presence

Parking activity and on-street parking presence follow a similar approach as that suggested for the Developed SLSG.

Because the on-street parking characteristics may vary within a section, the user is asked for the on-street parking characteristics that are predominant within the section. The user is asked:

- Is on-street parking activity “high” or “not high”? A high level of on-street parking can be characterized as having parking on both sides of the road with parking time limits.
- Is angle parking present for at least 40 percent of the section?

Crash Level

The suggested approach for crash level used with the Developed SLSG is suggested for the Full-Access SLSG, including using the default values from the HSIS for the Developed condition (see Table 56 and Table 57). For the Full-Access SLSG, a crash level of high or medium would trigger the use of rounding down from the 50th percentile; otherwise, using the closest 5-mph increment to the 50th percentile speed is suggested. See additional discussion in the Developed SLSG section.

Variables Considered but Not Included in SLS-Tool

The research team considered several other variables as part of either the Developed or Full-Access SLSG but did not select them for the SLS-Tool. See the discussion in the Developed SLSG section for additional details. Number of lanes and median type combination was included in the Developed SLSG but not in the Full-Access SLSG due to limited findings.

Input Variables

The user is asked to provide the following:

- Maximum speed limit (mph).
- 50th percentile speed.
- Section length (mi).
- Number of traffic signals in the section.

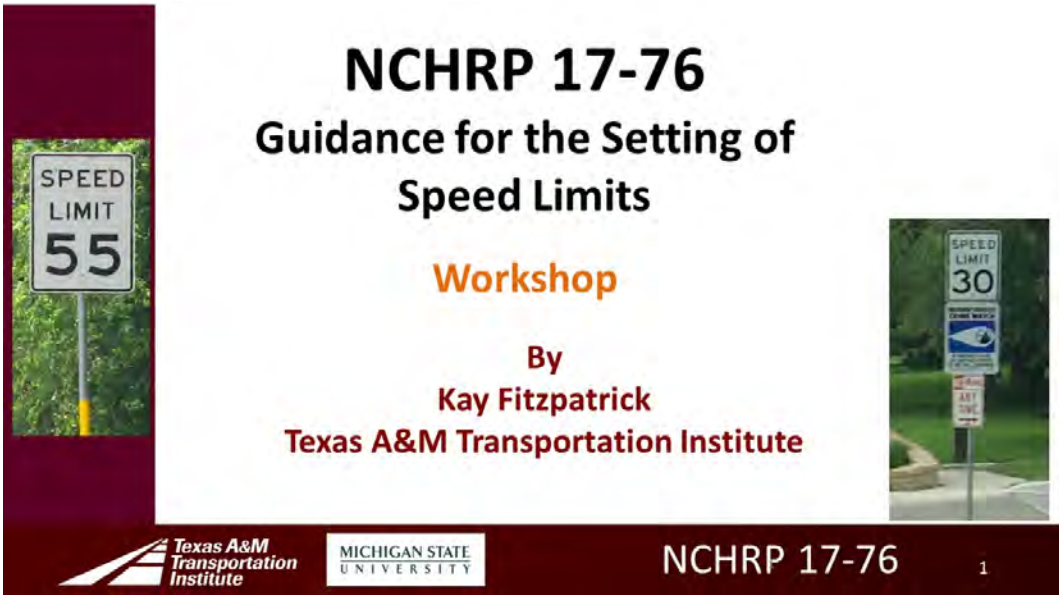
- Number of access points (i.e., driveways and unsignalized intersections) in the section.
- Bicyclist activity (high or not high).
- What is the predominate width of the sidewalk within the section?
  - None, no sidewalk is present on either side of the street.
  - A narrow sidewalk is present (sidewalk that is < 5 ft if set back from curb or 6 ft if at the curb face).
  - An adequate sidewalk is present (sidewalk is between 5 ft and 8 ft if set back from curb or between 6 ft and 8 ft if at curb face).
  - A wide sidewalk is present (sidewalk is 8 ft or greater).
- Is a sidewalk separation (or buffer) present between road (face of curb when curb and gutter are present or edge of travel lane when a shoulder is present) and sidewalk (present or not present)? A buffer could include a nature strip, a bike lane, or on-street parking.
- Pedestrian activity (high, some, or negligible).
- Is on-street parking activity “high” or “not high”? A high level of on-street parking can be characterized as having parking on both sides of the road with parking time limits.
- Is parallel parking (marked or unmarked) permitted in the section?
- Is angle parking present for at least 40 percent of the section?
- Is there adverse alignment (yes/no)?
- Are crash data available (yes/no)?
- If crash data are available, provide:
  - Number of years of crash data.
  - Average AADT for crash data period (veh/d).
  - Number of all (KABCO) crashes for crash data period.
  - Number of fatal and injury (KABC) crashes for crash data period.
  - Average KABCO crash rate (per 100 million VMT) for similar sections during the same time period. If not provided, average KABCO rate from HSIS is used.
  - Average KABC crash rate (per 100 million VMT) for similar sections during the same time period. If not provided, average KABC rate from HSIS is used.

Warning Messages

USLIMITS2 checks for several conditions and issues warnings as needed. The NCHRP Project 17-76 SLS-Tool also issues warnings. The guide discusses the warning messages included in the SLS-Tool. The suggested minimum section length used in the warning message is from USLIMITS2, which notes that the minimum length values are the same as used in the USLIMITS1.0 and Australian XLIMITS expert systems (see Table 49).

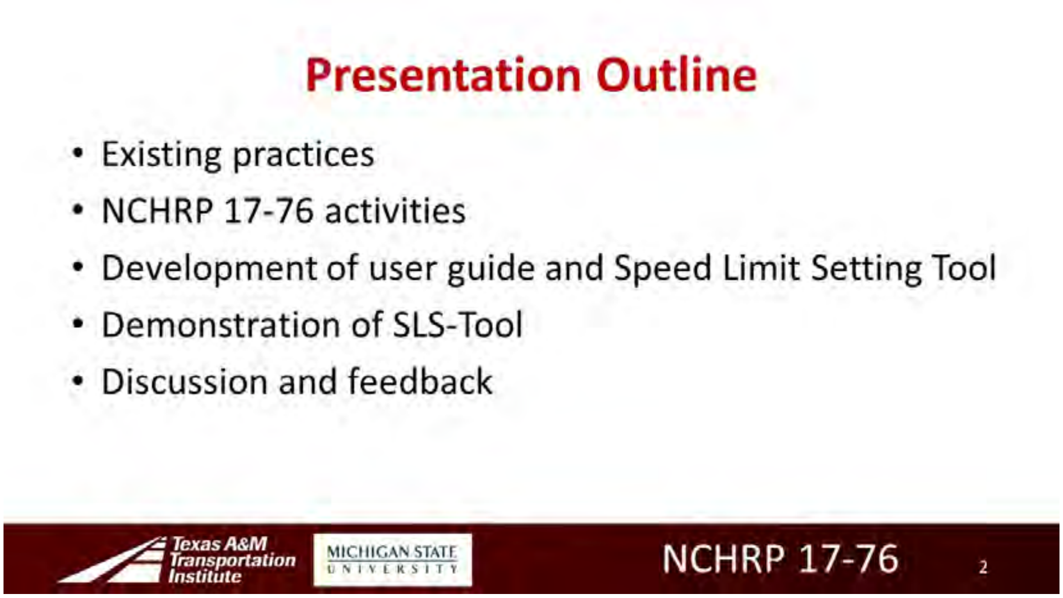
APPENDIX G. WORKSHOP SLIDES

This appendix includes the slides and presenter notes used in one of the workshops presented during the project.



1.

This presentation will give you an overview of a new tool that is being developed in NCHRP 17-76 for setting speed limits.

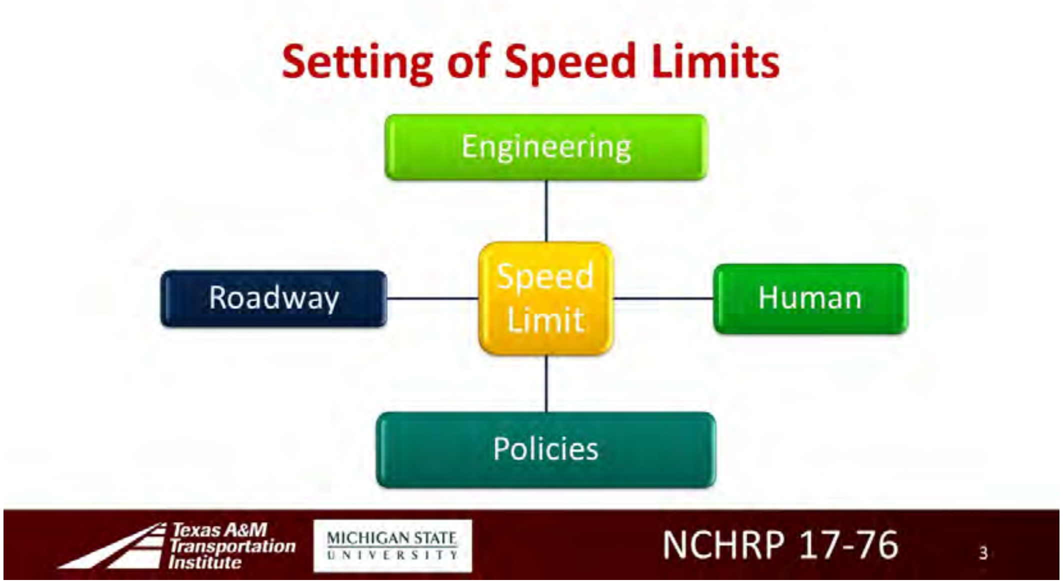


2.

The workshop will cover the following:

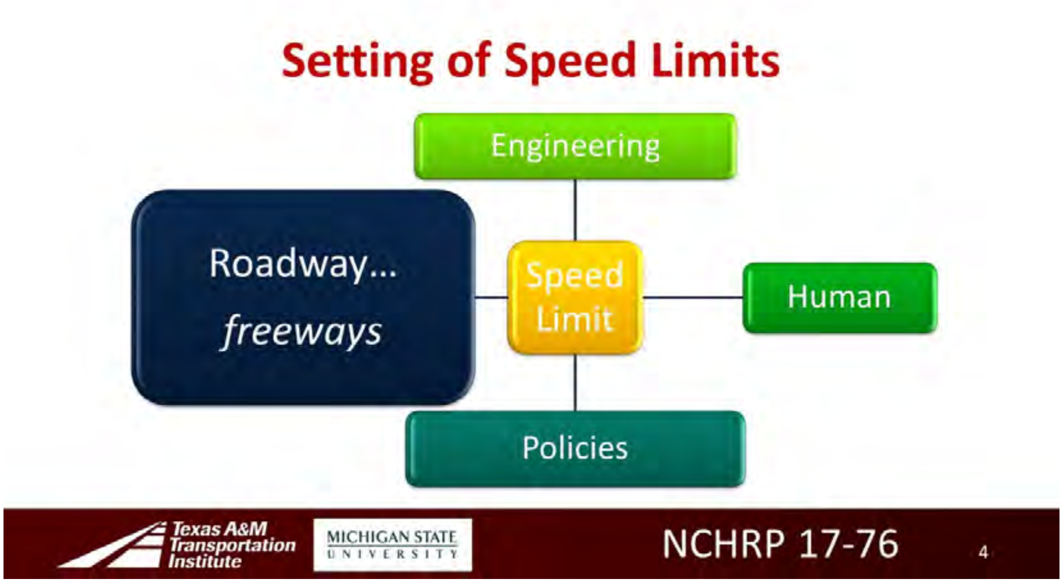
- Existing practices with regards to posting speed limits.
- The activities within the NCHRP 17-76 project.
- Background on the development of the user guide and the associated Speed Limit Setting Tool.

- A brief demonstration of the SLS-Tool.
- Opportunity for discussion and feedback on the user guide and the SLS-Tool.



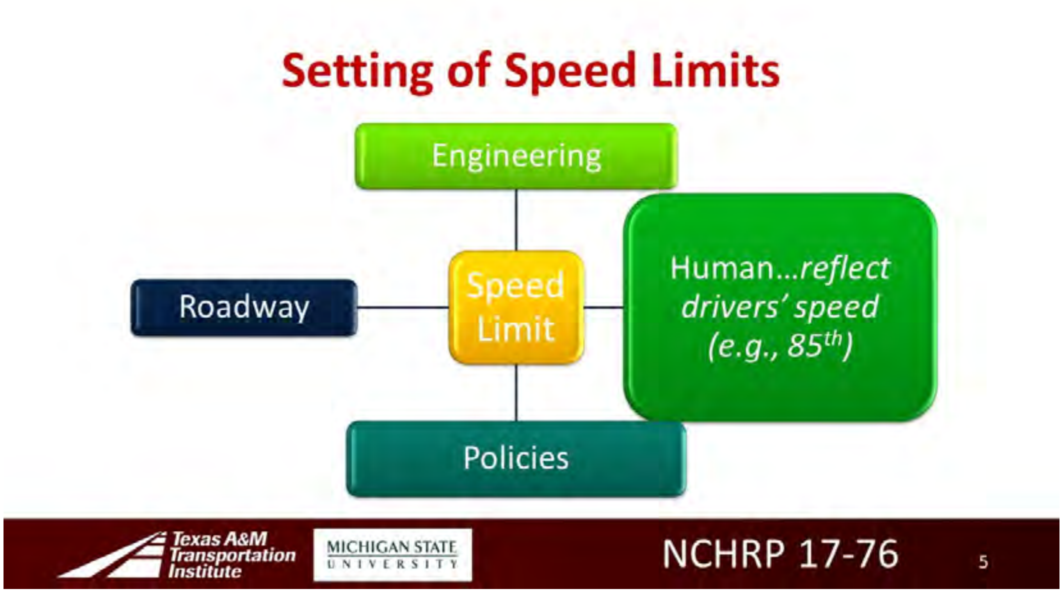
3.

Several factors are considered when selecting a speed limit for a speed zone.



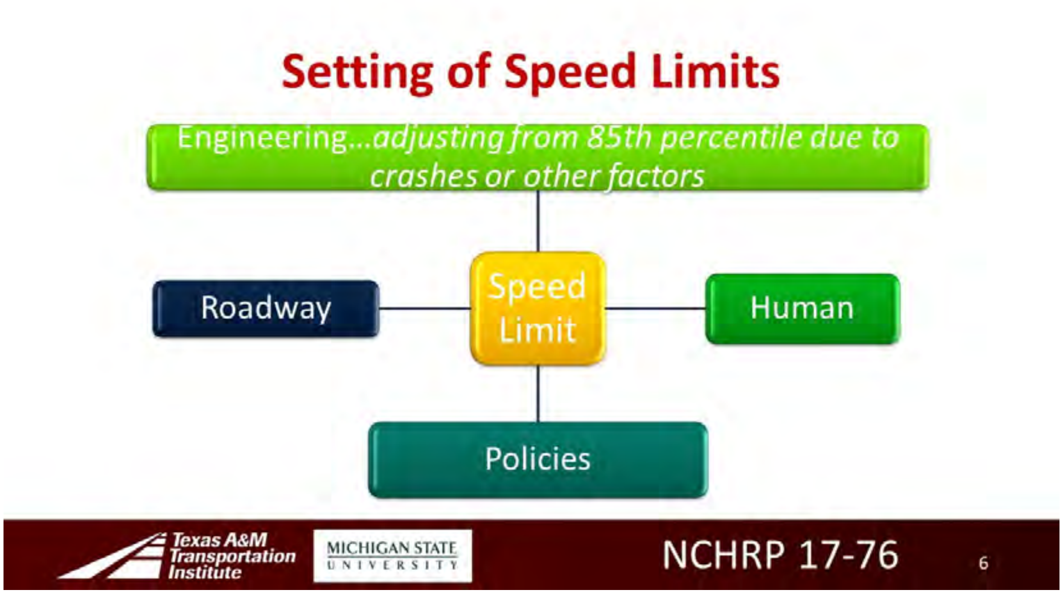
4.

The type of roadway influences the selection. For example, appropriate speed limits vary for freeways as compared to residential streets.



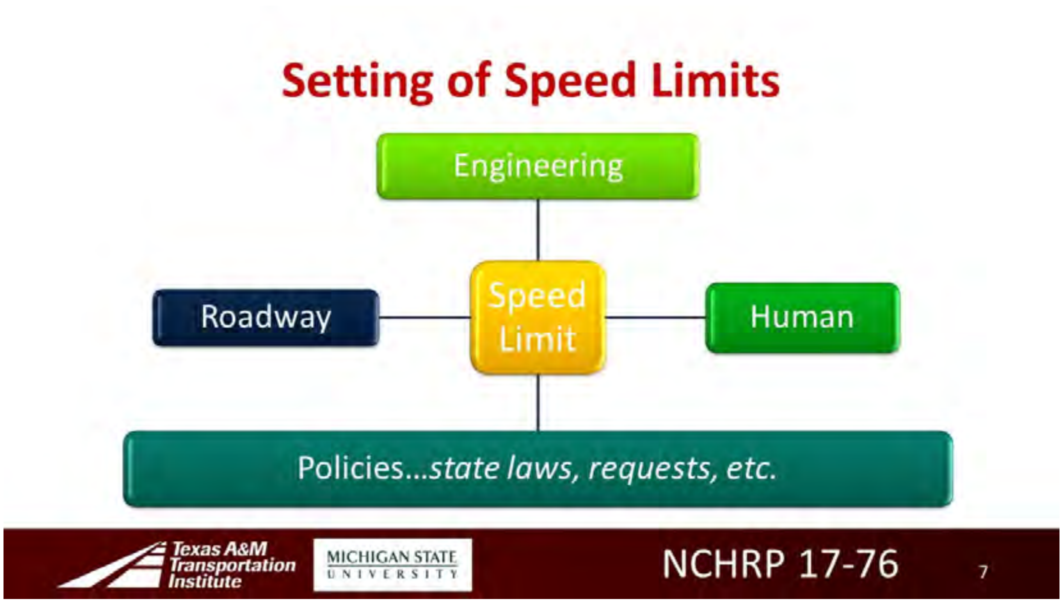
5.

Human factors are another consideration. When using 85th percentile speed as a starting point, you are considering the driver's (human's) interpretation of what is appropriate for the facility.



6.

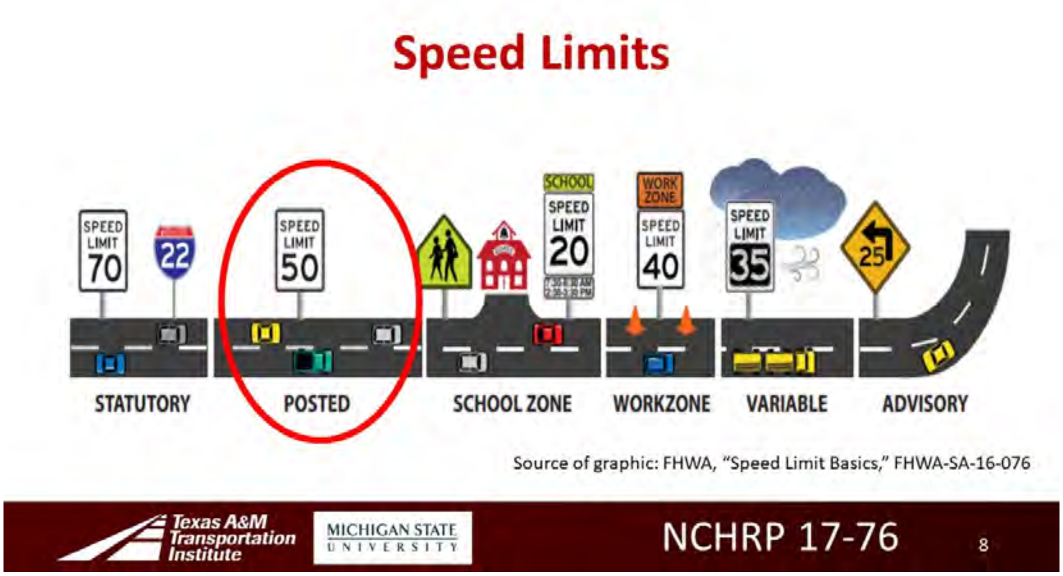
Engineering judgment is used when selecting the roadway factor or the safety factors that will influence your decision along with how much those factor will affect your recommendation.



7.

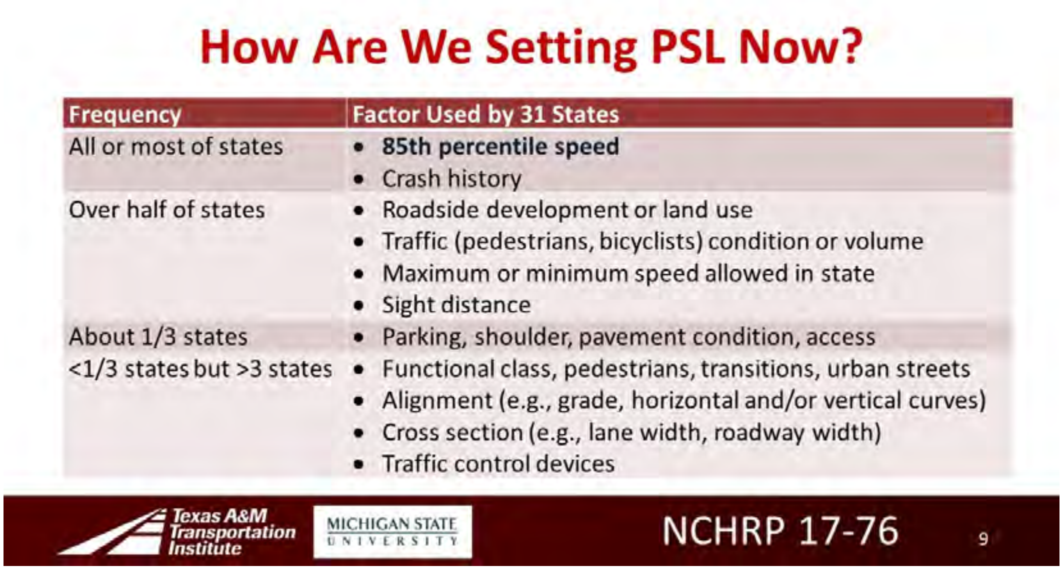
An agency's policy can also be a major factor in the setting of speed limits. Some locations have laws that restrict the posted speed limit to not exceed a certain value for a facility.

The personal experience from some transportation engineers is that politics can influence decisions. Engineers may be under considerable pressure to propose speed limits below the 85th percentile, while a strict, objective, engineering approach might suggest a higher speed limit. While not a desirable situation, this can be the political reality of a job.



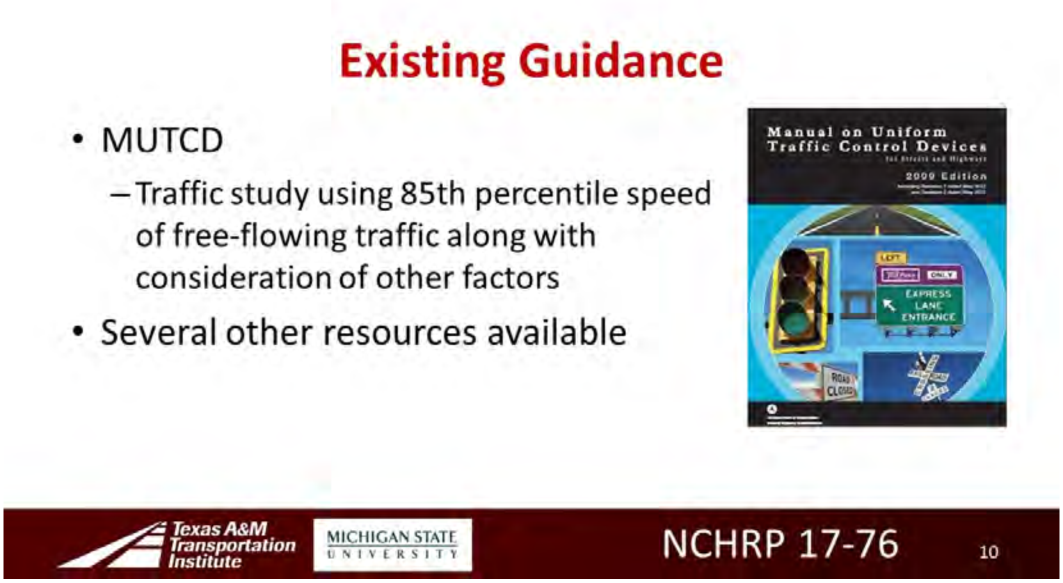
8.

The user guide developed in NCHRP 17-76 focuses on posted speed limits within speed zones. Other speed limits illustrated on this slide such as school zones or advisory speed limits were outside the scope of the 17-76 project.



9.

As part of the NCHRP 17-76 project, the research team reviewed state websites to identify materials that document how to set a posted speed limit. We found 31 documents on the web. Of those documents, all stated that 85th percentile speed is to be used, and most stated that crash history should be considered. Several various factors are also to be considered. For example, about half of the states reviewed noted that roadside development should be considered. The bottom of the slide lists other factors being considered by at least three states, such as alignment or cross section.



10.

While statutory speed limits form the basis for many posted speeds limits, non-statutory speed limits are established by engineering studies. The *Manual on Uniform Traffic Control Devices* (MUTCD) provide some uniformity in setting of non-statutory speed limits. A guiding principle of the MUTCD is that through uniformity, consistent driver expectations can improve safety.

Within Section 2B.13 of the MUTCD are several paragraphs related to the selection of the posted speed limit value including Paragraph 1 (standard), Paragraph 12 (guidance), and Paragraph 16 (option). Other paragraphs within Section 2B.13 focus on statutory speed limits, need for engineering study, requiring limits to be multiples of 5 mph, placement of signs, use of warning signs with speed limit signs, where to conduct speed studies, special speed limits, changeable message signs, and school zones. Relative to setting speed limits, the key paragraphs in Section 2B.13 are:

"01 Speed zones (other than statutory speed limits) shall only be established on the basis of an engineering study that has been performed in accordance with traffic engineering practices. The engineering study shall include an analysis of the current speed distribution of free-flowing vehicles."

"12 When a speed limit within a speed zone is posted, it should be within 5 mph of the 85th percentile speed of free-flowing traffic."

"16 Other factors that may be considered when establishing or reevaluating speed limits are the following:

- Road characteristics, shoulder condition, grade, alignment, and sight distance,
- The pace,
- Roadside development and environment,
- Parking practices and pedestrian activity, and
- Reported crash experience for at least a 12-month period."

11.

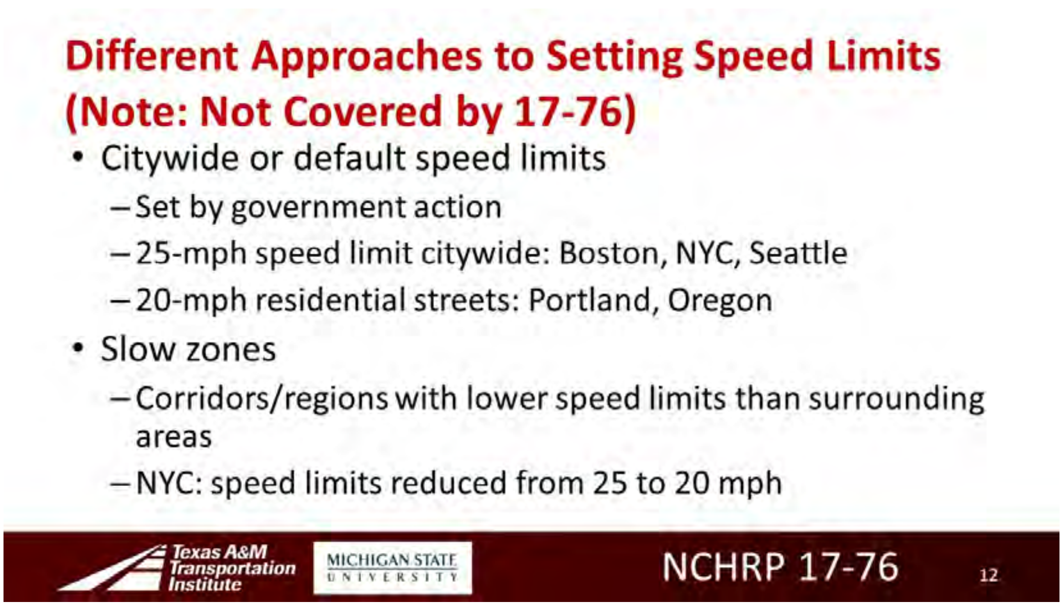
Recently, the speed limit debate has increased with two publications. In March 2017, the National Association of City Transportation Officials (NACTO) released a policy statement. One of the action items in that statement would "permit local control of city speed limits." They recommend "state rules or laws that set speed limits at the 85th percentile speed should be repealed."

In July 2017, the National Transportation Safety Board (NTSB) published a report on speeding (*Reducing Speeding-Related Crashes Involving Passenger Vehicles*). That document included several recommendations for reducing speed-related crashes including two recommendations directed to the Federal Highway Administration for changes to the MUTCD (p. 57):

- Revise Section 2B.13 of the *Manual on Uniform Traffic Control Devices* so that the factors currently listed as optional for all engineering studies are required, require that an expert system such as USLIMITS2 be used as a validation tool, and remove the guidance that speed limits in speed zones should be within 5 mph of the 85th percentile speed (H-17-27).
- Revise Section 2B.13 of the *Manual on Uniform Traffic Control Devices* to, at a minimum, incorporate the safe system approach for urban roads to strengthen protection for vulnerable road users (H-17-28).

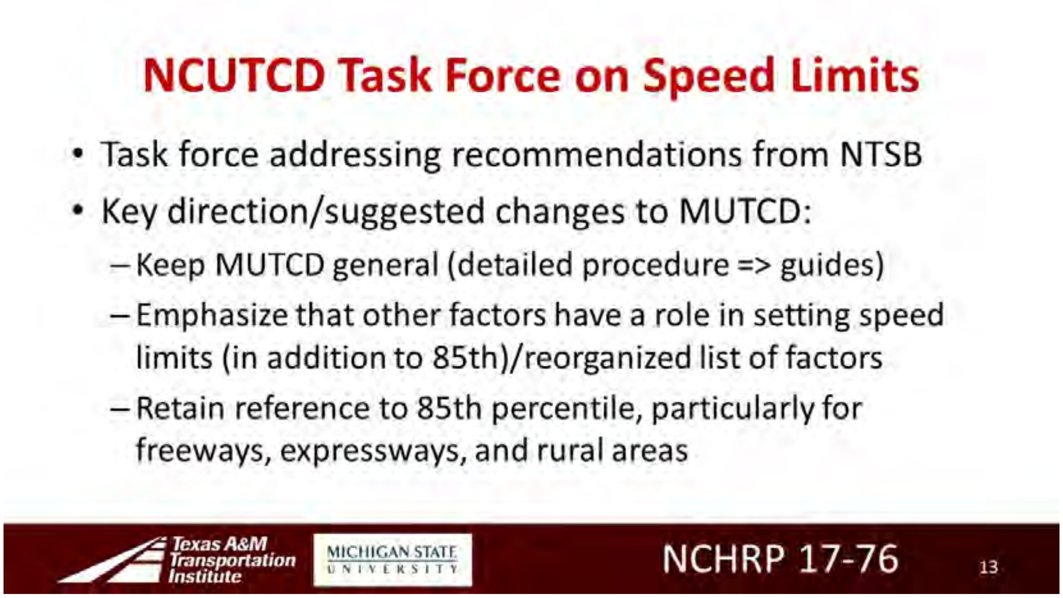
Documents referenced:

- NACTO (2017). "Creating Safe, Sustainable, Multi-modal Urban Transportation." National Association of City Transportation Officials. www.nacto.org.
- NTSB (2017). *Reducing Speeding-Related Crashes Involving Passenger Vehicles.* NTSB/SS-17/01 PB2017-102341. National Transportation Safety Board.



12.

Other new approaches to setting speed limits have been implemented recently, including citywide or default speed limits and implementing slow zones. These approaches are outside of the NCHRP 17-76 scope but are being providing as an example of how posting speed limits is evolving.

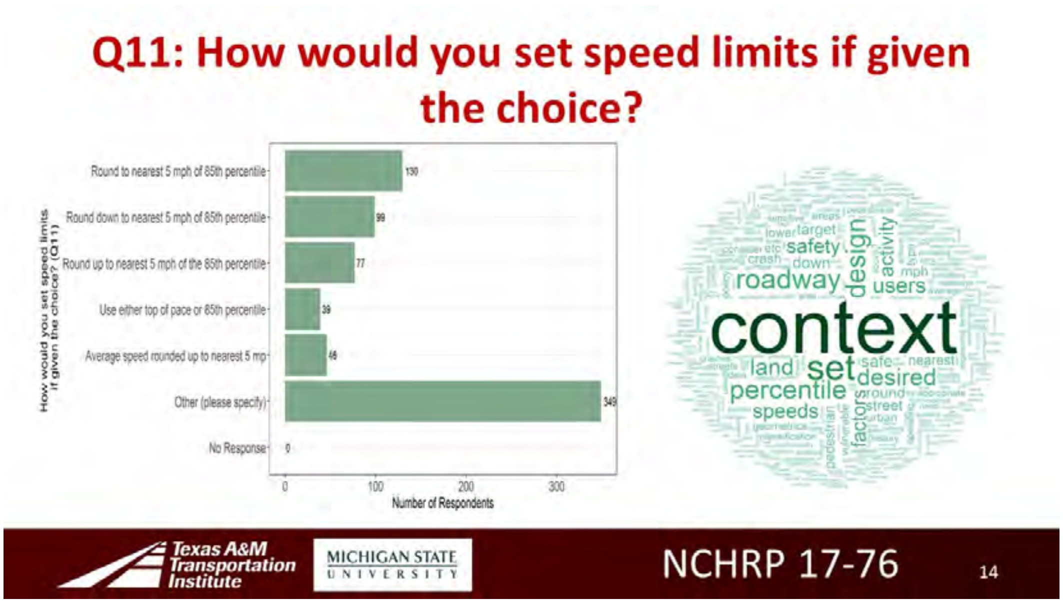


13.

To address the NTSB recommendations, the National Committee on Uniform Traffic Control Devices (NCUTCD), Regulatory and Warning Signs Technical Committee established a task force to explore current and potential approaches to the setting of posted speed limits. The task force started the process by creating a survey to gather an understanding of how practitioners actually applied current practices in setting speed limits and queried their opinions on the topic. The findings from the surveys were presented to several groups, and discussions were held on the findings and the potential direction that should be taken.

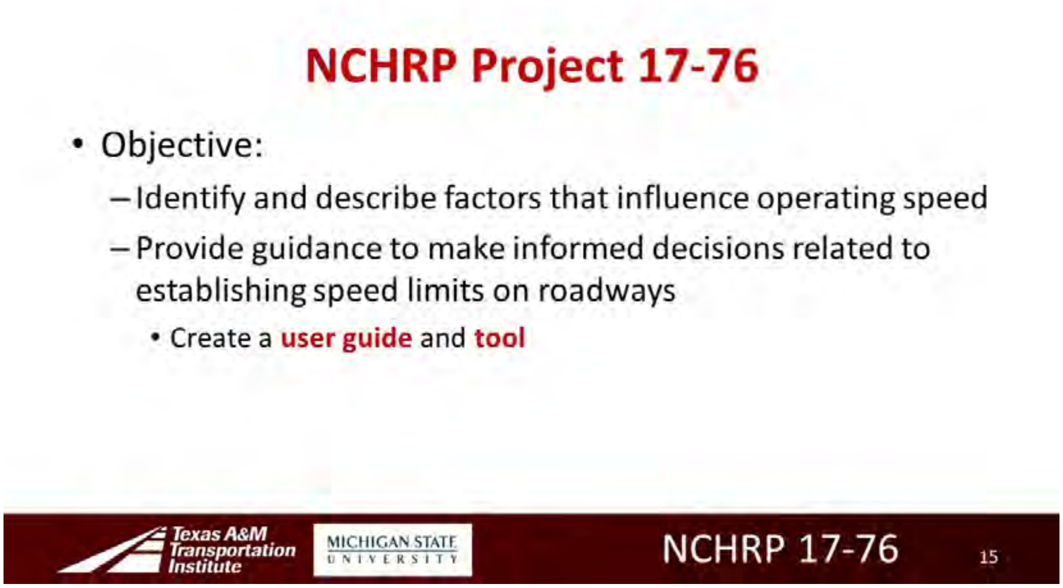
The task force's suggested changes to the MUTCD are shown on this slide and include:

- Changing the MUTCD to reinforce the stated understanding that other factors have a role in setting speed limits (in addition to 85th percentile). Refine the factors in Paragraph 16 and group the paragraphs that speak to setting of speed limits.
- Retaining reference to 85th percentile as a factor that should be considered, particularly for freeways, expressways, and rural areas.
- Keeping the MUTCD broad. While it could be reorganized to better present the material for setting speed limits (by minor reorganization), it should not be expanded into greater detail. The detail should be provided from national research and state/local procedures and promoted by FHWA.
- Not including reference of specific processes, such as USLIMITS2, but promoting this level of detail in state/local procedures and investigating more deeply the reasons why after more than 20 years a small fraction of practitioners use this expert system.



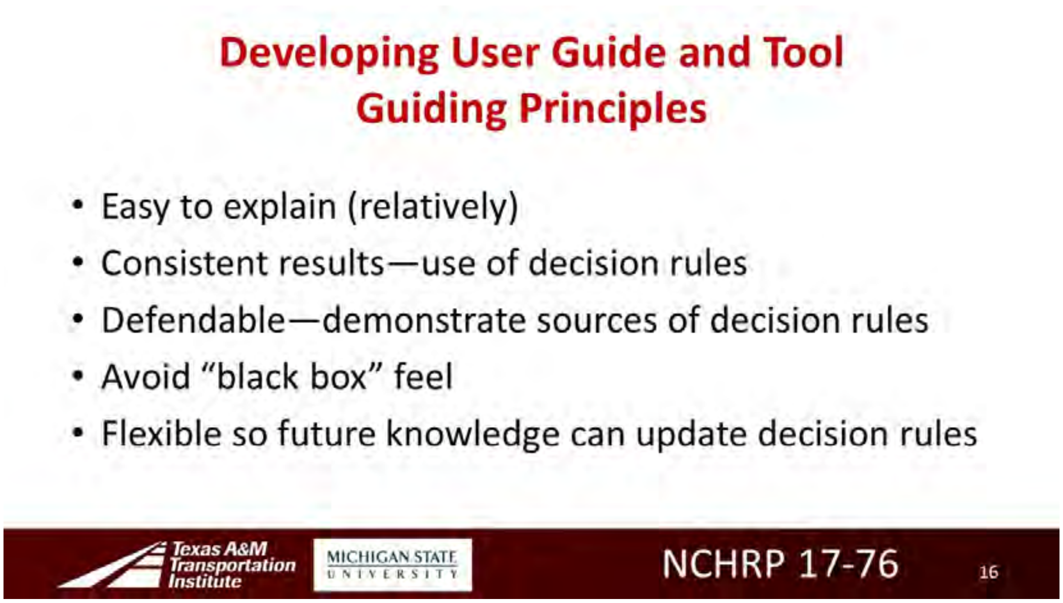
14.

One of the questions from the NCUTCD task force survey was “How would you set speed limits if given the choice?” The provided responses included rounding to nearest 5 mph of 85th, or rounding up or down, etc. Half of the survey participants selected “other” and typed a response. To the right of the graph on this slide is a word cloud where the size of the word reflects the use of that word in the responses. As you can see, the word *context* was used more than any other word. The research team incorporated context into the SLS-Tool.



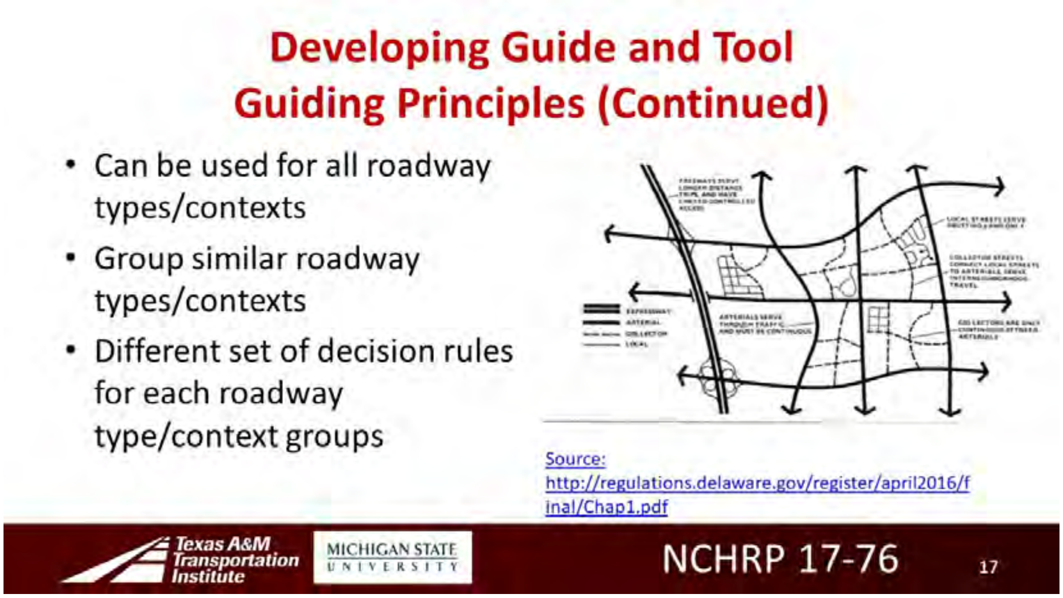
15.

The objectives for the NCHRP Project 17-76 were to identify and describe factors that influence operating speed, and to create a user guide and a tool that will provide guidance in making informed decisions related to establishing speed limits on roadways.



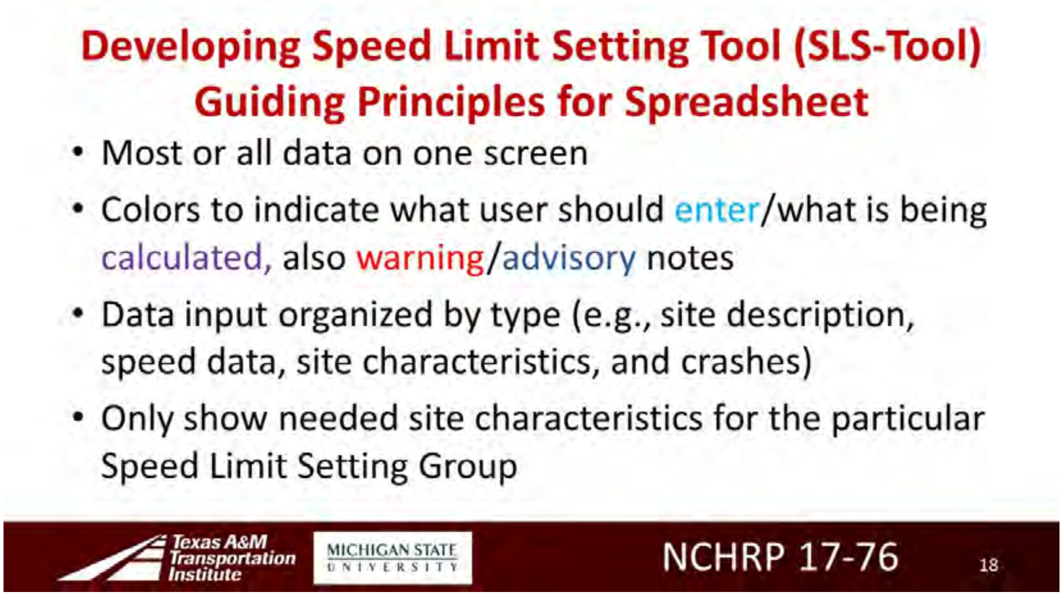
16.

When developing the user guide and the SLS-Tool, the research team established guiding principles. We wanted the procedure to be easy to explain—at least relatively easy to explain because the setting of speed limit is a complex and involved process. The use of decision rules will provide the ability to have consistent results. How those decision rules are established must be defendable, and the research report will document those sources. We wanted the tool to be transparent so the user can trace how a suggested speed limit was reached. We also wanted the tool to be flexible so future knowledge can update the decision rules and the procedure.



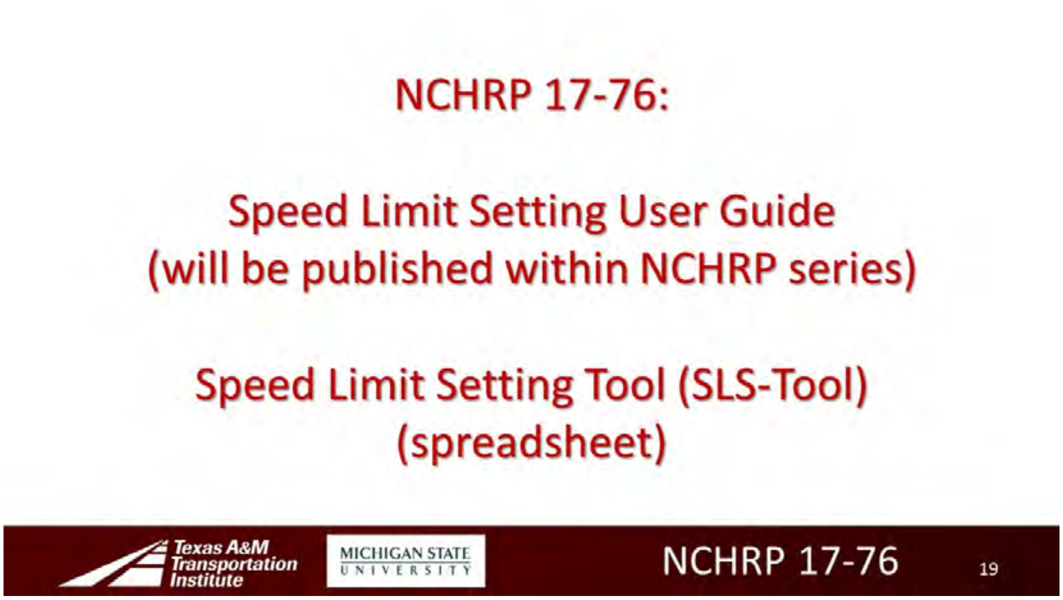
17.

Another guiding principle is that we wanted the SLS-Tool to be able to be used for all roadway types and contexts, rather than forcing a user to obtain different tools. Given the number of roadway types and context, the research team recognized that the decision rules may apply to a groups of roadway types and contexts.



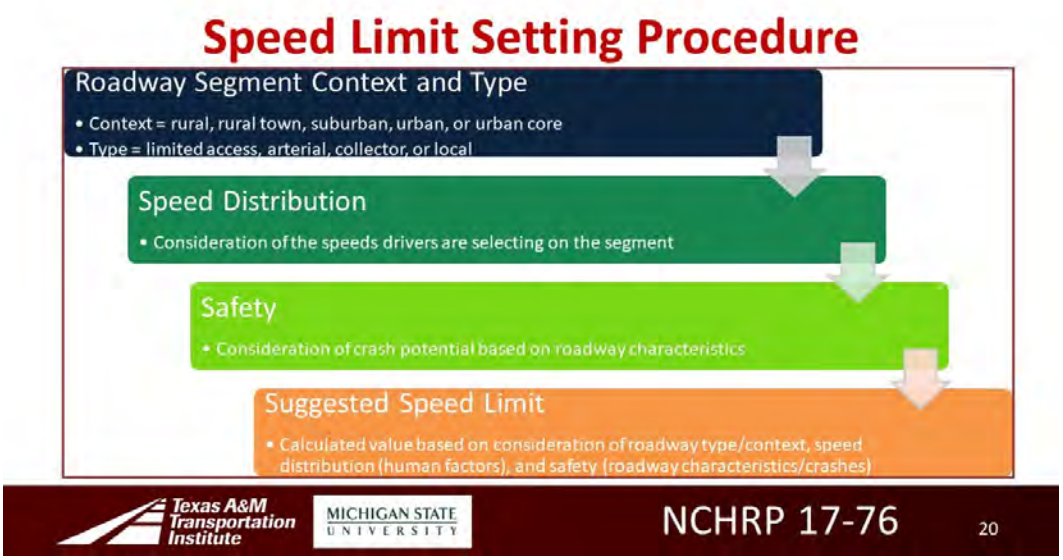
18.

Additional guiding principles for the spreadsheet tool are listed on this slide. The SLS-Tool will have most of the data on one screen and will use colors to show what data needs to be provided versus warnings or the suggested speed limit. Per requirement of the contract, the tool was to be spreadsheet based.



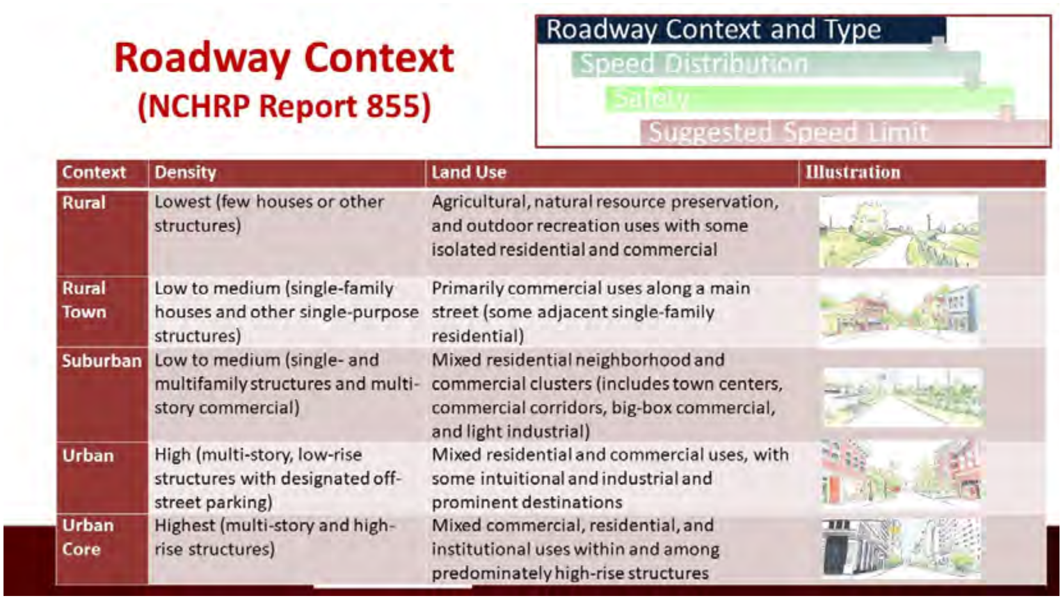
19.

At the time of this workshop, we anticipate that the user guide will be published within the NCHRP series and the research report will be a web-only document. The user guide will be accompanied by the SLS-Tool.



20.

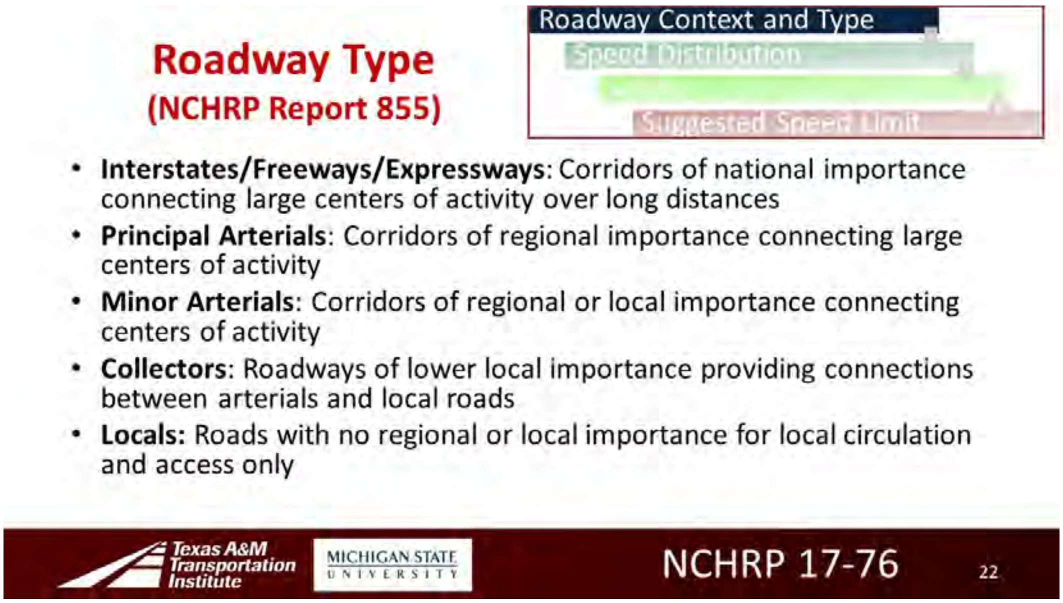
Overall, the development of the suggested speed limit follows the four steps shown on this slide. You start with identifying the roadway segment's context and type. The user then enters the existing operating speed to consider the speeds drivers are selecting for the segment. The crash experience or potential is the next step within the procedure, resulting in a final suggested speed limit for the segment. The next slides will go into details for each step.



Context	Density	Land Use	Illustration
Rural	Lowest (few houses or other structures)	Agricultural, natural resource preservation, and outdoor recreation uses with some isolated residential and commercial	
Rural Town	Low to medium (single-family houses and other single-purpose structures)	Primarily commercial uses along a main street (some adjacent single-family residential)	
Suburban	Low to medium (single- and multifamily structures and multi-story commercial)	Mixed residential neighborhood and commercial clusters (includes town centers, commercial corridors, big-box commercial, and light industrial)	
Urban	High (multi-story, low-rise structures with designated off-street parking)	Mixed residential and commercial uses, with some intuitional and industrial and prominent destinations	
Urban Core	Highest (multi-story and high-rise structures)	Mixed commercial, residential, and institutional uses within and among predominately high-rise structures	

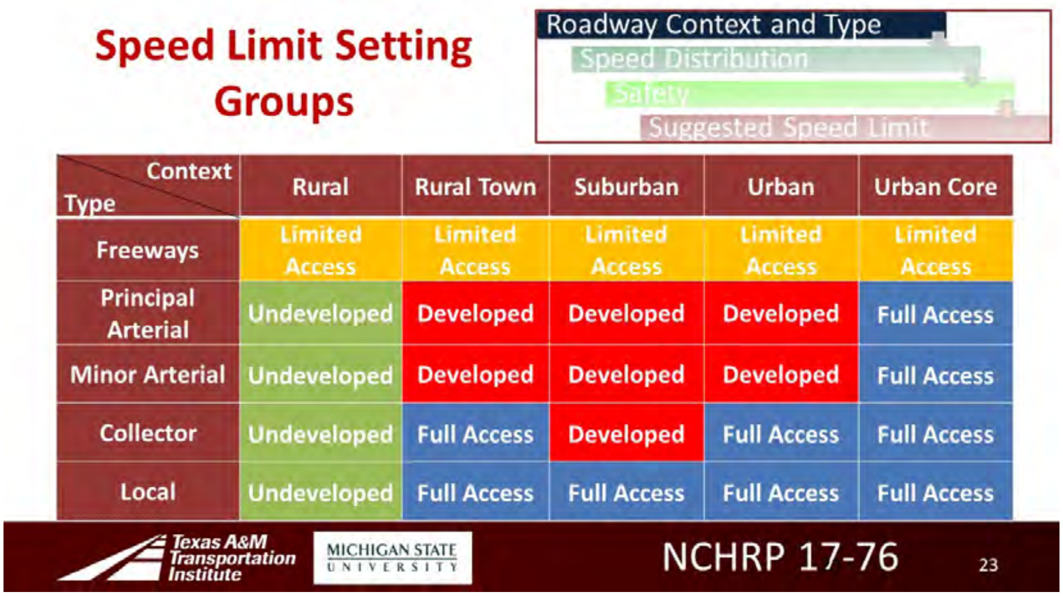
21.

The roadway context uses the Expanded Functional Classification System developed as part of NCHPR Report 855. It includes five roadway contexts as shown on this slide.



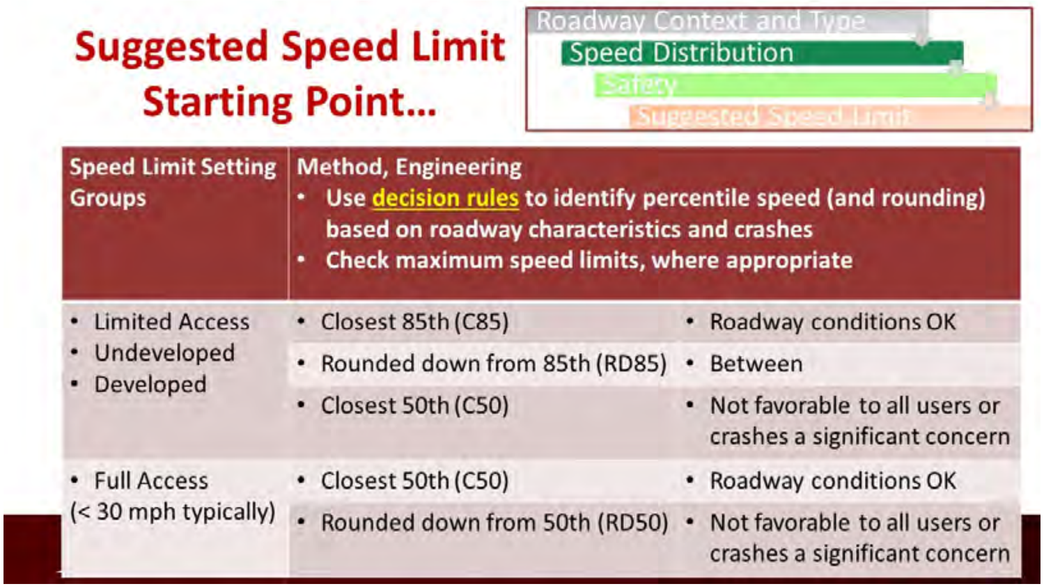
22.

The user identifies the roadway type, again using the definitions provided in *NCHRP Research Report 855*. A brief description is provided on this slide.



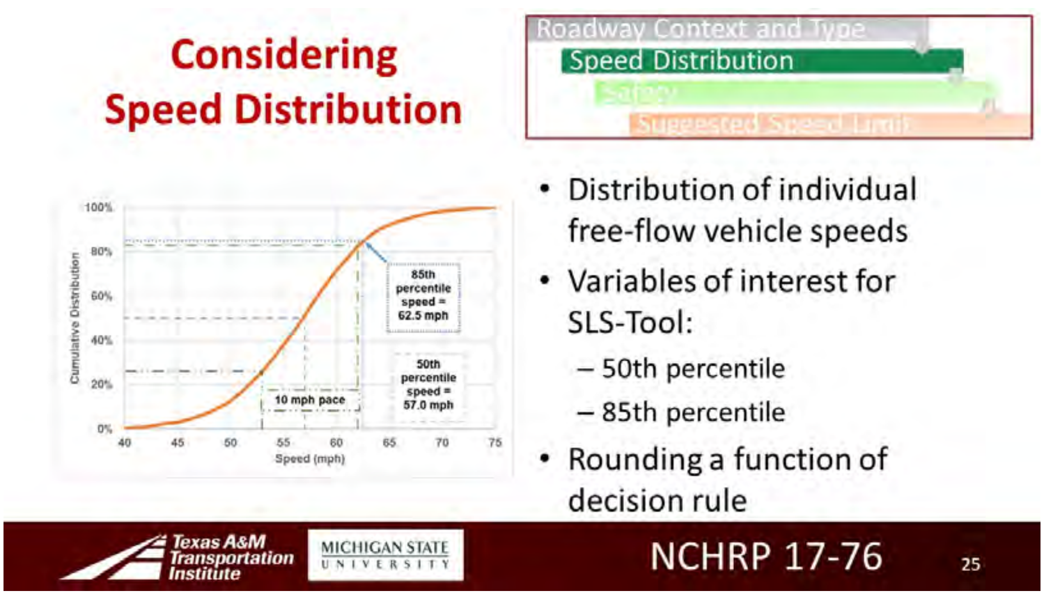
23.

The combination of five roadway types and five roadway contexts results in a matrix with 25 cells. When reviewing these cells, it is reasonable that the decisions rules used for some of the cells would be the same. This slide shows the Speed Limit Setting Groups identified by the research team. The groups include **Limited Access** for freeways and **Undeveloped** for all rural roadway contexts except freeways. How to groups the remaining cells into categories led to several discussions within the research team, the panel, and other subject matter experts. This slide shows the final recommendation where two additional groups, **Developed** and **Full Access**, are established.



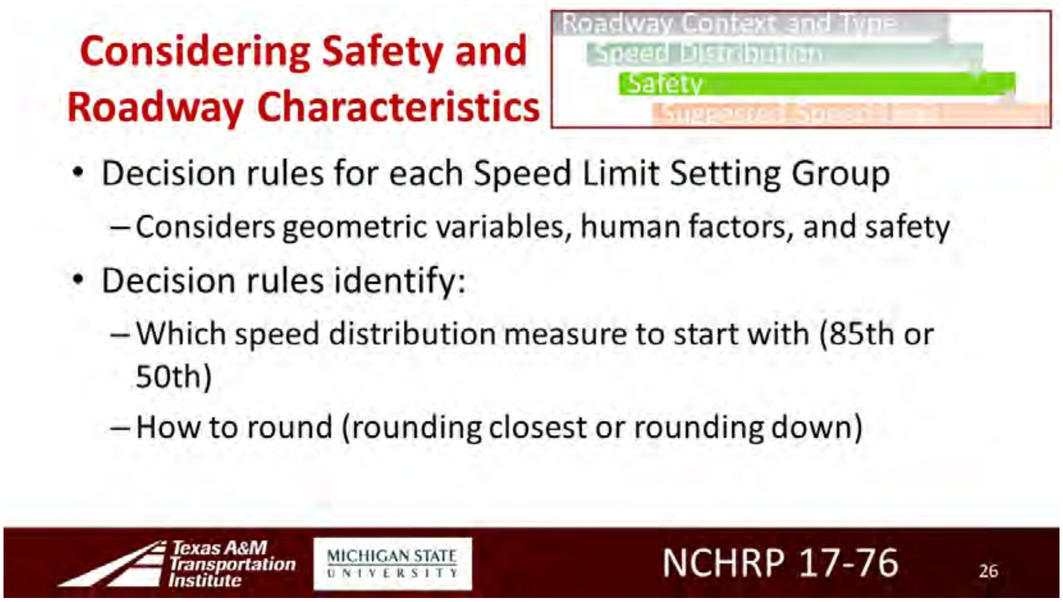
24.

The driver's operating speed, as measured by the 85th percentile speed and the 50th percentile speed, is used as starting points for identifying the suggested speed limit. How to round the appropriate speed is based on decisions rules that consider roadway characteristics and crashes. The procedure also includes a maximum speed limit check, where appropriate. Similar to USLIMITS2, the research suggested that most roadway context/type combinations consider three percentile/rounding groups: closest 85th, rounded down 85th, and closest 50th. The closest 85th would be used when roadway conditions and safety are acceptable. When roadway conditions or safety is not favorable to all users or a concern, the other extreme of closest 50th is suggested. The rounded down 85th would be used for between conditions. Full Access as a roadway context/type group only uses the 50th percentile speed distribution. Full Access would have speed limits of 35 mph or less.



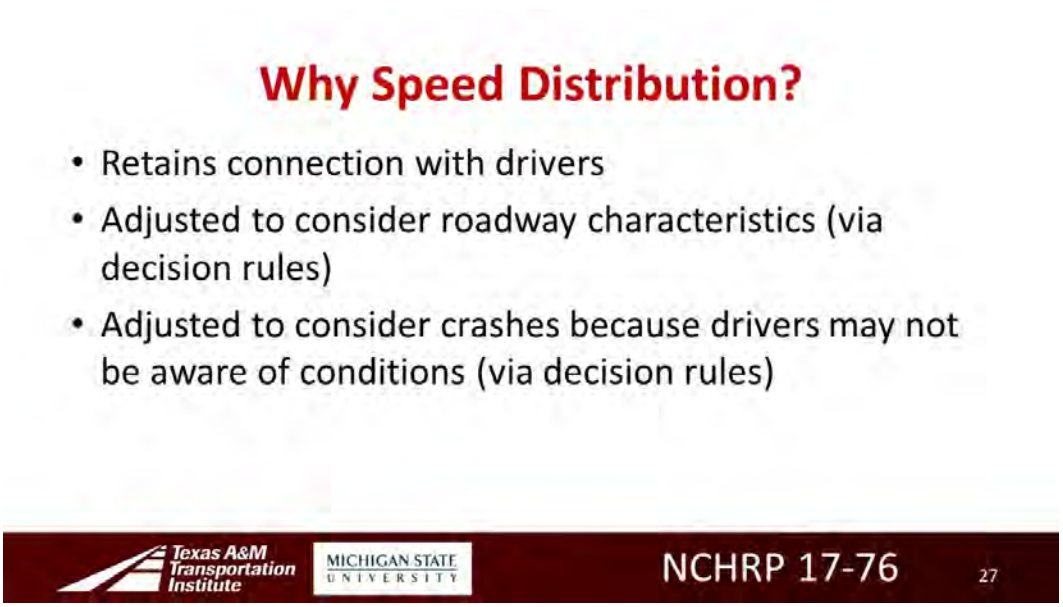
25.

Speed distribution is obtained by measuring the speed of free-flow vehicles.



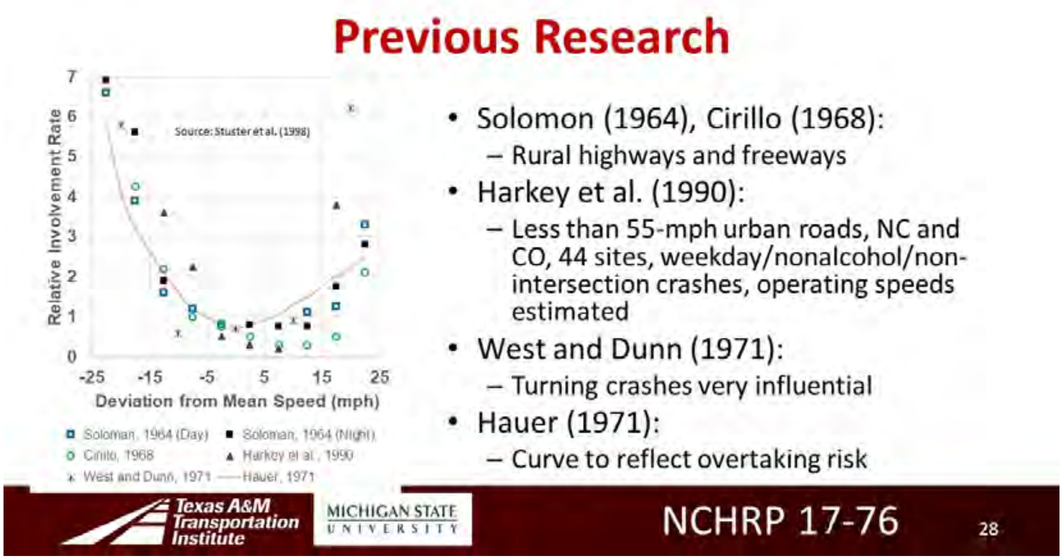
26.

Safety is considered through the provision of crashes. It is also considered in the decision rules when a geometric variable has been shown through other research to be associated with more crashes.



27.

The research team has been asked why the SLS-Tool uses speed distribution. The research team included speed distribution to retain a connection with drivers. The speed distribution is adjusted to consider roadway characteristics and crashes via the decision rules.



28.

The graph shows the relative rate of involvement of being in a crash when compared to the average speed. It is based on six studies (1968-1990). The lowest point on the curve is where the relative involvement rate is lowest: some studies found that point to be about 7 mph higher than the average speed (near the 85th percentile), and others found it to be closest to the average speed of the traffic stream.

Involvement rate is relatively low at 85th percentile speed, which has been the key variable for many methods of setting speed limits. Many guidelines suggest starting with 85th and rounding down depending upon conditions.

The gray u-shape curve reflects work by Hauer that considers the rate at which motorists experience overtakings. You minimize the number of motorists who catch up or overtake you and the number of vehicles that you catch up with or overtake by traveling at the median speed. There appears to be a 10-15 mph band of speeds where accident risk is minimal.

To effectively manage crash risk, the speed limit should be set within the low-risk region.

It should be noted that the speed of the crash-involved vehicles is rarely known very accurately. The study by West and Dunn is probably the most reliable; turning vehicles were excluded; they relied on multidisciplinary teams to investigate the crashes and had speed sensors on some of the roads.

There are numerous factors that can confound the results. For example, younger drivers, because of their inexperience, tend to have higher crash rates but also tend to drive faster than average. Older drivers, who as a group also have higher than average crash rates, tend to driver slower.

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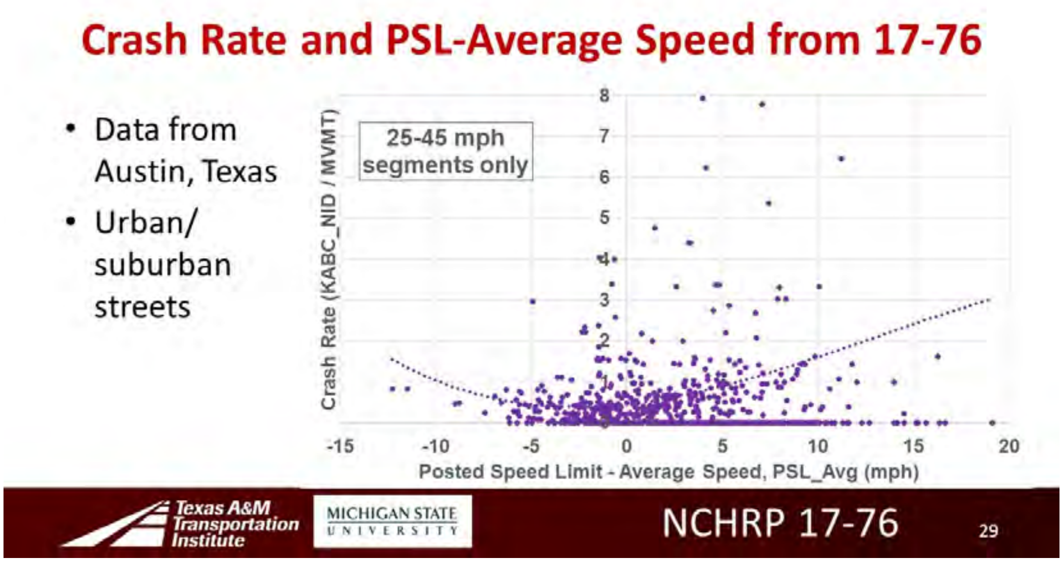

29.

This graph shows the relationship between crash rate and the difference between posted speed limit and average speed for 649 sites in Austin, Texas. The dataset represents urban and suburban streets. Speed data were obtained from traffic counters either installed by the research team or installed by the city when responding to requests for traffic calming or changes in posted speed limits or other needs.

A trend line was added to aid in seeing the relationship between crash rate and the difference between posted speed limit and average speed. The minimum crash rate is occurring near the point where the majority of drivers are driving at the posted speed limit.

While other research has suggested setting the posted speed limit at the 85th percentile, this study indicates that setting urban/suburban streets closer to the 50th percentile will result in minimizing crashes.

The study is also supporting the goal of minimizing the variation in speeds. We prefer drivers to be driving a uniform speed. The trend line demonstrates that when speeds are notably difference from the average speed—either higher or lower—more crashes can be expected.

There are several cautions with this finding. It represents data for one city. Additional studies should be conducted to validate this finding for urban/suburban streets. The speed limit range included residential streets and higher-speed arterials. It is preferred to have unique results for each roadway type; however, we do not have an adequate number of sites to permit such an analysis. A larger study is needed.

Source of Data for Upcoming Slides

State	Urban Arterial	Urban Collector	Urban Local	Grand Total
CA		116		116
IL		93	62	155
NH	10	48	8	66
TX	133	182	116	431
Other states	51	163	9	223
Grand total	194	486	195	875

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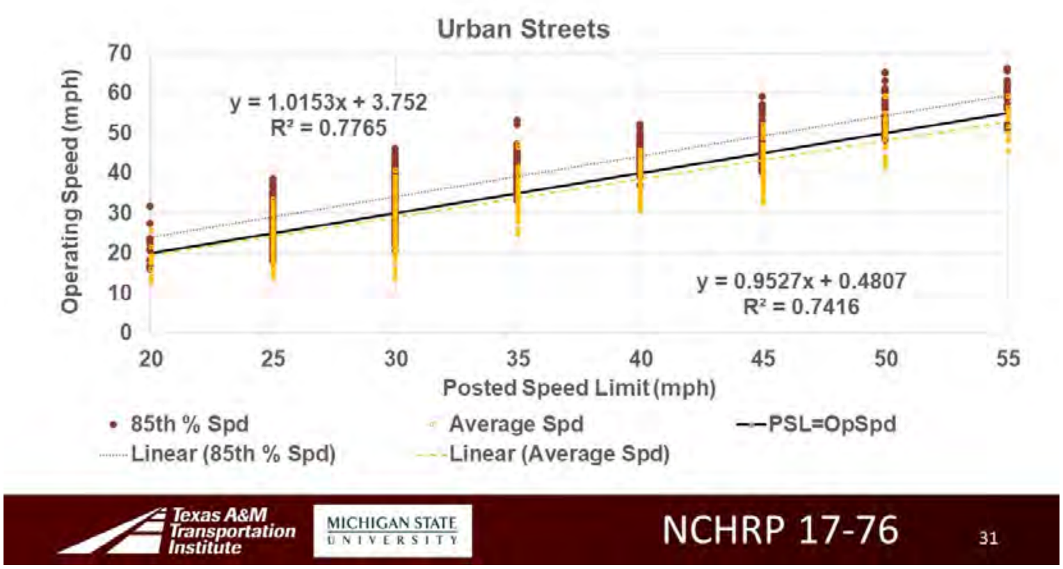
30.

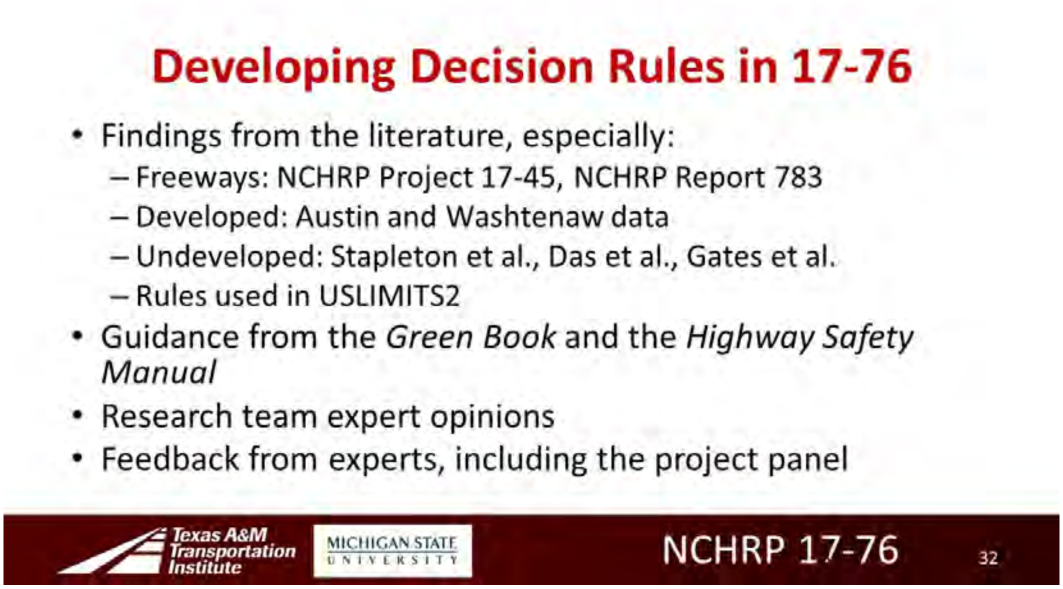
In addition to the hundreds of operating speed data available from the Austin, Texas, dataset, the research team has been provided speed limit studies for several other sites. As shown on this slide, slightly less than half of our sample is from Texas, and more than half is from other states.



31.

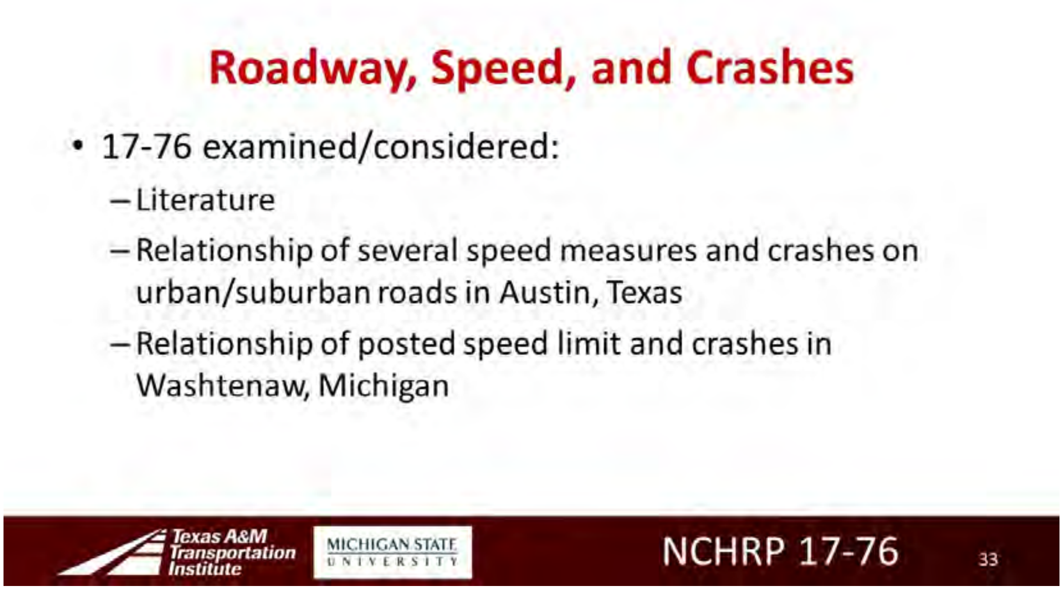
This slide shows the 85th and average speed data for 875 speed studies. The yellow squares are the average speed on the roadway for the given posted speed limit, and the red dot is the 85th percentile speed for that site. The graph also shows trendlines for the 85th percentile data with a red dotted line and the average speed with a yellow dashed line. The solid black line represents the condition when the operating speed would equal the posted speed limit.

The graph illustrates several relationships. First, since all the trend lines have an upward slope, it demonstrates that overall higher posted speed limits are associated with higher operating speeds. Stated in another manner, the number on the speed limit sign does matter, and it does have a relationship with the operating speed. A second relationship that can be seen is that there is a wide range of operating speeds for a given posted speed limit, which indicates that there are other factors that are influencing the operating speed of drivers in addition to the posted speed limit number.



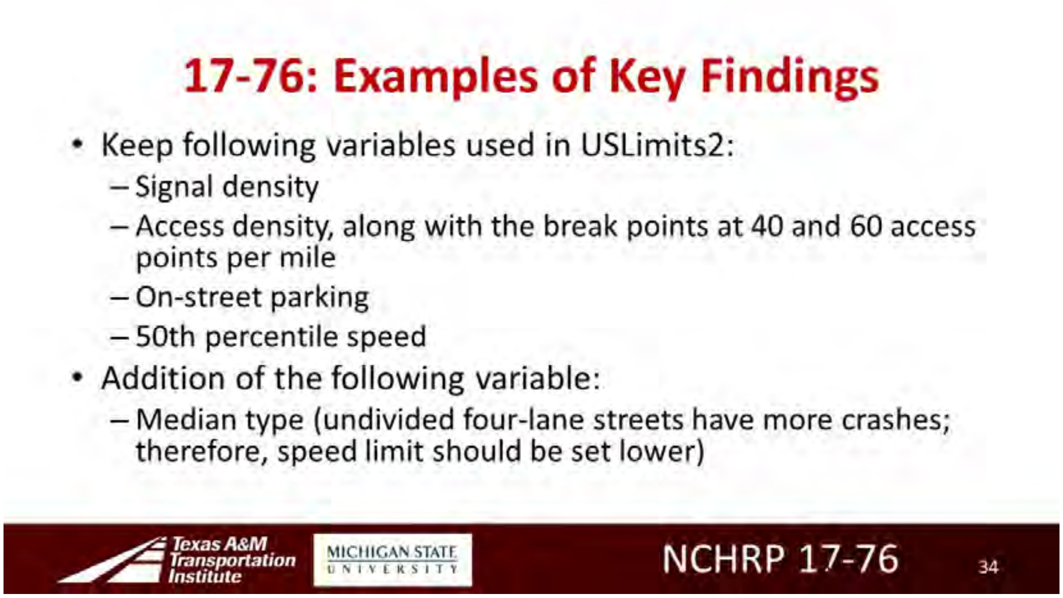
32.

The decision rules used in the SLS-Tool were developed based on research findings, consideration of information in the AASHTO *Green Book* and *Highway Safety Manual*, the research team's expert opinions, and feedback from experts including the project panel.



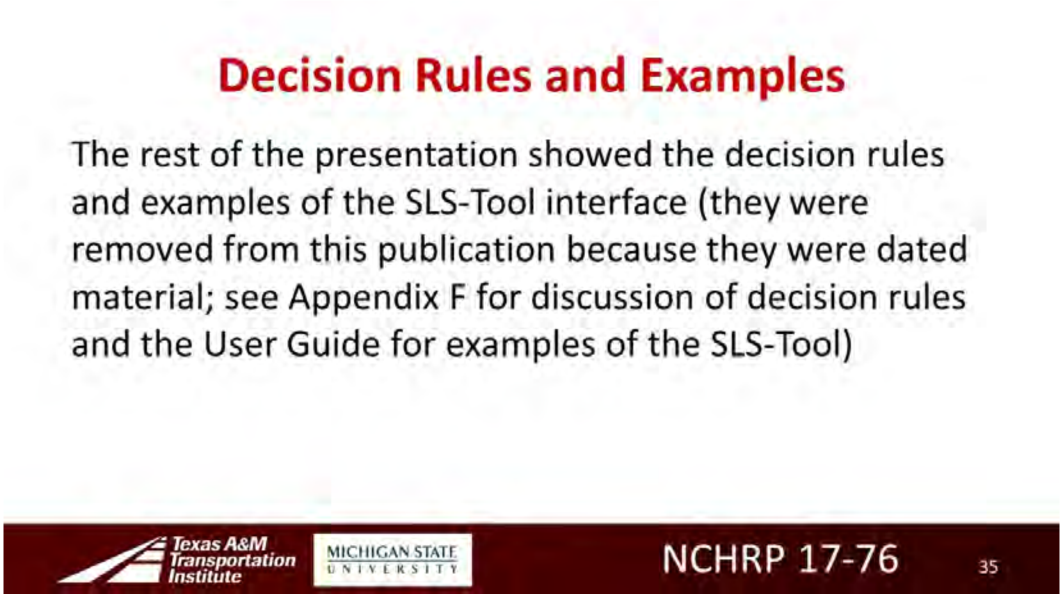
33.

As part of 17-76, the research team reviewed the literature and key reference documents like the *Highway Safety Manual*. Because fewer insights are available for urban/suburban roads, NCHRP 17-76 focused Phase II research efforts on those functional class roads. Two databases were created. The one using Washtenaw, Michigan, data (e.g., Ann Arbor) included roadway characteristics, posted speed limits, and crash data. The other database used Austin, Texas, data. The City of Austin had posted several of its speed studies online, and the research team obtained that data along with collecting additional speed data, especially on four-lane streets.



34.

This slide shows examples of the key findings from the NCHRP 17-76 Phase II research efforts. USLIMTS2 included decisions rules based on several variables. Based on NCHRP 17-76 research efforts, the research team recommended keeping for the Developed SLSG signal density, access density, and on-street parking variables. The research team suggested the inclusion of median type when the cross section has four or more lanes and the median type is undivided (i.e., none; note TWLTL is not considered to be in the undivided median type group). The NCHRP 17-76 research also expanded upon the use of the 50th percentile speed.



35.

The rest of the presentation showed the decision rules and examples of the tool interface (they were removed from this publication because they were dated material; see Appendix F for discussion of decision rules and the user guide for examples of the SLS-Tool).

36.

Thank you for your time.

ABBREVIATIONS

Abbreviation	**Term**
4U	Four-lane undivided
5T	Four lanes and a TWLTL
AADT	Annual average daily traffic (veh/d)
AADTR	AADT estimate from FHWA HPMS or SEMCOG system-wide data rounded to nearest 10
AASHTO	American Association of State Highway and Transportation Officials
Abs(PSL−Avg)	Absolute value of posted speed limit minus average speed (mph)
AccessDen	Data for DrvUsigPerMileBoth regrouped into three levels: LT40=less than 40 driveways/unsignalized intersections per mile, 40to60=between 40 and 60 driveways/unsignalized intersections per mile, and GT60=greater than 60 driveways/unsignalized intersections per mile
ACUB	Adjusted census urban boundary
ADA	Americans with Disabilities Act
ADT	Average daily traffic
Beg_IT_Legs	Number of legs for intersection at beginning of segment
BIC	Bayesian information criterion
Bike_1yes	Bike lane presence: 1=yes, 0=no
Bike_Lane	Bike lane presence: 1=yes, 0=no
Bus	Bus stop presence collected via “Places” in Google Earth: 1=yes, 0=no
C50	The 5-mph increment that is closest to the 50th percentile speed
C85	The 5-mph increment that is closest to the 85th percentile speed
CBD	Central business district
CMF	Crash modification factor
CoefVar	Coefficient of variation of speed
CRIS	Crash Records Information System
Curb_1yes	Is curb present (for at least 50% of segment): yes=1, no=0
Develop	Development: Com/Ret/Ind (for commercial, retail, or industrial), Residential, or Rural/Parks (for areas with park-like or rural-like settings)
DOT	Department of transportation
DrvUsigPerMileBoth	Per mile rate for driveways (residential and commercial) and public intersections along the segment in both directions
End_IT_Legs	Number of legs for intersection at ending of segment
F&I	Fatal and injury crashes (KABC)
FCS	Functional classification system
FHWA	Federal Highway Administration
ft	Feet
FuncClass	Revised National Functional Class Code
GEE	Generalized estimating equations
GLM	Generalized linear model
GPS	Global positioning system
HCM	Highway Capacity Manual
Horz_1tan	Horizontal alignment: 1=straight (tangent), 0=some horizontal curvature

Abbreviation	**Term**
HPMS	Highway Performance Monitoring System
HSIS	Highway Safety Information System
HSM	Highway Safety Manual
Int_Type1	Description of End Point #1: signal, all-way stop, stop, roundabout, or other break point
Int_Type2	Description of End Point #2: signal, all-way stop, stop, roundabout, or other break point
ISW	Inside shoulder width (ft)
K	Constant associated with the confidence level (1.645 for 95% confidence)
KABC	Fatal and injury crash severity levels
KABCO	All crash severity levels
km/h	Kilometers per hour
Len_mi	Segment length (mi)
LnWdG	Lane width (ft) for the segment grouped into: N=Narrow (7, 8, 9, or 10 ft), T=Typ (11 or 12 ft), W=Wide (13 ft or more)
LOS	Level of service
LW	Lane width
M	Exposure (100 million vehicle miles)
Median	Median type: none (undivided), raised (also depressed), TWLTL (also delineated)
MedWidth	Typical or average median width for the segment (ft)
MGF	Michigan Geographic Framework
mi	Miles
mph	Miles per hour
MPO	Metropolitan planning organization
MSP	Michigan State Police
MSU	Michigan State University
MUTCD	Manual on Uniform Traffic Control Devices
MVM	Million vehicle miles
N	Number of lanes
NACTO	National Association of City Transportation Officials
NB	Negative binomial
NCHRP	National Cooperative Highway Research Program
NCUTCD	National Committee on Uniform Traffic Control Device
NDS	Naturalistic Driving Study
NID	Not intersection and driveway
NPMRDS	National Performance Management Research Data Set
NTSB	National Transportation Safety Board
Num_Lanes	Number of through lanes (not including exclusive turn lanes)
NumSigInt	Number of signalized intersections along segment, including the signals at the begin or end of the segment
OnStreet_Parking	On-street parking: yes=1 or no=0
Pace	Percent of vehicles in 10-mph pace for the site (%)
Pace_Bin	Range of the pace

Abbreviation	**Term**
Pace_LV	Lower speed value of 10-mph pace for the site
Pace_Per	Percent of vehicles in 10-mph pace for the site
Pace_UV	Upper speed value of 10-mph pace for the site
PDO	Property damage only
PedAuto	Typical or average distance between the sidewalk and the automobile lane for the segment, sum of the following (when present): parking width, bike width, bike-auto separation, and sidewalk to road separation (ft)
PedCross_1yes	Is a midblock marked pedestrian crossing present within the segment: 1=yes or 0=no
PerOverPSL	Percent of observations over the speed limit for the site (%)
PerOvPSL	Percent of observations over the speed limit for the site (%)
POSTED_SPE	Posted speed limit per SEMCOG system-wide data
PROWAG	Public Rights-of-Way Accessibility Guidelines
PSL	Posted speed limit (mph)
PSL−Avg	Posted speed limit minus average speed (mph)
PSLMinusSped85	Posted speed limit minus 85th percentile speed (mph)
PSL−S85	Posted speed limit minus 85th percentile speed (mph)
R_a	Average crash rate for a given road type, provided by the user or obtained from HSIS tables
R_c	Critical crash rate for a given road type
RD50	The 5-mph increment obtained by rounding down the 50th percentile to the nearest 5-mph increment
RD85	The 5-mph increment obtained by rounding down the 85th percentile to the nearest 5-mph increment
RHiNO	Roadway Highway Inventory Network Offload
RHR	Roadside hazard rating
RoadSurf	Distance between the driving surface edges, calculated as number of through lanes multiplied by average lane width plus median width plus parking widths plus bike widths
RTS	On-road tube site
RU_F_SYSTEM	TxDOT functional classification for street: U3=Urban Other Principal Arterial, U4=Urban Minor Arterial, U5=Urban Major Collector, U6=Urban Minor Collector, U7=Urban Local
RW	Regulatory and Warning Signs Technical Committee
S85−Avg	85th percentile speed minus average speed (mph)
School	School zone presence collected via “Places” in Google Earth: 1=yes, 0=no
SchZone_1yes	School zone presence: 1=yes, 0=no
SEM	Structural equation modeling
SEMCOG	Southeast Michigan Council of Government
SHRP2	Second Strategic Highway Research Program
Sidewalk_1yes	Is a sidewalk present within the segment: 1=yes or 0=no
Site	Unique name for each site, consist of a segment number plus the primary direction for traffic (e.g., NB, SB, EB, or WB)

Abbreviation	**Term**
SLSG	Speed Limit Setting Group
SLS-Procedure	Speed Limit Setting Procedure
SLS-Tool	Speed Limit Setting Tool
Spd85	85th percentile speed (mph)
SpdAve	Average speed for the site (mph)
SpdAve	Average speed (mph)
SpdAve_Hr_Ca.Qa	Average speed per hour per site for both the City of Austin traffic count data and the data collected as part of this research (mph)
SPF	Safety performance functions
SSL	Suggested speed limit
StdSpd	Standard deviation of speeds for the site (mph)
SW	Shoulder width
TCD	Traffic control device
TRB	Transportation Research Board
trk/hr	Trucks per hour
TTI	Texas A&M Transportation Institute
TWLTL	Two-way left-turn lane
TxDOT	Texas Department of Transportation
U3	Urban Other Principal Arterial
U4	Urban Minor Arterial
U5	Urban Major Collector
U6	Urban Minor Collector
veh/d	Vehicles per day
VMT	Vehicle miles traveled
Vol_Day	Volume per day in both directions
vph	Vehicles per hour

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