Texas A&M Transportation Institute

Speed Limits in Texas

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16. Abstract

Posted speed limits (PSLs) are a highly complex issue involving engineering, human factors, and political and societal concerns. On a national level, recent research along with calls to change how speed limit are set, especially for city streets, have generated extensive discussion on future speed limit setting procedures. Within this TxDOT project, the Research Team conducted dialogs with TxDOT districts to learn about the practices and procedures being used, developed a number of products designed to increase the understanding of operating speed and of PSLs, and performed new research into operating speed relationships with roadway characteristics. The developed communication products include videos (one for engineers and one for the public), a pamphlet for public distribution, answers to common questions about speed and speed limits, and a workshop on state and national speed limit setting practices. Review of the literature along with this study’s evaluations confirmed that an increase in the PSL is typically associated with a smaller magnitude increase in operating speed and that higher operating speeds are associated with higher PSLs. Freeway geometric factors, including left and right shoulder widths and distance to downstream and upstream ramps by ramp type (entrance or exit), demonstrated to have a significant impact on operating speed. This study estimates that a strategy that entails modifying geometry, changing the PSL, and varying the level of law enforcement presence within the ranges included in this study may impact freeway operational speeds up to 6.2 mph (depending upon existing conditions along with the changes in the geometry, PSL, and enforcement). An evaluation of speeds on a sample of Texas non-access-controlled highways used speed study data collected by TxDOT and the Research Team within the past 20 years. For all development levels, speeds increased with outside shoulder width and overall roadway width. Suburban roadway factors resulting in reduced operating speed included driveway/access point density, signal density, presence of sidewalk, and higher traffic volumes or truck percentages.

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DISCLAIMER

This research was performed in cooperation with the Texas Department of Transportation (TxDOT) and the Federal Highway Administration (FHWA). The contents of this report reflect the views of the authors, who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official view or policies of FHWA or TxDOT. This report does not constitute a standard, specification, or regulation. This report is not intended for construction, bidding, or permit purposes. The engineers in charge of the project were Kay Fitzpatrick, P.E. (TX #86762) and Steve Venglar, P.E. (TX #84027).

The United States Government and the State of Texas do not endorse products or manufacturers. Trade or manufacturers' names appear herein solely because they are considered essential to the object of this report.

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TABLE OF CONTENTS

Page

LIST OF FIGURES

Page

LIST OF TABLES

Page

CHAPTER 1: INTRODUCTION

BACKGROUND

Speed limits are among the most visible and routinely enforced traffic control devices motorists encounter in their everyday driving. Given this high degree of exposure and scrutiny, speed limits—and the practices and procedures used to develop them, inform drivers, and help enforce them—must be appropriate for their environment, defensible from an engineering and legal perspective, and comprehensible to the full range of mobility and safety stakeholders. In summary, posted speed limits (PSLs) are a highly complex issue involving engineering, human factors, and political and societal concerns.

PROJECT OBJECTIVES AND SCOPE

This research project was designed to increase the profession's understanding of the fundamental relationships between posted and operating speed, identify procedures for the establishment of PSLs, identify technologies that increase driver awareness and comprehension, and provide content to support external and internal Texas Department of Transportation (TxDOT) dialog about speed limits and their development for all roadway environments. The research team produced several products including the following:

- **Video**. Two videos were developed to address two very different audiences. The video oriented to the public focused on the steps used to study speed and roadway data and implement a new PSL. A second video was created to communicate the process for performing a speed study for public agency stakeholders and engineering staff.
- **Pamphlet**. The performing agency designed the speed management pamphlet to clearly communicate how speed limits are set based on collected data and context-sensitive roadway and driving environment factors. The document is intended to replace the existing receiving agency informational pamphlet entitled "Setting Speed Limits." A copy of the pamphlet is in Appendix A.
- **Talking Points**. The talking points took the form of answers to questions to increase awareness among TxDOT staff regarding speed limit setting procedures and means for promoting speed limit compliance. The questions and answers are in Appendix B.

- **Workshop.** Materials were developed that can be used to train traffic engineers and staff on speed studies. The initial workshop was held on April 19, 2022.
- **Speed Management Techniques**. Current TxDOT practices with regards to implementing speed management techniques are in Appendix C.
- **Suggested Revisions**. Suggested revisions to TxDOT's *Procedures for Establishing Speed Zones* manual (*1*) are provided in Appendix D.

With respect to increasing the profession's understanding of the relationships between posted and operating speed, the research focused on two areas: freeways and higher speed rural/suburban highways.

ORGANIZATION OF REPORT

This report consists of seven chapters and four appendices. In addition to this introductory chapter, the report contains the following material:

- Chapter 2 provides an overview of current practices with regards to the setting of PSLs.
- Chapter 3 provides the literature review on the relationship among operating speed, roadway geometric design, vehicle volume, and PSL for higher speed roads.
- Chapter 4 summarizes the findings from dialogs conducted with 11 TxDOT districts.
- Chapter 5 evaluates the relationships among operating speed, roadway geometric design, vehicle volume, and PSL for Texas freeways.
- Chapter 6 evaluates the relationships among operating speed, roadway geometric design, vehicle volume, and PSL for Texas highways with rural, ex-urban, or suburban development.
- Chapter 7 summarizes the researchers' findings and conclusions, and it provides recommendations for future action.
- Appendix A contains a copy of the "Setting Speed Limits" pamphlet.
- Appendix B answers several speed limit related questions identified during the project that can be used to increase awareness among TxDOT staff regarding speed limit setting procedures and means for promoting speed limit compliance.

- Appendix C lists the common TxDOT implementation order for speed management techniques.
- Appendix D summarizes suggested revisions to the *Procedures for Establishing Speed Zone* manual (*1*).

CHAPTER 2: SETTING OF POSTED SPEED LIMITS

OVERVIEW ON SETTING POSTED SPEED LIMITS

Current Practices within Texas and the Nation

Within Texas, the *Texas Manual on Uniform Traffic Control Devices* (TxMUTCD) (*2*) and the TxDOT *Procedures for Establishing Speed Zones* (*1*) are used in the setting of speed limits. The *Manual on Uniform Traffic Control Devices* (MUTCD) (*3*) and the TxMUTCD provides guidance in the setting of non-statutory speed limits. The selection of the speed limit value is via an engineering study. The speed limit is to be within 5 mph of the measured 85th percentile speed for the roadway segment. Several factors can be considered for adjusting the 85th percentile speed such as road characteristics, roadside development, parking practices, pedestrian activity, and crashes. Other state speed limit setting procedures include factors in the MUTCD along with others such as bicyclist activity or alignment.

On a national level, to update the procedures used in setting PSLs, a recent National Cooperative Highway Research Program (NCHRP) Project (Project 17-76) investigated the factors that influence operating speed as well as safety and used that knowledge to develop a Speed Limit Setting Procedure (SLS-Procedure) that can be used to 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 *User Guide for Posted Speed Limit Setting Procedure and Tool* publication (*4*).

The timing of NCHRP Project 17-76 along with the increased exploration of other methods for setting PSLs (see following section) provided the opportunity to better integrate consideration of context into a refined proposed speed limit setting procedure.

Calls for Change

The speed limit debate increased in 2017 with two publications. In March 2017, the National Association of City Transportation Officials (NACTO) released a policy statement (*5*). One of the action items in that statement was to “permit local control of city speed limits.” NACTO recommended “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 (*6*). That document contained several recommendations for reducing speed-related crashes, including two recommendations directed to the Federal Highway Administration (FHWA) for changes to the MUTCD (*6*, pp 57). NTSB recommended that FHWA require the MUTCD factors currently listed as optional for all engineering studies, require that an expert system such as USLimits2 be used as a validation tool, remove the guidance that speed limits in speed zones should be within 5 mph of the 85th percentile speed, and incorporate the safe system approach for urban roads to strengthen protection for vulnerable road users.

A National Committee on Uniform Traffic Control Devices (NCUTCD) task force was formed to consider the NTSB recommendations. The task force conducted a survey on speed limits with the findings documented in two 2019 papers (*7*, *8*). 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.

In California, a Zero Traffic Fatalities Task Force was formed to "develop a structured, coordinated process for early engagement of all parties to develop policies to reduce traffic fatalities to zero"(*9*). In addition, the task force also examined alternatives to the 85th percentile method for determining speed limits in California. The California Zero Traffic Fatalities Task Force made several recommendations (*10*), including having a policy that would allow increase deviation (more than 5 mph) from the 85th percentile speed for high injury networks and areas adjacent to land uses and types of roadways that have high concentrations of vulnerable road users.

The California Zero Traffic Fatalities Task Force made several recommendations (*10*), including developing a different approach to setting speed limits that provides a roadway-based context sensitive approach that prioritizes the safety of all road users. Activities are also occurring in Oregon to change how speed limits are set in cities and counties.

City Speed Limits

Several U.S. cities have recently campaigned to be able to set lower citywide default speed limits. NACTO and Vision Zero are contributing to the speed limit discussion and using speed-related pedestrian/bike crash survivability to justify uniformly low posted speeds. In 2020

NACTO released a publication that provides guidance on the "setting of safe speed limits on urban streets"(*11*). Examples of U.S. cities that are setting a 25-mph citywide speed limit include Boston, Massachusetts (*12*); New York City, New York (*13*); Seattle, Washington (*14*); and Austin, Texas (*15*). Cities in other countries are also implementing citywide speed limits.

Portland, Oregon, has the authority to set the speed limit on residential streets at 20 mph. In 2018, Portland City Council approved an ordinance that lowered the speed limit on all residential streets to 20 mph, a change that resulted in reductions on 70 percent of the city's street network (*16*).

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 (*13*). 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. These neighborhood slow zones 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 (*13*).

85TH PERCENTILE SPEED

On a national level, until very recently, most, if not all, of the speed limit setting procedures used in the United States were based on the 85th percentile speed (*17*). The process of selecting a PSL 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. Many states/local agencies have their own laws and criteria for setting speed limits (many are very detailed). The operating speed approach typically relies on the 85th percentile speed with adjustments used to account for existing roadway geometry or crash experience. Professionals who perform PSL studies rarely use *only* the 85th percentile speed (i.e., they use several other factors).

Currently, the predominant method for setting speed limits is with the use of the 85th percentile speed. In general, it is calculated from a sample of passenger car drivers operating at free flow (i.e., drivers are free to travel at their desired speed and are not constrained by the presence of other vehicles or downstream traffic control devices). The 85th percentile speed is defined as the speed at or below that which 85 percent of all vehicles are observed to travel under free-flowing conditions.

The 85th percentile speed has been viewed as being representative of a safe speed that will minimize crashes, and the 1964 Solomon study (*18*) is frequently quoted as being the source to justify the use of the 85th percentile 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.

The use of the 85th percentile speed has been supported with the following (*4*):

- 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 PSL.

Criticisms of the 85th percentile speed method have included the following (*4*):

- Setting the PSL 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 PSL 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.

Rising Operating Speeds, Sometimes Called Speed Creep

An argument against using the 85th percentile speed to set speed limits is that using measured operating speeds could cause operating speeds to increase over time. This phenomenon has been called *speed creep*. The claim is that drivers frequently select speeds a certain increment above the PSL, anticipating that they will not receive a ticket if they are not above that assumed enforcement speed tolerance. In this case, the resulting operating speed would be above the PSL. Using the 85th percentile speed approach in this situation would result in recommending a PSL that is higher than the existing PSL. 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.

NCHRP PROJECT 17-76 DEVELOP SPEED LIMIT SETTING PROCEDURE

Overview

NCHRP Project 17-76 collected insights into how the roadway environment influences operating speed and safety (i.e., 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 PSLs, the research team developed the SLS-Procedure and then automated that procedure with the SLS-Tool and explained that procedure with a user guide (*4*).

The SLS-Procedure (see overview in Figure **1**) 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 (see Table 1).

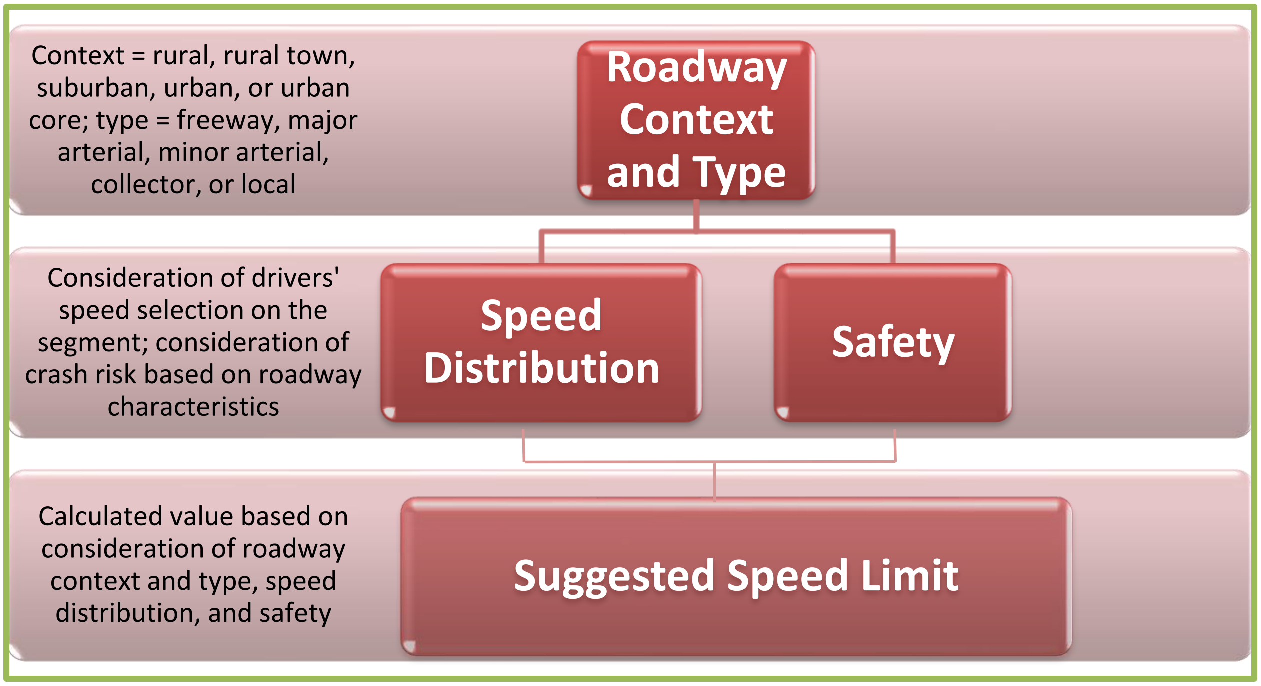


Figure 1. Overview of SLS-Procedure to Calculate the Suggested Speed Limit (*17*).

Table 1. Suggested Speed Limit Setting Groups (*17*).

Context and Type	Rural	Rural Town	Suburban	Urban	Urban Core
Freeways	**Limited Access**	**Limited Access**	**Limited Access**	**Limited Access**	**Limited Access**
Principal Arterial	**Undeveloped**	**Developed**	**Developed**	**Developed**	**Full Access**
Minor Arterial	**Undeveloped**	**Developed**	**Developed**	**Developed**	**Full Access**
Collector	**Undeveloped**	**Full Access**	**Developed**	**Full Access**	**Full Access**
Local	**Undeveloped**	**Full Access**	**Full Access**	**Full Access**	**Full Access**

For the Limited Access and Undeveloped suggested speed limit setting groups (SLSGs) with their higher operating speed and greater emphasis on mobility, retaining a connection to measured operating speed, specifically the 85th percentile 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; this decision was made with the knowledge that the measured operating speed that would serve as the starting point (e.g., 85th percentile or 50th percentile) and whether the closest speed or the speed round down to the nearest 5-mph increment would be used, would be influenced by the consideration of safety through the use of decision rules. Extensive debate was then conducted regarding 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 those settings.

In summary, for the SLS-Procedure, researchers recommended considering the measured operating speed as the starting point for selecting a PSL, 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.

Develop Decision Rules

Within each of the SLSGs, a unique set of decision rules was developed. Additional details on the sources used to create the decision rules are available in Fitzpatrick et al. (*17*). That information is not provided here due to space concerns; however, a list of the variables selected for each SLSG can provide the reader with an appreciation of what is being used within the 17-76 SLS-Procedure. The variables needed within the 17-76 SLS-Procedure for speed data are listed in Table 2. Table 3 shows the roadway segment input variables, and crash data variables are in Table 4.

Table 2. Input Variables for Speed Data (*17*).

Speed Data Variable	Limited Access	Undeveloped	Developed	Full Access
50th percentile speed (mph)	✓	✓	✓	✓
85th percentile speed (mph)	✓	✓	✓	—
Maximum speed limit (mph)	✓	✓	✓	✓

Note: ✓ = variables used in SLSG, — = variables not used in SLSG.

Table 3. Roadway Segment Input Variables (*17*).

Roadway Segment Variable	Limited Access	Undeveloped	Developed	Full Access
AADT (two-way total), annual average daily traffic (veh/d)	✓	✓	—	—
Adverse alignment present (yes or no)	✓	✓	✓	✓
Angle parking present (no, yes for at least 40 percent of the segment, or yes for less than 40 percent of the segment)	—	—	✓	✓
Bicyclist activity (high or not high)	—	—	✓	✓
Design speed (mph)	✓	—	—	—
Directional design-hour truck volume (trk/hr)	✓	—	—	—
Grade (%)	✓	—	—	—
Inside (left) shoulder width (ft)	✓	—	—	—
Lane width (ft)	—	✓	—	—
Median type, developed or full access (undivided, two-way left-turn lane [TWLTL], or divided)	—	—	✓	✓
Median type, undeveloped (undivided or divided)	—	✓	—	—
Number of access points (total of both directions)	—	✓	✓	✓
Number of interchanges	✓	—	—	—
Number of lanes (two-way total)	✓	✓	✓	✓
Number of traffic signals	—	—	✓	✓
On-street parking activity (high or not high)	—	—	✓	✓
Outside (right) shoulder width (ft)	✓	—	—	—
Parallel parking permitted (yes or no)	—	—	✓	—
Pedestrian activity (high, some, or negligible)	—	—	✓	✓
Segment length (mi)	✓	✓	✓	✓
Shoulder width (ft)	—	✓	—	—
Sidewalk buffer (present or not present)	—	—	✓	✓
Sidewalk presence/width (none, narrow, adequate, or wide)	—	—	✓	✓

Note: ✓ = variables used in SLSG, — = variables not used in SLSG.

Table 4. Input Variables When Crash Data Are Available (*17*).

Crash Data Variable	Limited Access	Undeveloped	Developed	Full Access
Number of years of crash data.	✓	✓	✓	✓
Average AADT (two-way total) for crash data period (veh/d).	✓	✓	✓	✓
All (KABCO) crashes for crash data period.	✓	✓	✓	✓
Fatal and injury (KABC) crashes for crash data period.	✓	✓	✓	✓
Average KABCO crash rate (crashes/100 million vehicle-miles traveled [MVMT]) and average KABC crash rate (crashes/100 MVMT)? If not provided, the KABCO and KABC crash rates from the FHWA Highway Safety Information System is used.	✓	✓	✓	✓
Is the segment a one-way street?	—	—	✓	✓
Number of lanes.	✓	✓	✓	✓
Median type.	—	✓	✓	✓

Note: ✓ = variables used in SLSG, — = variables not used in SLSG.
KABCO = injury scale for crashes where K = fatal, A = incapacitating injury, B = non-incapacitating injury, C = possible injury, and O = no injury/property damage only.

In NCHRP Project 17-76, the research team focused a portion of the Phase II funds 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 PSLs. The findings from those evaluations supported including the following variables within the Developed and Full Access SLSGs' 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.

The data available from Austin also provided the opportunity to examine the operating speed and crashes relationship. The team found that crashes on city streets were lowest when the posted speed limit was within 5 mph of the average operating speed, see Figure 2 for a summary graphic illustrating that finding. 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.

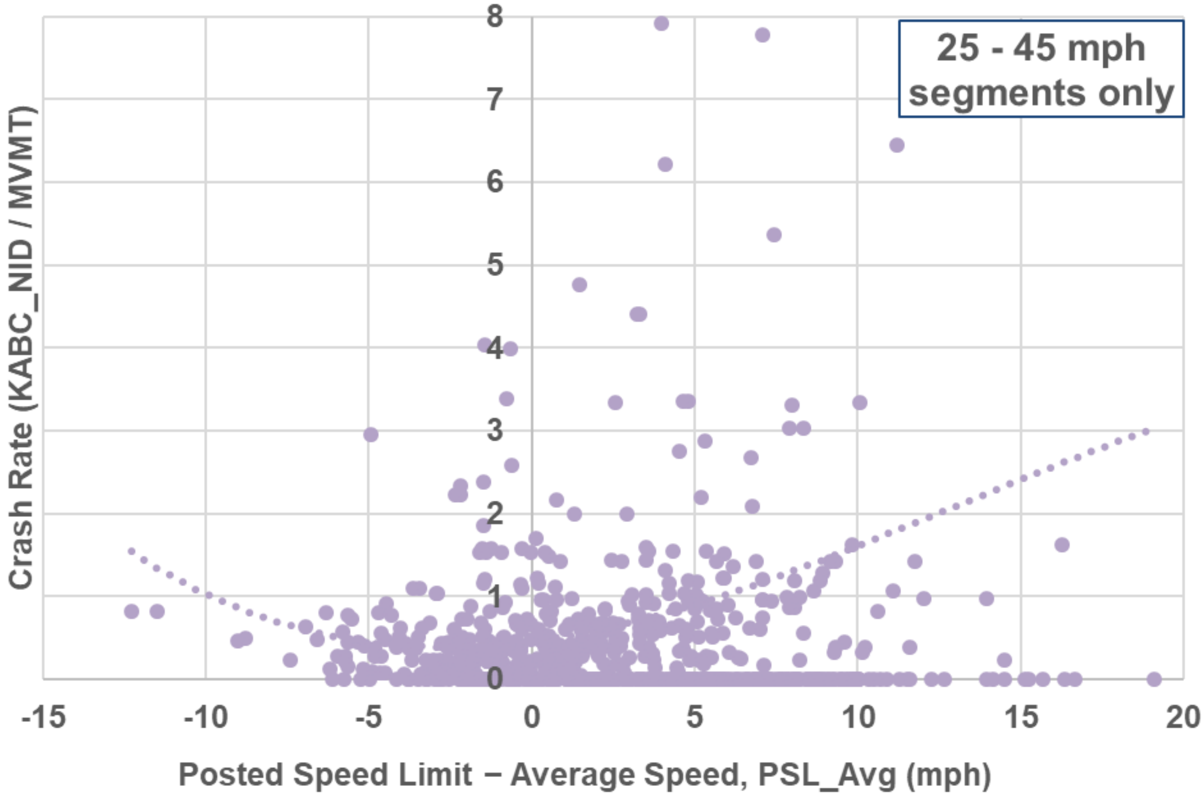


Figure 2. Comparison of Crash Rate to the Difference between PSL and Average Speed (*17*).

Develop SLS-Tool

The SLS-Procedure was automated into an SLS-Tool using a spreadsheet as the base format. Included with the SLS-Tool is a stand-alone document, the *User Guide for Posted Speed Limit Setting Procedure and Tool* (*4*), that provides information regarding the variables used in the spreadsheet tool along with general information about the setting of speed limits. In the SLS-Tool, users input data for a roadway segment to obtain the suggested speed limit. The NCHRP Project 17-76 SLS-Tool includes three worksheets:

- Welcome. This worksheet provides an overview of the SLS-Tool.
- Analysis. This worksheet is used to enter input data and obtain analysis results. Key cells on this worksheet have been color-coded to indicate the type of data entered or displayed (see top right corner of the Analysis worksheet for legend). An example Analysis worksheet is provided below.

- Support Tables. This worksheet contains several tables that are used in the Analysis calculations. The values can be changed but only if based on agency policy or new knowledge (i.e., new research, extensive local data, etc.).

An example of the analysis worksheet is shown in Figure 3.

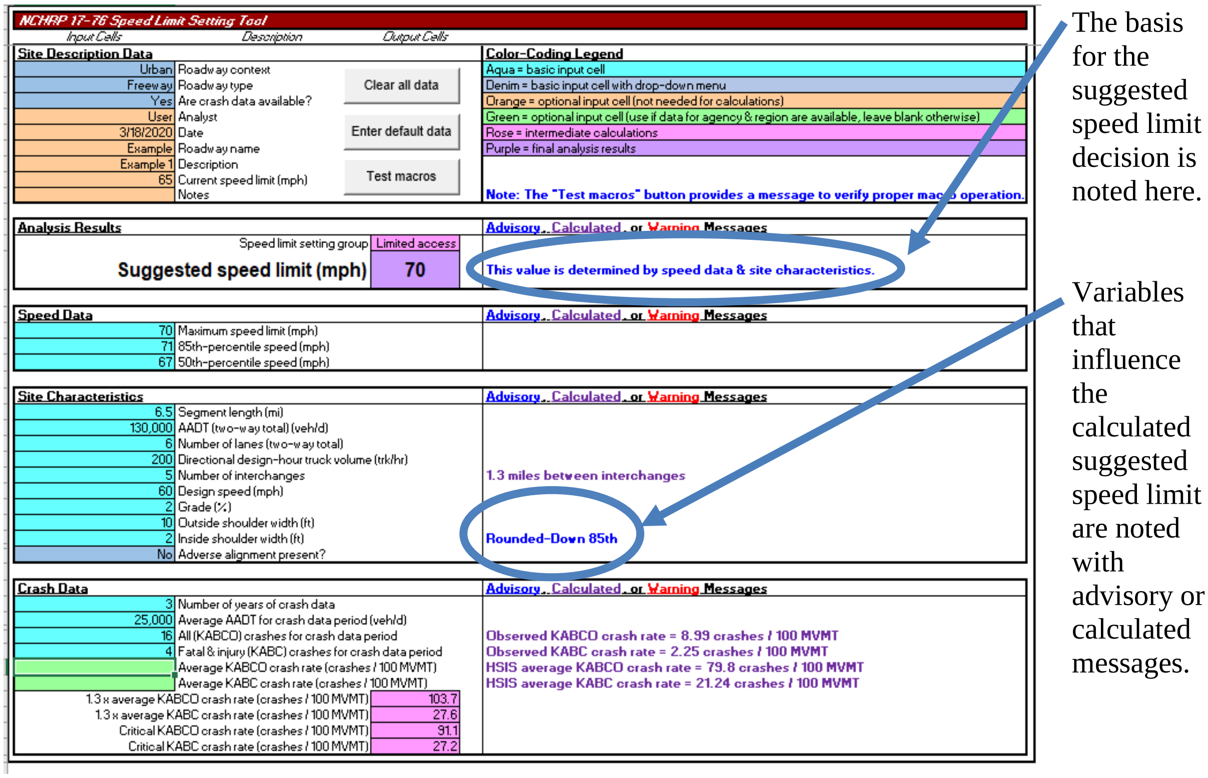


Figure 3. Example of SLS-Tool (*17*).

PRACTICES IN TEXAS CITIES

Researchers conducted brief conversations with the traffic engineering staff of different-sized municipalities in Texas to readily summarize current practices and considerations in speed zone development for municipalities. No effort was made to exhaustively perform such a review across the entire state due to the inordinate resources that would be necessary for comprehensive practice documentation.

San Antonio

The following information documents informal discussions with City of San Antonio staff regarding speed limits and speed limit setting procedures:

- City ordinances, passed by city council, establish speed limits through a list, or schedule, of PSLs for all city roadways.
- State roadways within city limits have speed limits established by the Texas Transportation Commission.
- Speed studies following Institute of Transportation Engineers (ITE) practices (*20*) are used to collect representative speed data for city roadway sections.
- 85th percentile speed is the primary determinant of PSL.

A broad range of speed management devices—most frequently lane narrowing and speed feedback signs—are used to normalize speed and reduce speeding. These devices are often implemented in response to neighborhood and citizen concerns and represent joint efforts by municipal engineering staff and city council district staff to address local concerns regarding speed and safety.

Austin

As of June 2020, Austin engineering staff determined that city speed limits should be reduced for safety reasons:

- Neighborhood streets 36 feet wide or less and serving residential land use will be posted at 25 mph.
- Urban core arterial roadways will primarily be posted at 35 mph.
- Most downtown streets will be posted at 25 mph except for a few major arterials, which will be posted at 30 mph.
- Some speed management strategies, such as narrow lanes, will be instituted along with, and in reinforcement of, the mandated speed reductions.
- This initiative is one component of the city's implementation of roadway system management changes to reduce fatalities under their goal to achieve Vision Zero safety/crash reduction objectives.

New Braunfels

City council has the authority to establish PSLs on city streets that differ from state prima facie speed limits (30 mph in an urban district on a street other than an alley, and 15 mph in an alley).

City council has the authority to lower the speed limit to 25 mph without the support of an engineering study.

The TxMUTCD (*2*), TxDOT *Procedures for Establishing Speed Zones* (*1*), and ITE study approaches (*20*) are the primary means of performing field studies. The 85th percentile speed, as identified by the traditional ITE process, is a major determining factor in speed limit selection.

Speed management devices—most commonly lane narrowing—are primarily used on collector and minor arterial roadways.

PRACTICES IN OTHER LARGE STATES

Researchers investigated speed zoning and management practices from the six most populous states (excluding Texas) in the country as a means of gathering additional information from state transportation agencies whose roadway network coverage and diversity of conditions most closely resemble Texas practices. Though Texas is the second most populous state in the country, its practices are not included here since TxDOT practices are known to the research study panel and are the subject of the current investigation.

California

As discussed previously, California is in the process of examining their PSL setting procedures (*9, 10*). Currently, the *California Manual for Setting Speed Limits* (*19*) (the Manual) establishes uniform procedures for setting speed limits in California. Section 627 of the California Vehicle Code (CVC) gives the California Department of Transportation (Caltrans) the authority to set procedures for engineering and traffic surveys (ETS), which are then used as the primary determinant of PSLs. Other sections of the CVC set statutory maximum speed limits of 55 mph on two-lane divided roadways and 65 mph on all other roadways.

Caltrans normally uses the 85th percentile speed to determine PSL but does allow variations from this practice as justified by an ETS. Prima facie speed limits established by the CVC include:

- 15 mph, which applies to uncontrolled railway crossings; blind, uncontrolled intersections; and alleyways.
- 25 mph, which applies to business and residential areas without other PSLs, school zones, and areas immediately around senior centers.

When an ETS shows that a speed limit other than the prima facie or statutory speed limit applies, the PSL is established based on the results of the ETS. The CVC addresses increasing freeway speeds to 70 mph, decreasing highway speeds from 65 mph (where appropriate), and decreasing local speed limits.

The Manual lists the roadway elements that place limitations on the safe operating speed of vehicles, including:

- Roadway geometrics, shoulder condition, grade, alignment, and sight distance.
- Roadside development, zoning, and environment.
- Parking practices and pedestrian activity.
- Driveway density.
- Intersections.
- Rural, residential, or developed areas.

The Manual describes the procedures for performing ETS in detail. The documentation components (*19*) of the ETS include:

- A "strip map" with a schematic plan drawing of the roadway showing the results of the speed measurements, collision data, and related physical information.
- A justification memo, discussion of the roadway characteristics, 85th percentile speeds, collision data, non-apparent conditions, and a summary with a recommended speed limit.
- Order or ordinance documenting the speed limit. An ETS may have any number of speed zones on the strip map, but each speed zone should have a separate justification and order.

Speed data recorded for the ETS must document speeds in free-flow conditions. If automated equipment is used to collect speed data, an analyst must filter the data to exclude readings that are determined not to be under free-flow conditions. The Manual includes a

"Vehicle Speed Survey Sheet" for recording speed measurements collected manually, and this form is very similar to forms developed by ITE (*20*) and TxDOT.

The Manual includes sample letters for sharing ETS results with law enforcement and other affected engineering agencies to share and discuss the results. If a PSL change is indicated, a letter to local officials is used to allow for a public hearing. If no speed limit change results from an ETS, notification of the new ETS is simply sent to law enforcement and courts. Jurisdictional issues play a role in implementation, since an ETS is necessary for local roads (except those covered with prima facie speed limits), and reductions from 65 mph need to be codified with local ordinances.

The CVC states that ETSs are valid for five years, though some can be extended for up to seven or 10 years. However, if a speed limit is established at a statutory maximum speed limit (as set in the CVC) or higher, no further studies are required; the CVC requires ETSs for speed zone reductions only.

Florida

The purpose of the Florida *Speed Zoning* manual (*21*) (the Manual) is to "provide guidelines and recommended procedures for establishing uniform speed zones on state, municipal, and county roadways throughout the State of Florida." Legal authority for the practices in the Manual is established by Chapter 316 of Florida Statutes, Florida Statutes Rule 14-15.010, and/under the Florida Administrative Code (FAC).

The Manual, as an implementation of the law embodied in the FAC, seeks to operate facilities at speeds which are safe for all users and improve safety. Statutory, or maximum allowable speeds, prevail on most roadways under state, county, and municipal jurisdictions. Statutory speed limits may be altered with speed zoning, as supported by an engineering and traffic investigation (ETI). Criteria for this investigation is set forth by the Florida Department of Transportation.

The Manual cites research from the FHWA to substantiate that the 85th percentile speed generally reflects drivers' collective judgment as to the reasonable speed for conditions. The Manual lists factors that influence drivers' speed choice, including vehicle density, weather, road conditions, road geometry, traffic control devices, and adjacent land use; however, the actual list of factors is extensive (35 factors).

Florida statutes require that an ETI be conducted for any alteration of speed limits. Basic data collected include speeds of free-flowing traffic for the calculation of 85th percentile speed, 10-mph pace (10 mph range having the highest number of speed measurements), and average test run speed. Data can be collected using a number of technologies (travel time between predetermined study end points, fixed radar, pneumatic tubes, etc.), but the preferred method is pneumatic tubes collecting at least 24 hours' worth of data. Whatever data collection is used, a minimum directional sample size of 100 vehicles is desired.

Field data from an ETI are analyzed, and the PSL is based on the calculated 85th percentile speed being rounded to the nearest multiple of 5 mph or the upper limit of the 10-mph pace, whichever is less. A speed limit of 4 to 8 mph less than the 85th percentile can be used if a supplemental investigation reveals unusual road factors or other speed measures have been applied but found ineffective. The PSL is usually not changed if the calculated speed is within 3 mph of the existing posted speed or if it exceeds the roadway's design speed (if it is known).

Statutes stipulate that the maximum speed within local jurisdictions (counties and cities) is 30 mph, and municipalities can set maximum speeds of 20 or 25 mph in residential districts (following appropriate investigation). ETIs can be performed to identify roadways where these jurisdictional limits can be raised or lowered but not to exceed statutory minima and maxima. No such speed zone shall permit a speed of more than 60 mph.

New York

Despite a focused search, researchers could not readily find a New York state manual on speed zones. However, some information was available through the New York State Department of Transportation's *Highway Design Manual* (HDM) (*22*). Under Chapter 5 "Basic Design," a section titled "Speed Studies" both describes the calculated 85th percentile speed and differentiates this speed from both the regulatory speed limit and the statutory speed limit. The regulatory/legal speed limit is the PSL when regulatory signs are posted. Where no signs are posted, the speed limit is the statutory speed (i.e., 55 mph as established by "New York State Vehicle and Traffic Law").

Speed studies as described in the HDM involve at least 30—but preferably 50—individual speed measurements under off-peak/free-flow conditions. Speed data can also be obtained with (automated) speed measuring devices, data used to set the speed limit at the site (source is not described), test car techniques, or statewide operating speed studies for similar facilities.

New York state law (*23*) establishes basic rules and maximum limits that apply across the state. The basic statutory speed limit is 55 mph, but select roadways (listed in the "Maximum Speed Limits" section of the law) can be posted with a speed limit of up to 65 mph when/if they meet department of transportation criteria for such maximum speeds. Residential roads typically have a speed limit of up to 45 mph, but such speeds vary between 25 and 45 mph. Some neighborhood "slow zones" do exist in New York City with a PSL of 20 mph. No minimum speed is enumerated in the law, but drivers can be cited for impeding "the normal and reasonable movement of traffic except when reduced speed is necessary for safe operation or in compliance with law."

Pennsylvania

Pennsylvania Code is the codified administrative regulations for the Commonwealth of Pennsylvania. Title 75: Vehicles, Chapter 33: Rules of the Road in General, Section 3362: Maximum Speed Limits sets the following maximum speed limits:

- 35 mph in any urban district.
- 65 mph for all vehicles on freeways where the (transportation) department has posted a 65-mph speed limit.
- 25 mph in a residence district if the highway is not a numbered traffic route and is functionally classified by the department as a local highway.
- 55 mph in other locations.

The Pennsylvania Department of Transportation's (PennDOT) *Traffic Engineering Manual* (TEM) (*24*) indicates that the Pennsylvania Motor Vehicle Code (75 Pa. C.S.), Chapter 212, Section 108(b) establishes speed limits at the 85th percentile speed unless:

- There are sight distance restrictions (stopping and corner sight distance).
- The majority of crashes are related to excessive speed, and the crash rate is greater than the applicable rate in the most recent high-crash rate or high-crash severity rate table.

PennDOT developed a four-page form (Speed Restrictions, Engineering and Traffic Study) to guide the conduct for a (speed limit–related) ETS. The form contains operational and physical checklists to gauge the quality of site elements such as sight distance, signing, driver behavior, safety (observational), and congestion. Existing speed limit and area type are also recorded. Data recording of speed measurements can be performed based on sample speed runs (five per direction) or samples of motorists' speeds (100 observations, although 50 is acceptable for low volume conditions). Crash analysis is required in order to establish whether the majority of road section crashes are speed related, and documentation is noted for which agency (PennDOT or municipality) will be responsible for signing.

Illinois

The Illinois Department of Transportation developed the *Policy on Establishing and Posting Speed Limits on the State Highway System* (the Policy) (*25*) to comprehensively guide practitioners in the development and application of speed zones. Statutory speed limits in Illinois are based on Article VI of the Illinois Vehicle Code and include the following (Section 11-601):

- 65 mph for freeways and expressways, but 55 mph for trucks on non-interstate routes and within select counties.
- 55 mph for conventional highways.
- 35 mph for streets and highways in urban districts.
- 15 mph in alleys (within urban districts).

Speed limits can be altered up or down based on an engineering study, but statutory 55 and 65 mph speed limits can only be adjusted downward. Speed measurement is an essential component of the engineering study, and such measurements must be based on vehicles operating under free-flow conditions. Speed documentation includes at least 100 vehicle samples or, under lower volume conditions, three hours of measured speeds, upon which an 85th percentile speed is calculated. The upper limit of the 10-mph pace is calculated based on the same data set used to determine 85th percentile speed. Finally, average speed runs are performed (five runs in each direction) to approximate and document median speed.

Policy practice allows for the adjustment of the speed limit by up to 9 mph based on high crash locations, access control, pedestrian activity, parking, and other (site specific) factors.

Altered speed limits based on these adjustments should not differ from the prevailing speed by more than 9 mph or 20 percent, whichever is less. A minimum speed limit of 45 mph applies to access-controlled facilities whose speed limit is 60 or 65 mph.

Speed study documentation includes a field speed recording form that is similar to the form used by TxDOT and a data sheet to document the results of the speed sample runs, 85th percentile speed and pace, posted speed violation rate, speed limits in adjacent zones, access conflicts and driveway types, pedestrian volume, crash rate, and speed adjustments. A general condition diagram showing land use, driveways, traffic control, and cross roadways completes speed study site documentation.

Ohio

The Ohio Department of Transportation's (ODOT) speed management practice is guided by the *Ohio Manual on Uniform Traffic Control Devices* and Section 4511.21 of the Ohio Revised Code (ORC). Statutory speed limits guide speed zone implementation throughout the state, and such limits can be adjusted based on an engineering study. The 85th percentile speed and 10-mph pace are identified as very important factors in speed limit determination, but other factors—including area development, roadway features, traffic volume, and crashes—also have an influence on ODOT speed zones (*26*).

Statutory speed limits in Ohio, as listed and codified in the ORC, are conditionally dependent and lengthy in description. Generally, the following limits apply:

- 70 mph for the Ohio Turnpike, rural freeways, and some U.S. highways.
- 55–70 mph for other divided highways.
- 50–65 mph for urban interstates and highways.
- 50 mph for controlled-access highways and expressways within municipal corporate districts.
- 25 mph for residential and urban districts.
- 20 mph for school zones during school hours.
- 15 mph for alleys in municipal corporate districts.

ODOT-approved speed zones are needed for roads and streets that are to have a speed limit <u>lower</u> than the statutory prima facie speed limits given in the ORC, including rural state highways, county roads, and city streets. A board of trustees does have the authority to lower speed limits without ODOT approval on “unimproved” roads and in areas identifiable as commercial or residential subdivisions. Speed limits can be raised by cities without ODOT approval, up to 50 mph, as long as appropriate signs are used.

The ODOT *Traffic Engineering Manual* (*27*) describes the procedures and contains the forms for ODOT speed studies. Data collected for speed studies includes highway development (building type and classification of intersections), roadway features (lane width, shoulders, curves, and grades), 85th percentile speed (100 measurements or one hours’ worth of data under free-flow conditions, whichever is reached first), 10-mph pace, crash rate, and test run data. Different speed zone evaluation forms are used based on roadway type and environment (urban/rural).

CHAPTER 3: LITERATURE REVIEW FOR HIGH-SPEED HIGHWAYS

Several factors are known or suspected to affect operating speed on rural or high-speed highways, such as horizontal/vertical alignment, shoulder width, and access point density. As documented in the Transportation Research Board (TRB) *Modeling Operating Speed Synthesis Report* (*28*), 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 operating speed, rural highway roadway characteristics, and traffic control devices including PSL.

TRAFFIC—VEHICLES

Annual Average Daily Traffic Relationship with Operating Speed

The amount of annual average daily traffic (AADT) present may be associated with operating speed (*29*). For rural two-lane highways, Lamm et al. (*30*) found that speed increases as AADT increases, while Jessen et al. (*31*) 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. (*32*) 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. (*33*) found that AADT is associated with different speed profiles.

Percent Trucks Relationship with Operating Speed

Robertson et al. (*32*) and Himes and Donnell (*34*) identified the percentage of trucks as a relevant factor in their study of rural four-lane highways.

TRAFFIC CONTROL DEVICES

Posted Speed Limit Relationship with Operating Speed

For rural high-speed highways, PSLs 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 PSL, with vehicular speeds increasing as the PSL increases (*35*, *36*, *31*). Operating speed has also been found to be related to posted speed on curves (*37, 31*).

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 (*35, 36, 38*). For undivided high-speed rural roadways, mean speeds are generally 3 to 5 mph higher for every 10-mph increase in speed limits above 55 mph, with smaller increases at higher speed limits (*35, 39, 40*). Hu (*41*) showed that raising the PSL from 75 to 80 mph on rural interstate roadways leads to higher travel speeds and an increased probability of exceeding the new speed limit. Based on a study on rural two-lane roadways in Oklahoma, Maji et al. (*42*) showed that the most influential variable for low-speed limit roadway related operating speed is PSL.

The *Highway Capacity Manual* (HCM), version 6.0 (*43*), 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 PSL range of 55 to 75 mph as well as for multilane highway segments with a PSL 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. (*44*) 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 PSL. Himes and Donnell (*34*) identified the PSL as relevant to their study of rural four-lane highways. Robertson et al. (*32*) found the daytime PSL to be a significant variable based on data from 36 rural four-lane non-limited-access roadways. The findings from Gayah et al. (*45*) showed that operating speeds closely comply with the PSL when the PSL is set equal to or 5 mph lower than engineering recommendations.

Passing Lane Relationship with Operating Speed

Freedman and Kaisy (*46*) investigated the passing maneuvers within a passing lane section on a rural two-lane highway located on a U.S. highway in Montana. This study considered speed differentials for different passing maneuvers.

ROADWAY GEOMETRY

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. Studies on rural two-lane highways that have found a horizontal curvature measure influential include Wooldridge et al. (*47*), Lamm et al. (*30*), Morrall and Talarico (*48*), Islam and Senevirantne (*49*), Krammes et al. (*50*), Voigt and Krammes (*51*), Passetti and Fambro (*52*), McFadden and Elefteriadou (*53*), Fitzpatrick et al. (*54*), Gibreel et al. (*55*), Schurr et al. (*37*), Figueroa and Tarko (*56*), and Misaghi and Hasson (*57*). 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 (*58*).

Polus et al. (*59*) 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 (*60*) 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 (*32*), the angle of the next downstream horizontal curve influenced the speed of the daytime car drivers on the approach tangent. Bassani et al. (*61*) showed that an increase in the horizontal curvature results in a decrease in the observed average speed. Llopis-Castello et al. (*62*) 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 Operating Speed

Fitzpatrick et al. (*54*) conducted a study on rural two-lane 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. (*63*) used inferred design speed to predict the 85th percentile speed on vertical curves. Jessen et al. (*31*) 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. (*37*) found that speed decreases as approach grade increases on horizontal curves. Figueroa et al. (*56*) found decreasing speed as grade increases on tangents. In another study, Gibreel et al. (*55*) 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. Shallam et al. *(64)* found that curvature change rate and length of the vertical curve are influential in operating speed for rural two-lane roadways passing through hilly terrain.

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 (*60*) found the approaching section grade to be related to operating speed. Llopis-Castello et al. (*62*) 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.

Median Relationship with Operating Speed

A study on rural four-lane highways in Kentucky (*60*) found that the presence of a median barrier is related to operating speed. Dong et al. (*33*) 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. Pinna *(*65*)* also found that the type of median has influence on operating speeds on urban arterials.

Median Width Relationship with Operating Speed

Dong et al. (*33*) found that median width is associated with different speed profiles.

Lane Width Relationship with Operating Speed

For rural two-lane highways, Lamm et al. (*30*) found that speeds increase with wider lane width, while Figueroa et al. (*56*) found a similar relationship using pavement width. Bassani et al. (*61*) found that an increase in pavement width results in both an increase in mean speed and a decrease in speed deviation along tangent segments. Shallam et al. (*64*) showed that the interactions of radius with lane width were found to be significant in the operating speed measures for rural two-lane roadways passing through hilly terrain.

Shoulder Width Relationship with Operating Speed

For rural two-lane highways, Lamm et al. (*30*) found that speeds increase with wider shoulder width. A study on rural four-lane highways in Kentucky (*60*) found the presence of shoulders to be related to operating speed. In a study on rural four-lane highways in Texas (*32*), the left and right shoulder widths influenced the speed of daytime car drivers.

Lane Position Relationship with Operating Speed

Himes and Donnell (*34*) 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, PSL, and adjacent land use. Gong and Stamatiadis (*60*) 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 Operating Speed

Figueroa et al. (*56*) found lower speeds when an intersection was present for rural two-lane highways. In the Gong and Stamatiadis (*60*) study of four rural four-lane highways in Kentucky, access point density was observed to have an inverse relationship with vehicular speeds; mean speeds decreased as the density of access points increased. Mahmoud et al. (*66*) showed that the number of signalized intersections per mile has significant influence on the 85th percentile speed on urban roadways.

For rural four-lane non-limited-access roadways, Robertson et al. (*32*) found the number of access points significant only for 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.

Development (Surrounding Land Use) Relationship with Operating Speed

Figueroa et al. (*56*) found lower speeds to be associated with residential development for rural two-lane highways. Himes and Donnell (*34*) identified adjacent land use as relevant to their study of rural four-lane highways.

OTHER VARIABLES

Robertson et al. (*32*) identified the time of day as relevant to their study of rural four-lane highways. Bassani et al. (*67*) showed that average speeds and deviations from the mean operating speed are significantly affected by changes in time of day and related lighting conditions on urban arterials.

OVERVIEW OF VARIABLE RELATIONSHIP WITH SPEED

Based upon information in the literature, several roadway segment factors are known or suspected to affect a driver’s speed choice. Table 5 summarizes the high-speed highway factors that affect operation speed.

Table 5. 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	*46*
Traffic control device	PSL	Positively associated	*31*, *32*, *34*, *35*, *36*, *37*, *38*, *39*, *40*, *41*, *42*, *43*, *44*, *45*
Traffic	AADT	Mixed effect	*30*, *31*, *32*, 32
Traffic	Percent trucks or commercial AADT	Unknown	*34*, *32*
Surroundings	Access (driveways and intersections)	Negatively associated	*32*, 45, *56*
Surroundings	Development	Negatively associated	*34*, *56*
Roadway geometry	Horizontal alignment (curve radii and length)	Negatively associated	*30*, *36*, *37*, *47*, *48*, *49*, *50*, *51*, *52*, *53*, *54*, *55*, *56*, *57*, *58*, *60*, *61*, *62*
Roadway geometry	Lane width	Positively associated	*30*, *43*, *56*, *61*
Roadway geometry	Median type	Median type associated with different speed profiles	*60*, *44*
Roadway geometry	Median width	Positively associated	*33*, *34*
Roadway geometry	Number of lanes	Positively associated	*34*, *60*
Roadway geometry	Shoulder (paved) width	Positively associated	*30*, *60*, *32*
Roadway geometry	Vertical alignment	Negatively associated	*31*, *37*, *43*, *54*, *55*, *56*, *60*, *62*, *63*
Other factors	Time of day	Positively associated with nighttime	*32*, *46*

CHAPTER 4: DISTRICT SPEED DIALOGS

As part of this research project, the researchers held a speed dialog with selected districts. The goal was to identify the practice and procedures used across Texas to perform speed studies, develop PSLs, and implement speed management devices, including:

- Discuss the TxDOT *Procedures for Establishing Speed Zones* (*1*) with district personnel, including how engineering judgment is applied in the PSL development process.
- Assemble information on the conditions and environments where speed management devices are applied.
- Obtain the full case history of recent, demonstrative examples of situations with the public or decision makers where speed limits or the speed limit decision-making process was discussed.
- Summarize issues with speed management in interaction with county and municipal staff within district boundaries, including policy-driven speed management decisions that were made (and are being enforced) locally.

Each speed dialog between the TxDOT districts and TTI staff included a speed study/speed zoning practice review (12 questions), a discussion on the district use of speed management devices (10 device types), and a request for information about district sites with recent speed zone changes. Researchers adopted a balanced approach in selecting a limited number of districts for speed discussions, opting to gather input from all urban districts and a rural district from each geographic region of the state. Speed discussions were ultimately held with traffic operations staff from the Abilene, Atlanta, Austin, Corpus Christi, Dallas, El Paso, Fort Worth, Houston, Lubbock, San Antonio, and Waco districts.

PRACTICE REVIEW

Frequency of Speed Studies

Urban districts typically conduct between 20 and 80 speed studies per year, while rural districts perform five to 50 studies per year (largely dependent on population). One outlier is the Houston District, where up to 500 speed studies per year are performed. Staff availability and time are the major determining factor in whether the speed data and study corridor condition information are collected by TxDOT staff or contractors. Districts—especially urban districts—with a heavy speed study load may even have a staff position or two devoted to organizing and performing speed studies.

Speed studies are performed at safety "hot spots," identified by district staff, upon a request by municipal or county staff (or even a member of the public) or as part of a routine review of district-wide speed zones. Speed study requests in the vicinity of schools are common, especially for rural districts or rural portions of urban districts where school facilities are more likely located along state roadways. One reason that the Houston District has many annual speed studies is the district's effort to address all speed study requests in addition to trying to meet a three-year requirement for reviewing all speed zones (through a very large metropolitan region).

Standard equipment for performing speed studies is a radar/laser gun and manual measurements recorded by field staff, though both TxDOT staff and contractors have used portable radar units and pneumatic counters (with "road tubes") capable of recording speeds for individual vehicles. When contractors are used, it is often necessary for TxDOT staff to provide initial training to ensure that field speed data are recorded under the "free flow" conditions stipulated in the *Procedures for Establishing Speed Zones* (*1*). When a large number of speed studies need to be performed, it is typical for an urban district (and sometimes rural districts) to hire a consulting team to collect the data and perform the speed studies.

One recommendation for potential project deliverables is for TTI to develop a guide on conducting speed studies with examples for different types of equipment and roadway classifications. Some TxDOT districts use spreadsheet tools for organizing their speed study program and keeping track of the status of each study and outcome (e.g., whether the enabling municipal ordinance has been approved). Map-based tools could help this process and tracking effort, and concepts for such a system are a potential future research project.

Speed Study Data Collection

On higher-volume roadways, it is relatively simple to collect the necessary 125 free-flow speed samples within a two-hour field study. Sample data recording sheets are provided in the *Procedures for Establishing Speed Zones* (*1*), and the 85th percentile speed is determined by selecting the 85th percentile speed value from the dataset. However, for rural roadways (i.e., low volume roadways) it is often necessary to use the "trial run" method since two-hour (or even four-hour) studies are unlikely to produce an adequate sample of motorist speeds. TxDOT (or contractor) staff drive past the data collection station/location and record their comfortable speed under free-flow conditions. Several passes are made each direction through the study corridor.

Details of the existing strip map for the roadway section where staff are performing a speed study is reviewed while staff are in the field, and any changes are noted for revisions. One element of the strip map that needs relatively frequent editing is the city limits, especially for smaller communities that are growing. An updated strip map and field-collected speed measurements serve as the documentation of the speed study in most cases. If a speed zone change is necessary, any correspondence related to the requested speed zone change or the field study is retained with the strip map and speed data in support of the Texas Transportation Commission minute order or municipal ordinance that establishes the speed zone change.

District staff noted that if strip maps were not intended to be the official record of speed study results and speed limits in the future, then a statewide alternative solution is needed (and must be developed). Some districts use the TxDOT Statewide Planning Map (online resource) to help identify speed limits and zones, but this tool is not sufficiently detailed to document all the details of speed zones. No support tools currently exist for storing speed study data, visualizing accurate speed zone details for on-system roadways, or tracking the frequency with which road sections are reviewed for potential speed limit changes. Many districts expressed hope that a future research project or work by the Traffic Operations Division would soon identify a solution for managing and tracking speed studies and speed zones for on-system roadways.

Factoring the 85th Percentile Speed

Texas practice for speed studies involves the application of up to five factors to adjust the 85th percentile speed based on engineering judgment. The five factors identified in the *Procedures for Establishing Speed Zones* (*1*) are:

- Narrow roadway pavement.
- Horizontal and vertical curves.
- High driveway density.
- Lack of striped, improved shoulders.
- Crash history within the speed zone.

Variation exists in the extent to which these factors are applied in each TxDOT district. In many cases, a single factor—typically crashes, driveway density, or narrow roadway pavement—dominates. When considering multiple factors, a factor-by-factor application of the speed reduction does not, however, provide a means of evaluating the interrelationship of the many factors or the ability to holistically assess the corridor.

Narrow Roadway Pavement

Narrow roadway pavement factors are applied with much greater frequency by rural districts but may only be applied in select areas of urban districts (e.g., roadways in an area where there is high energy development traffic). Narrow pavement issues are prevalent with "legacy" rural road cross sections, especially on lesser-traveled portions of the state highway system in the lower-volume farm-to-market, ranch-to-market, and ranch road classifications. A 5-mph adjustment for road sections with narrow roadway pavement is the most common practice.

Horizontal and Vertical Curves

Horizontal and vertical curve factors are also used/applied more commonly by rural districts or in the rural areas of urban districts. Horizontal and vertical curve issues are important safety concerns but are addressed with site-specific warning signing before broader speed control measures are applied. In longer roadway sections where horizontal and/or vertical curvature is common and curve-specific signing treatments are either excessive or prove less effective over time, district staff typically apply a 5-mph adjustment to the 85th percentile speed. However, some rural districts apply a 10-mph adjustment in high-speed corridors.

High Driveway Density

In Texas, high driveway density is one of the two most common factors applied in adjusting the 85th percentile speed to account for field conditions; crash history is the other most common factor. The typical adjustment for high driveway density is 5 mph. For many urban districts, complex driving environments represented by high driveway density and crash history are so intermingled that these two issues are effectively considered in tandem. Where sight distance to/from driveways is an additional concern or where there are large speed differentials between higher-speed through and turning traffic, additional speed limit adjustments can be made. Up to 10-mph adjustments to a speed study's measured 85th percentile speed are made to mitigate safety concerns associated with high driveway density where crash history is also a concern.

Driveway density is also a factor of discussion between TxDOT and municipal engineering staff when there is disagreement on the appropriate speed limit for urban and suburban arterials. In virtually all such cases, municipal staff wanted a speed limit less than the suggested value determined using the 85th percentile value of the field speed data along with rounding down by 5 mph due to consideration of the driveway density and crash factors. Engineering judgment is necessary to account for the frequency, traffic distribution, and traffic volume of driveways, since no reference or scaling factors exist.

Lack of Striped, Improved Shoulders

Like narrow roadway pavement, a lack of striped/improved shoulders is most frequently an issue for rural districts or in rural areas. This factor tends to be used with greater frequency when making 85th percentile speed adjustments than either narrow pavement or horizontal and vertical curves, but its relationship to narrow roadway pavement is clear. When present along substantial sections of rural roadway to a degree where driver behavior is a concern, a lack of striped/improved shoulders commonly results in a 5-mph adjustment to the 85th percentile speed.

Crash History

Whether in an urban or rural district, crash history is a frequently applied factor in speed studies. This is true in most urban districts since development and its attendant higher traffic volumes are often the reason a speed zone change or speed study is requested. These same issues affect rural districts as smaller communities develop and they relocate their undeveloped/developed transition areas further from the center of town. To apply the crash history factor effectively, crash types must be investigated to establish a logical link between crashes and speed (e.g., run off road crashes in rural areas). Both driveway density and crash history tend to be stronger justification for speed zone changes than other factors in urban areas because of their ultimate influence on the complex relationship between speed and safety.

In areas where crash history alone is a factor, an adjustment of 5 or 10 mph is made. However, crash history is considered in the context of the roadway corridor and other factors (among the five factors affecting the 85th percentile speed) that are usually present. In combination with another factor or multiple additional factors, a 10-mph adjustment to the 85th percentile speed is typical practice but adjustments of up to 12 mph (the maximum allowed) can be made. If a road section's crash rate exceeds the statewide crash rate (for that classification of roadway), it is considered clear justification for a larger adjustment to the 85th percentile speed.

Extent of Speed Adjustments

Since site conditions vary greatly across Texas, there are a myriad of combinations of factors and the extent to which they are applied to modify the field-based 85th percentile (calculated) speed during a speed study analysis. However, it is very rare that factors are applied in such a way that a greater than 10-mph difference exists between the 85th percentile speed and the speed limit value that is ultimately posted. This is a logical outcome of the current process used in establishing speed limits in Texas, since field data collection (and the prescribed calculation of 85th percentile speed) creates consistency between what is considered "rational" driver speed choice and the PSL. Examples of state-maintained locations provided during the interviews where a disconnect may exist between PSL and driver speed choice are rural roadways with poor pavement quality or areas with high truck traffic (such as energy development areas) where the safety influences of large vehicles are not clear to background traffic except when heavy vehicles are immediately present.

It is worth noting that several districts did not adjust the 85th percentile speed by more than 5 mph unless the crash history was a significant factor in the speed study. Where large differences exist between field-measured 85th percentile speed and PSL, there is a background understanding and awareness among the engineering community that other issues—typically safety issues—are behind the discrepancy. If such speed differentials are present in the long term, community outreach to provide increased public awareness and education and/or cooperative work with law enforcement may be necessary to mitigate safety and operational concerns. Some districts noted that locations where a large discrepancy exists between the 85th percentile speed and PSL are locations where more enforcement is necessary.

Supplemental Tools for Developing Speed Zones

Across Texas, the *Procedures for Establishing Speed Zones* (*1*) is the primary—and in many cases the only—methodological resource used for performing speed studies. Since all speed studies include a review of crash history and safety, the TxDOT/Texas Department of Public Safety Crash Record Information System serves as a primary data source for crashes occurring along study corridors. These data are usually used to determine crash totals/frequency as an element of the speed study, but on busier roadways the data can be rendered as a corridor collision diagram.

Other resources used in the speed study analysis process are occasionally used and include the TxMUTCD (*2*) and FHWA's speed zone decision support tool USLimits2 (*68*). The TxMUTCD provides guidance on signing constraints and requirements, while USLimits2 has been used to verify the outcomes of district speed studies. Application of such tools is not wide-spread or consistent in Texas; many districts utilize only the *Procedures for Establishing Speed Zones* (*1*) as they perform their speed studies and develop PSLs.

One area district staff have identified where limited information and resources are available pertains to driveway density. The *Procedures for Establishing Speed* (*1*) identifies this as a factor to be considered in adjusting the 85th percentile speed in the development of a speed zone, but no threshold values are identified for when, and to what extent, the interplay of driveway density and speed can lead to safety or operational concerns. District staff and their experience frame and guide current analyses, but the provision of threshold values and/or application criteria would make this factor more uniformly applied across the state.

Additional Issues Affecting Speed Zones and Studies

Beyond the five factors explicitly mentioned in the *Procedures for Establishing Speed Zones* (*1*), speed zones are affected by the state policy of not having a PSL change greater than 15 mph between successive speed zones. If a change of greater than 15 mph is needed, graduated, or "buffer," zones may be used on approaches to cities and towns to accomplish a gradual reduction of highway speeds to the speed posted at the city limits.

District staff identified the following issues that have an impact on drivers or the driving environment and should be considered if changes are made to speed zoning practices:

- Older drivers and an aging population.
- Locations of city and county limits (and speed limits within city limits).
- Presence of pedestrian traffic, especially near schools.
- Future development (increases in access traffic and driveway density if large developments are known but development has not yet begun).
- An upcoming PSL change may be postponed if a construction/reconstruction project is scheduled for the same roadway section.
- Heavy vehicle volume and/or proportion of the traffic stream, especially if trucks frequently use access points in the corridor (plant entrances, etc.).
- Access/driveways for heavy trucking industries (e.g., quarries).
- Presence of signals or curb and gutter on higher-speed roadways.
- Pavement ride quality/roughness, including seal-coated sections.
- Without enforcement a speed management program cannot be effective.

All TxDOT districts conduct regular safety reviews as part of their roadway system management process. Speed is often an element discussed as part of this review process and conducting a new speed study is among the possible outcomes of these reviews. Such speed studies may identify the need for a speed limit change or can identify trends in speed data that suggest a need for increased enforcement. TxDOT staff communicate these enforcement needs when they are found, though such issues are more common in smaller communities.

Effects of Time on Speed Zones

Some districts have a speed zone review process through which speed zones are regularly reviewed on a three- or five-year cycle. However, in districts where resources are more limited the review process includes only sites where specific concerns have been identified or where speed zone changes can be anticipated, such as at the fringes/transition areas of growing communities. One risk in not being able to regularly review speed limits is that inconsistencies can arise within an area/region of a district. This is not desirable from a driver expectation perspective, so justification is needed to change a speed limit from its existing “baseline” value.

Areas where development is occurring (and driveway density is increasing) are the most frequent locations where speed zones require changing. As these speed studies are performed, the existing PSL can be used as a reference value and quality control check (i.e., speeds should not be increasing in these circumstances) and to monitor whether speed transition areas are needed or need to be repositioned, especially for smaller towns. One district noted that it is not common that an existing PSL will change up or down by more than 5 mph unless a significant change is made in the roadway (e.g., adding lanes and/or shoulders).

At least one district noted a long-term background increase in speeds across the TxDOT network. Possible influences supporting this trend include improved roadway design (e.g., lane and shoulder width) as infrastructure capital and safety improvements are made, as well as overall vehicle improvements as the automobile industry meets evolving/increasing federal requirements and manufacturers provide more safety features with each generation of new vehicles.

Interacting with Counties and Municipalities

District staff interact with staff of larger municipalities much less often than smaller and suburban communities on speed zoning issues. The speed study process and development of speed zones has been effectively institutionalized over time with large cities, but smaller communities—especially developing communities—tend to have more frequent speed zone concerns and questions. The tendency is for developing communities to either request lowered speed zones or adjustments to speed zone limits as the transition areas between rural conditions/undeveloped land shift outward with either commercial or residential development.

TxDOT interaction with smaller communities can involve educating them on speed zoning practices and the speed study process, as well as negotiations on PSLs and locations of speed zones. Some TxDOT districts use a "Setting Speed Limits" pamphlet developed by the TxDOT Government and Public Affairs Division to share basic information about speed zones, but active discussions about a speed study or speed zone issue involve communication by phone and email. While it does not have an easily-quantifiable impact on speed study outcomes, the negotiation process is necessary for meeting both state requirements and community needs.

TxDOT staff can receive pressure from stakeholders regarding their interpretation of the extent to which factors identified in the *Procedures for Establishing Speed Zones* (*1*) should be considered and the quantification of those impacts on the ultimate speed zone value. Negotiations always resolve these issues, though the timeline for a speed limit change can be extended significantly depending on the circumstances. Delays in the implementation of a new PSL can also occur as a speed limit change within municipal boundaries works its way through the development and adoption of a new ordinance. Six, and even eight, months can elapse between the TxDOT acceptance of a revised speed zone and its implementation.

Impacts of Safety Initiatives

TxDOT's "Road to Zero" and the municipal "Vision Zero" programs are relatively recent safety initiatives profoundly focused on reducing, and eventually eliminating, roadway fatalities. Since there is an inherent link between speed and safety, these efforts have potential lasting impacts on the approaches and policies used in selecting PSLs. However, since both programs are in their initial stages of deployment and involve a broad range of community and agency stakeholders, their influences on speed zones have not yet had an impact on TxDOT practice or the *Procedures for Establishing Speed Zones* (*1*).

One noticeable change in recent years has been the increased communication (and performance of cooperative safety studies) between TxDOT and municipal engineering staff. It is anticipated that this will eventually lead to more interaction directly related to speed studies, but this has not yet happened. However, TxDOT districts are becoming more proactive about speed zone reviews and documenting full records for speed studies. Geographic information system (GIS) and spreadsheet-based tools have been used by district staff in organizing their speed management program, but many districts have expressed a need to have agency-wide (TxDOT) tools specifically developed to organize and manage their speed management program.

SPEED MANAGEMENT DEVICES

During Task 2, the research team identified 10 speed management devices that have history in applications for speed management. Most devices have some application for other purposes, including advance warning for curves, advance warning of school zones, improving corridor multimodality, or providing access management; however, for purposes of the current research the attempt was to identify examples of devices applied only for speed management. Device application for speed management is relatively rare, indirectly indicating that the PSLs and enforcement of speed zones are the primary forms of speed management. Several speed management devices—especially speed feedback signs (SFS), lane narrowing, and road diets—

are generally considered urban techniques (and are rarely used in rural areas). District use of these devices varied, and notes pertaining to their application are found in Table 6.

Table 6. TxDOT Application of Speed Management Devices.

Device	Application Notes
Speed Feedback Signs	Applied sparingly to increase effectiveness A "last resort" method to reduce speed Temporary SFS (e.g., trailer-mounted SFS) have been deployed in areas with a speeding concern Maintenance concern where used May indicate enforcement needed Municipal use much more common than TxDOT use, and more common in areas around schools Applied for curve warning rather than speed management Modern units can store data and make them available for review
Transverse Rumble Strips	Applied for locations with unexpected speed change (e.g., intersection ahead, entering rural community, curve warning applications), not necessarily for speed management Can be used to emphasize a change in speed limit Noise complaints possible
Signing Enhancements	Very rare application in some districts, but more common use in others Need to maintain consistency as per TxMUTCD Oversize and red border speed limit signs have been used to highlight speed limit changes Flags have been used to highlight speed limit changes Red borders are used at the first lower speed limit sign drivers encounter as they enter a long section with reduced speed Used where municipalities have a speeding concern Applied sparingly to preserve effectiveness
Optical Speed Bars	Very rare, but usually for curve treatment rather than speed management
Pavement Markings (w/Legend)	Very rare, but usually for curve treatment rather than speed management Applied in school zones
Gateway Treatments	Some applications by smaller communities, but usually just roadside signing Speed reduction (and speed step down) signing routinely used for communities in rural areas Not many applications for speed management purposes to date TxDOT created 2015 guidelines for gateway monuments
Signal Timing	Typical practice is to coordinate signals to posted speed (rather than vice versa)
Reduced Lane Width	Has been applied in urban areas, though mostly by municipalities on local roads Applications found near schools, especially where bike lanes have been added Rural applications uncommon since road width is needed for heavy/large vehicles
Road Diet	Applied in urban areas for multimodal reasons, not necessarily for speed management (though that can be an outcome) Most applications are by municipalities on off-system roads

Device	Application Notes
	Cross section changes usually made to provide turn lanes or other safety improvements Four-lane undivided converted to a two-lane with turn lanes in part to help manage speed In two districts (of the eleven where speed dialogs were held), past applications did not affect corridor operating speeds
Islands/Raised Medians	Applied as an access control or component of another treatment (i.e., pedestrian Z crossing), but not as a speed management technique Applied to provide a pedestrian refuge Overall corridor safety improvement was a main goal of project, so speed management influences helped
Other	Curb delineators are applied for access management, but some speed impacts have been observed Median rumble strips are applied to reduce crashes on undivided roads; may have speed impacts since lanes are often narrowed to provide for installation LED sequential chevrons used in curve warning applications Roundabouts have been or are being considered as an intersection treatment, but not directly for speed management

SPEED ZONE CHANGE SITES

Conducting after studies of sites where recent speed zone changes have been made is intimately linked with the researchers' understanding of driver speed choice response to different PSLs under the same operating conditions. Further, if data are available for several speed studies conducted in the same location over a number of years, researchers can gain additional insight into the impacts of time on speed choice and behavior. The most data for historical speed study locations were supplied by San Antonio District staff, and these data will be considered as part of Task 4. For all district speed dialogs, TTI asked TxDOT staff to identify locations where recent speed limit changes had been made and if there were unique speed zone sites in the study district where the research team should consider performing speed field studies.

Historical Speed Study Data

Historical speed data available from TxDOT districts exists in the form of speed study data recording sheets. An example of such a sheet is provided in Figure 4. To date, TxDOT staff have provided over 200 such data sheets for nine study roadways. All speed sample and site descriptive information from these sheets has been converted to digital data for later analysis by the research team. Speed study sites will be reviewed in order to identify speed data sets at the same location conducted over a cycle of several years. Where available, these sites will be studied for speed change trends over time, whether a speed limit change occurred or not.

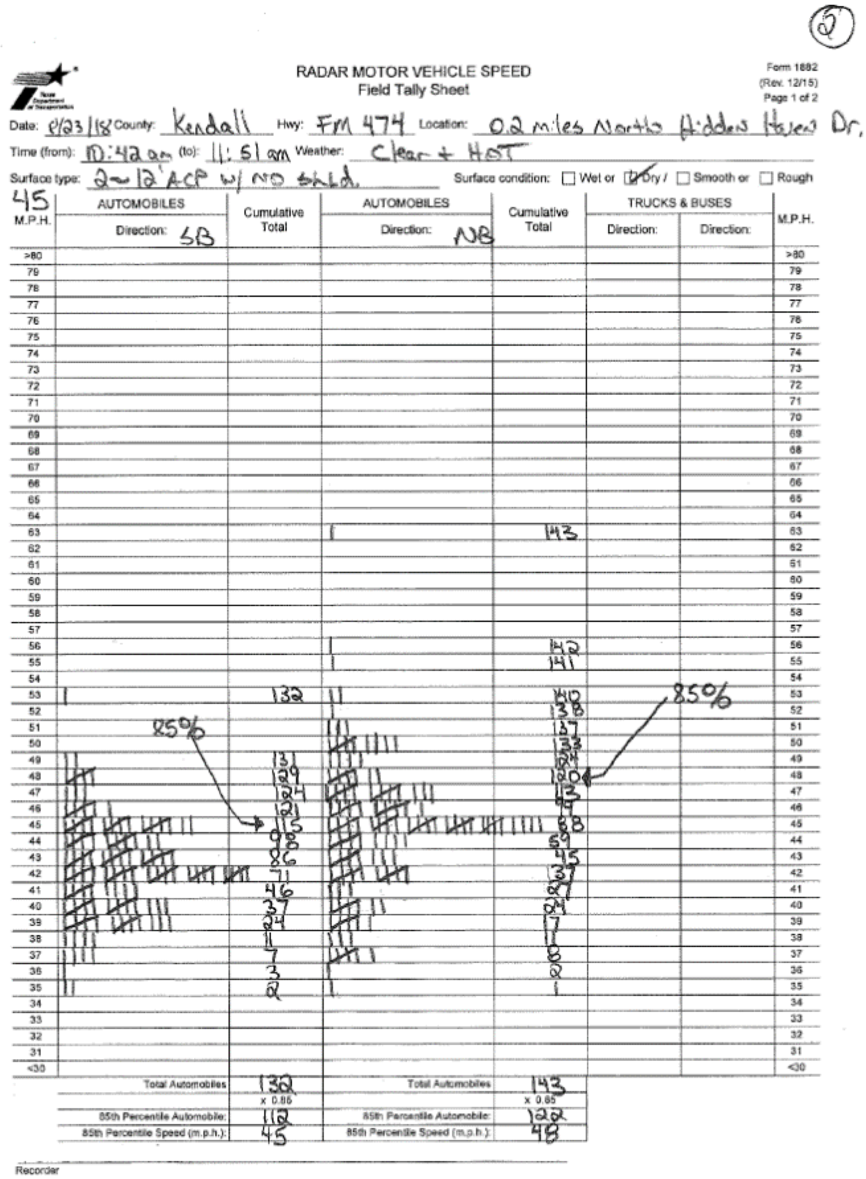


Figure 4. Sample TxDOT Speed Study Data Sheet (Form 1882).

COMMUNICATIONS NEEDS

The research team received a range of input from TxDOT districts regarding their interactions with other public agencies and the public regarding PSLs and the speed zoning process. To facilitate later use by researchers, this feedback has been organized based on the audience with which TxDOT staff have been engaged.

Interaction with the Public

TxDOT engineering staff organizing and performing speed studies typically interact directly with the public at least a few times per year. In urban districts—especially large urban districts with suburban communities surrounding larger metropolitan areas—this interaction can take place as often as once per month. TxDOT staff most often find themselves explaining the process for developing speed zones to the public in these situations and have shared the TxDOT "Setting Speed Limits" pamphlet with the public. For some districts, the pamphlet meets their needs but for others the existing pamphlet falls short as a tool for clearly identifying issues present at a specific site (which is usually the focus of questions directly from the public). Suggestions for changes to the "Setting Speed Limits" pamphlet include:

- Apply modern communications graphics to update and simplify the content.
- Make the material brighter and make better use of color.
- Clarify the relationship between speed and safety and between safety and speed differential.
- Include material on speed limits and safety on the TxDOT website.
- Different pamphlets/material may be needed for communicating with the public compared with communicating with municipal or county officials.
- Use common terms rather than engineering terms (e.g., 85th percentile speed).
- Clearly indicate that speed limits are legal and enforceable, not just the product of an engineering study.
- Clearly indicate whether or not a PSL change improves safety and explain why or why not.

At least two district speed dialog participants indicated that TxDOT staff should always be able to clearly and easily explain how the data and analysis produce the appropriate speed limit value. The speed limit setting process should be readily comprehensible, and the current method (reliant on 85th percentile speed and adjusting based on the five factors listed in TxDOT's *Procedures for Establishing Speed Zones* (*1*)) is confusing to both public audiences and local politicians. "Better" materials are needed to communicate speed management decision making to the public and local politicians. Future, improved tools that incorporate this feedback may provide more information about the process and why it produces the outcomes it does, rather than simply describing how studies are currently performed.

Interaction with Other Public Agencies

When in speed zoning discussions with other agencies—usually municipal staff, but county staff are also sometimes in direct contact with TxDOT—it is common for TxDOT to follow the proscribed process of letter writing (outlined in the *Procedures for Establishing Speed Zones* (*1*), including draft transmittals) to inform other agencies about the results of a speed study and to initiate the process for changing a PSL within municipal boundaries. Because of this open channel of communication before a PSL change is made, any issues are identified—and can usually be addressed—before the change is implemented. Area engineers are engaged in the communications process and can help share information about potential speed limit changes since they are most frequently in contact with municipal staff. It is common for the speed data to "speak for itself" in framing the discussion regarding the potential speed zone change, though municipal or county staff may have a different perspective on how to interpret the various speed study adjustment factors and how they should influence the adjustment of the 85th percentile speed.

Engineering staff from larger municipalities are most familiar with the overall process for setting speed zones, and the process involving interaction with TxDOT for on-system roadways is effectively institutionalized. Smaller and "suburban" municipalities (i.e., independent municipalities surrounding or in close proximity to a large city) usually have the most questions about the procedures for establishing speed zones and the most interaction with TxDOT on behalf of their concerned public to suggest that lower speed limits are needed in their community for "safety reasons." TxDOT access to communication materials indicating that lower speed limits do not necessarily increase safety (i.e., speed differentials may increase, but motorists would drive faster regardless of speed limit because of the nature of the roadway and driving environment, etc.) would help TxDOT staff best support speed study outcomes.

Inasmuch as municipal and county staff are usually contacted on speed-related matters when a member of the public (or public group) is concerned about perceived roadway safety issues, there is a tendency for other public agencies to communicate a need for a lower speed limit than the 85th percentile speed and TxDOT speed study outcome would suggest. This is especially true for smaller communities/cities. TxDOT staff and their ability to communicate a need for following procedures and establishing consistency in practice may not always harmonize with municipal staff and/or the concerns such staff receive from their constituencies. Flexibility exists to some degree in the starting location of a reduced speed zone on the approach to a smaller community; a compromise between a speed study's resultant speed zone value and a community's desire for reduced speed could be relocating the start of a lower-speed zone to include new development at the fringe of a growing community. Also, if the public or public agency's concern is safety, TxDOT can explore safety treatments for corridor-specific issues rather than using a reduced speed limit as a catch-all or proxy means of attempting to improve safety.

Though advance notice of a speed limit change is communicated to municipal engineering staff, there is no control over how thoroughly the upcoming change is communicated within municipal departments. Occasionally law enforcement is not aware of a change in PSL until new signs are erected in the field, reducing early enforcement effectiveness. Ideas for improving this information flow and guaranteeing the information is shared with law enforcement can smooth the transition for a speed zone change.

Interaction with Other TxDOT Staff

TxDOT staff in the district office typically perform speed studies and interact with the Traffic Operations Division regarding the documentation and approval of a speed study and proposed speed limit change, but district area engineers are the frontline staff who generally interact more often (than district office staff) with municipal/county engineering staff and the public. Since area engineers do not have the years of accumulated experience performing speed studies and applying the requirements of TxDOT's *Procedures for Establishing Speed Zones*(*1*), there can be gaps in the communication stream when outside parties are trying to find the full rationale behind the results of a particular speed study.

In circumstances where there are large discrepancies between the results of a speed study and the speed limit expected or desired by local (municipal or county) officials, a district's director of operations or deputy district engineer may become involved in the process. In these cases, the district administration staff may have limited speed study experience and would need to quickly become familiar with the process and the justification for speed study outcomes.

CHAPTER 5: EVALUATION OF SPEEDS ON FREEWAYS

The primary goal of the evaluation using freeway sites was to investigate how much operating speed increased after a change in a PSL and the long-term potential changes in operating speeds.

RESEARCH QUESTIONS

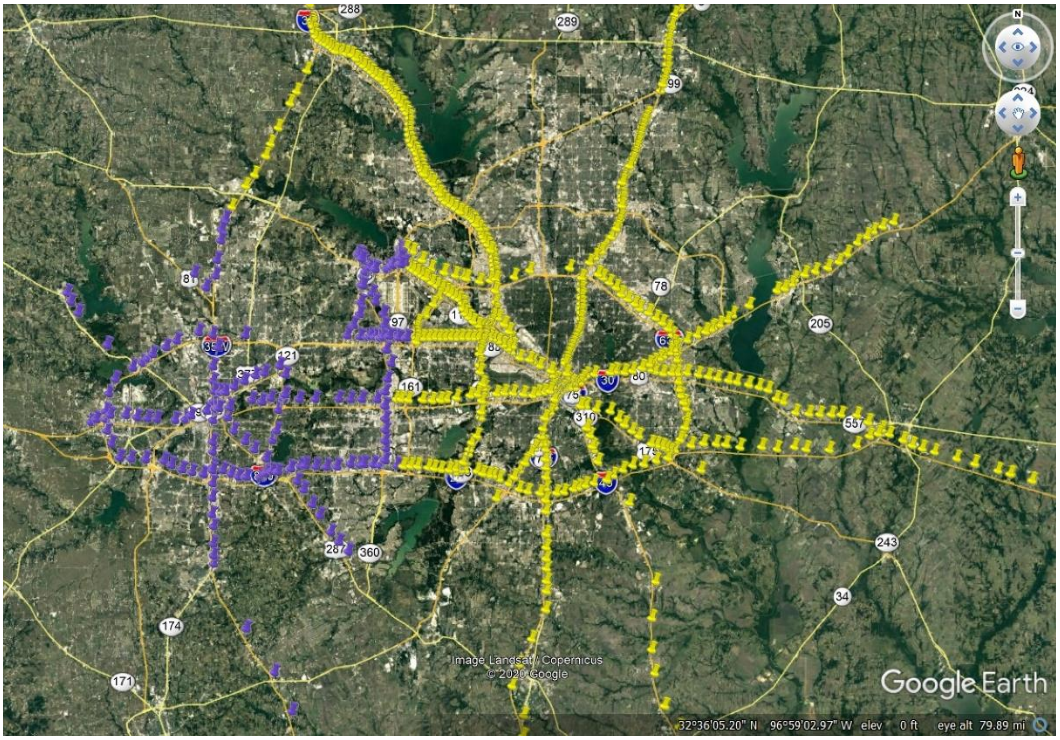
The following research questions guided the development and analysis of the freeway database:

- Freeway Question 1: Do freeway operating speeds change following an increase in PSLs?
- Freeway Question 2: What is the relationship between daytime operating speed (average speed) and the PSL value (after accounting for other factors)? Within this question are the following related questions:
    - What is more influential, PSL or the freeway geometry (cross sections and ramps)?
    - What is the relative contribution to the variability of speed for cross-sectional elements, such as number of lanes, average lane width, or shoulder width? What is the relative contribution of distance to ramps and the type of ramps?
    - What is the relative contribution of variability in volumes in the non-congested range?
    - What is the relative variability by hour of day and day of week?
- Freeway Question 3: On Texas freeways, are operating speeds increasing over time?

SITE SELECTION/SPEED DATA

For the analysis focusing on the relationship of freeway operating speed with PSL, roadway characteristics, and traffic, it was desired to obtain a robust speed dataset, particularly one with several locations of speed and volume data where the PSL was changed. TxDOT operates traffic management centers (TMCs) in all large urban areas of Texas, including Fort Worth and Dallas. Each TMC manages and operates TxDOT freeways within its district. This management is accomplished, in part, by monitoring traffic data from various Intelligent

Transportation System devices such as closed-circuit television cameras, dynamic message signs, and roadway smart sensors (*69*). The smart sensor locations for Fort Worth and Dallas are shown in Figure 5. The smart sensors collect speed, volume, and occupancy (SVO) data.



Source: Background Map Source: Google Maps.

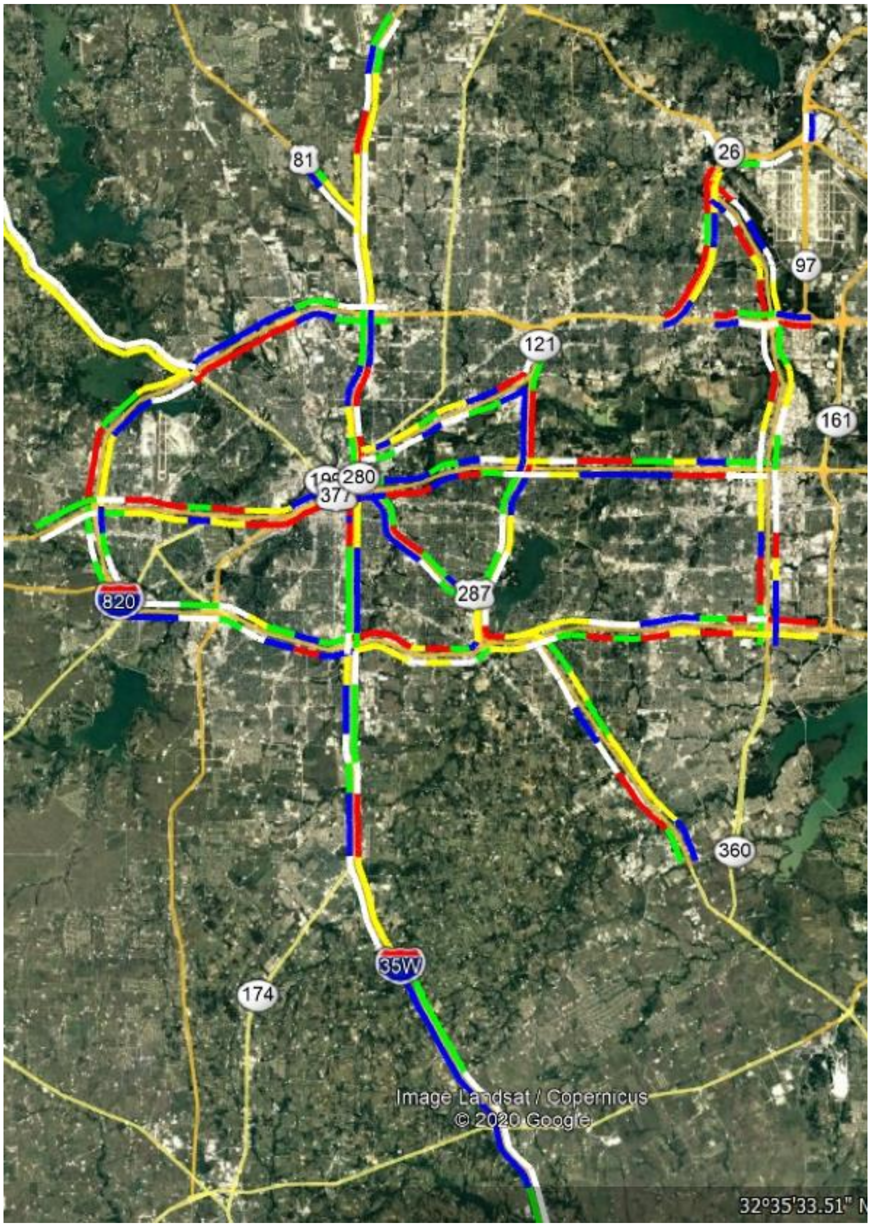
Figure 5. Smart Roadway Sensors for Fort Worth (Purple Pins) and Dallas (Yellow Pins).

The smart sensor data are stored locally in the field then aggregated and archived via the TxDOT Lonestar© advanced traffic management system. A regional data warehouse has been developed for the district's smart sensor data (or detectors). The SVO data are archived by lane at 20-second intervals; however, the system aggregates the data into 5-minute intervals for storage purposes. The lanes are also grouped to links in the database for analysis purposes.

Figure 5 shows approximately 610 detectors in Dallas and 185 in Fort Worth, most of which monitored traffic in both directions on each freeway section. After some review and discussion, researchers decided to use the SVO data from the Fort Worth District but not the Dallas District. The Dallas SVO data use a 'virtual' detector link concept where the data are averaged by lane from one detector at each end of the link. Because the study preferred time-mean speed, this detector link configuration was not as preferrable. Thus, Dallas SVO data were not considered further.

The Fort Worth detector links in Figure 6 are assigned to each detector. Note, most of the links are in Tarrant County. Typically, two detector links are assigned to one detector (one in each direction). There was an initial total of 384 directional links. The researchers reviewed the links and removed several for various reasons such as construction, being on ramps, or data availability. For example, 33 detector links associated with ramps or exits were removed. There were also 20 links that spanned multiple detectors. Upon further inspection, these links had not been updated to reflect the recent detector additions to the network and thus were not considered further. Ultimately, the researchers used 268 detector links for the final dataset.

Researchers examined recent PSL changes within the Fort Worth District with a focus on the ones in Tarrant County. For air quality purposes, the North Central Texas Council of Governments worked with the TxDOT Dallas and Fort Worth Districts to develop a plan to adjust speed limits on environmental speed limit (ESL) designated roadways in 2001 (*70*). However, this action was essentially reversed when the state implementation plan was revised and House Bill 1353, related to speed limits, was signed in 2010. TxDOT districts conducted speed studies to determine the appropriate speed limits needed for each ESL roadway segment. Subsequently, Texas Transportation Commission Minute Order 114203 approved the removal of regional ESLs in January 2015. The research team consulted with Fort Worth's traffic operations special projects coordinator to ascertain when the ESL changes went into effect. The district's records showed the PSL signs were replaced in July 2015. Therefore, researchers had selected the speeds in May 2015 before the speed limits were changed in July. Because researchers also wanted to investigate whether speeds are increasing over time, the data for May of subsequent years 2016–2019 were also gathered. Only one month per year was used to keep the database a manageable size. The researchers also wished to include May 2020 but TxDOT lost the data due to a ransomware attack, so April 2020 was obtained instead.



Source: background from Google Maps.

Figure 6. Fort Worth Detector Links Where a Change in the Colors Reflect a Different Link.

DEVELOPING STUDY DATABASE

The research team assembled a merged database incorporating the following data sources:

- Roadway geometric data gathered from aerial photographs for each of the 268 freeway links selected for study.

- Archived speed data from the detectors on the freeway network, recorded as time-mean speeds for vehicles in 5-minute time slices.
- Light condition data (sunrise and sunset time) from archived almanac records (timeanddate.com).
- Weather (precipitation and visibility) data from the Automated Surface Observing Systems of the National Weather Service.
- Traffic incident data (crashes, vehicle disablements, etc.) from the Fort Worth TMC.

Roadway Geometric Data and PSL Data

The roadway dataset included geometric data, PSL, and presence of construction. The data included observations extracted from aerial and street-level photographs. The roadway dataset consisted of the following:

- The geometric data included lane count, lane width, and characteristics of upstream and downstream ramps.
- The PSL data included the assumed PSL for the segment containing the detector for each year. For example, posted speed limit signs were identified in Google Earth Street Views, and the detectors on the links downstream of such locations were assumed to have a similar PSL. The historical street views were reviewed to determine if a different value for the PSL was present in earlier years.
- The detector year was flagged as having construction when, in the opinion of the research team, the level of construction was believed to affect operating speed. Presence of construction was obtained from reviewing historical aerial and street-level photographs.

The PSL per year data were used to classify each detector location as being in one of the following categories:

- Control(60) = the detector location had a 60-mph speed limit for all years in the database.
- Control(65) = the detector location had a 65-mph speed limit for all years in the database.

- Control(70) = the detector location had a 70-mph speed limit for all years in the database.
- Treat(60-65) = the detector location had a 60-mph speed limit in 2015 and a 65-mph speed limit in other years.
- Treat(60-70) = the detector location had a 60-mph speed limit in 2015 and a 70-mph speed limit in other years.
- Treat(65-70) = the detector location had a 65-mph speed limit in 2015 and a 70-mph speed limit in other years.
- Treat(other) = the detector location had a 60-mph speed limit in 2015, 2016, and 2017 and a 65-mph speed limit in 2018, 2019, and 2020. Only four detectors were in this category, and these sites were dropped from the analysis because of the small sample size with those characteristics.

Weather Data

The weather data file consisted of hourly records of precipitation (inches) and visibility (miles) readings at four weather stations in Tarrant County. The research team merged the hourly precipitation and visibility values into the speed database using the latitude and longitude coordinates for the detectors and the weather stations as well as the date and time variables. Each speed record was matched with the data from the closest weather station or the next-closest weather station if the closest station was non-functional during the hour of interest.

Speed data were marked for removal if within the hour, more than 0 inches of rain occurred. The research team initially considered including speed data when a small amount of rain was present; however, a study in 2017 (*71*) found that free-flow speed decreased by 4.4 percent when rain between 0 and 0.20 in/h was present. Therefore, any 5-minute time slice associated with any rainfall was marked for removal.

Incidents

Because traffic incidents are a major source of nonrecurring congestion (*72*), TMC incidents were compiled from the TxDOT Lonestar© database for the same months as the speed data. This information was used to remove potentially “abnormal” speeds that could have been influenced by these nonrecurring events (discussed in next section).

Table 7 summarizes Fort Worth's TMC incidents by year and type for the month of May for each year between 2015 and 2019, as well as April 2020. The "Other" incident type varied widely and was essentially the catch-all when the event was not classified as any of the other incident types. All amber and news alerts, public service announcements, and public emergency incidents were not included because they are more areawide in nature rather than being associated with a specific detector or freeway section.

Incidents were divided into two categories: Planned (14 percent) and Unplanned (86 percent) events. Planned events typically involve construction, a special event, or a sporting event. Researchers used the "Active" timestamp associated with unplanned events whenever possible ("Pending" timestamp otherwise). The "Detected" timestamp was used for all unplanned events. The significant increase in the number of incidents after 2015 was likely due to the growth in the number of TMC operators available to monitor traffic events.

The research team merged the incident data with the speed data using the latitude and longitude coordinates for the incident as well as the detector and the date and time variables.

Table 7. Fort Worth TMC Incidents in May by Year and Type Considered in this Study.

Incident Type	2015	2016	2017	2018	2019	2020*	Total	Percent
Abandonment	80	96	1	2	155	256	590	3%
Abnormal Congestion	4	2	2	1	—	—	9	0%
Collision	2016	4582	4500	1869	510	243	13720	63%
Construction	945	1614	1890	718	155	214	5536	25%
Special Event	1	3	13	15	—	—	32	0%
Sporting Event	4	6	21	6	6	—	43	0%
Disabled Vehicle	102	390	344	85	180	153	1254	6%
Other	25	140	28	24	6	8	231	1%
Stall	43	17	1	2	5	11	79	0%
Hazmat Spill	—	—	—	2	1	—	3	0%
High Water	18	9	14	9	7	—	57	0%
Ice	2	—	5	1	—	—	8	0%
Maintenance	12	9	8	4	2	3	38	0%
Pedestrian	—	—	2	—	—	—	2	0%
Road Debris	15	17	17	3	3	1	56	0%
Vehicle On Fire	5	12	20	11	4	3	55	0%
Grand Total	3272	6897	6866	2752	1034	892	21713	100%

Note: — = not applicable. * April 2020 (during COVID-19).

Upon additional discussions within the research team, the decision was made to expand the identification of the link-time slice combinations that could be affected by an incident. The researchers believed incidents could be affecting speed for a greater distance than just at the nearest detector. The speed record was flagged as being associated with an incident if the following conditions were met:

- The incident occurred on the same roadway as the speed record.
- The incident started within 10 minutes prior to the 5-minute time slice for the speed record or ended within 20 minutes of the 5-minute time slice.
- The distance between the incident and the detector was less than or equal to 3 miles.
- The incident was not an abandonment. An abandonment is when an unattended vehicle is located and tagged by law enforcement on one of the shoulders. Abandonments were not flagged because they are assumed to cause minimal disruption to traffic flow in the travel lanes.

Light

The research team identified the sunrise for each day represented in the data using archived almanac records (timeanddate.com). Dawn was defined as the time 30 minutes before or after sunrise. Dusk was defined as the time 30 minutes before or after sunset. The research team combined light condition data with the speed records and designated each record as dawn, day, dusk, or night. Data for daytime light condition were used in the analysis.

Databases

Full Freeway Database

The research team imported and processed the speed data for the months of May 2015, May 2016, May 2017, May 2018, May 2019, and April 2020. Each record in the speed data represented vehicles at one detector for one 5-minute time slice. The data records included overall time-mean speeds and lane-weighted time-mean speeds. Records were removed for the following reasons:

- Record contained no vehicles or no speed observation.
- Long-term construction was present on the link during the given month and year.
- Precipitation was recorded during the hour that included the 5-minute time slice.
- Record was associated with an incident.

The research team merged the speed and roadway data using the detector numbers in the files. Both the speed database and the roadway database contained unique numbers for the speed detector at each link. Once the preceding steps were completed, the research team obtained a database with approximately 8 million records, where each record was one roadway link during a 5-minute time slice. This query included incident-flagged speed observations but excluded speed observations that were linked to long-term construction or precipitation during the hour that included the 5-minute time slice. The sample size is shown in Table 8 by year and Table 9 by PSL value; however, these samples were reduced based on additional steps.

Table 8. Distribution of Speed Observations by Year (Full Dataset).

Year	Number of Observations	Percent of Sample
2015	271,586	3.42
2016	1,350,570	17.03
2017	1,432,491	18.06
2018	1,622,474	20.45
2019	1,654,638	20.86
2020	1,600,212	20.17
Total	7,931,971	100.00

Table 9. Distribution of Speed Observations by Speed Limit Value (Full Dataset).

Speed Limit (mph)	Number of Observations	Percent of Sample	Average Speed (mph)
55	89,737	1.13	67
60	2,231,887	28.14	66
65	2,119,030	26.72	68
70	3,491,317	44.02	70
Total	7,931,971	100.00	68

Screened Sample Freeway Database

The database was reduced further by removing the following links:

- As noted above, data occurring during long-term construction.
- Speed limit was 55 mph (small number of sites).
- The segment had five or six general-purpose lanes.
- The segment had one or more managed lanes.
- The next upstream or downstream ramp was a left-side ramp.

The database was reduced further by removing the following time slices:

- As noted above, data occurring during precipitation or when an incident was present.
- Speeds (average or lane-weighted) were less than 53 mph or greater than 90 mph.
- Vehicle count that would suggest a flow of greater than 3,000 veh/hr/lane.
- Dusk, night, or dawn.

The sample size for the screened data is shown in Table 10 by year and Table 11 by PSLs.

Table 10. Distribution of Speed Observations by Year (Screened Sample).

Year	Number of Observations	Percent of Sample
2015	52,118	1.83
2016	435,929	15.28
2017	519,975	18.22
2018	719,368	25.21
2019	570,133	19.98
2020	556,266	19.49
Total	2,853,789	100.00

Table 11. Distribution of Speed Observations by Speed Limit Value (Screened Sample).

Speed Limit	Number of Observations	Percent of Sample	Average Speed
60	762,330	26.71	66.9
65	706,853	24.77	68.6
70	1,384,606	48.52	70.0
Total	2,853,789	100.00	68.8

Binned Freeway Database

Initial attempts to use the screened sample database with approximately 3 million records resulted in multiple computer failures because of the size of the database. Preliminary evaluations used a random sample of the data; however, the researchers decided it was better to address the database size issue by creating 15-min speed readings based on merging data from three consecutive 5-min time slices. The research team binned the screened-sample observations into 15-min periods. The purpose of the binning was to facilitate file handling and modeling efforts, since the analysis software used for modeling (R) was limited in its capabilities to handle large files. This approach allowed the research team to use the entire database rather than doing initial evaluations using a sample of the data and then attempting to use the entire database to confirm the preliminary findings from those initial evaluations.

Descriptive statistics for the binned sample that includes only the 15-min periods starting on the quarter hour that had all three 5-minute periods of speed data available are provided in the following:

- Table 12. Distribution of Speed Observations by Year (Binned Sample).
- Table 13. Distribution of Speed Observations by Speed Limit Value (Binned Sample).
- Table 14. Vehicle Speed and Volume Statistics (Binned Sample).
- Table 15. Cross-Sectional Width Variable Statistics (Binned Sample).
- Table 16. Ramp Distance Statistics (Binned Sample).
- Table 17. Percentage Distribution of Ramp Type (Binned Sample).
- Table 18. Percentage Distribution of Binned Sample by Year and Speed Limit.
- Table 19. Percentage Distribution of Binned Sample by Number of Lanes and Speed Limit.

Table 12. Distribution of Speed Observations by Year (Binned Sample).

Year	Number of Observations	Percent of Sample
2015	16,126	1.80
2016	139,487	15.60
2017	160,671	17.97
2018	216,529	24.22
2019	181,399	20.29
2020	179,921	20.12
Total	894,133	100.00

Table 13. Distribution of Speed Observations by Speed Limit Value (Binned Sample).

Speed Limit	Number of Observations	Percent of Sample	Average Speed
60	238,461	26.67	67.0
65	220,750	24.69	68.7
70	434,922	48.64	70.1
Total	894,133	100.00	68.9

Table 14. Vehicle Speed and Volume Statistics (Binned Sample).

Speed Limit (mph)	Speed (mph)			Volume (veh/hr/lane)		
	Mean	Std. Dev.	Range	Mean	Std. Dev.	Range
60	67.0	3.6	53-82	622	426	2-2971
65	68.7	3.7	53-83	647	422	3-2976
70	70.1	3.8	53-90	692	444	3-2944
Total	68.9	4.0	53-90	662	435	3-2976

Table 15. Cross-Sectional Width Variable Statistics (Binned Sample).

Speed Limit (mph)	Lane Width (ft)			Left Shoulder Width (ft)			Right Shoulder Width (ft)		
	Mean	Std. Dev.	Range	Mean	Std. Dev.	Range	Mean	Std. Dev.	Range
60	12.0	0.3	11.0-12.5	9.8	3.6	4-25	10.6	2.4	4-19
65	12.0	0.3	11.3-12.5	9.4	2.3	4-18	10.2	2.5	4-20
70	11.9	0.3	11.2-12.5	8.9	2.3	4-14	10.9	2.1	6-21
Total	12.0	0.3	11.0-12.5	9.2	2.7	4-25	10.7	2.3	4-21

Table 16. Ramp Distance Statistics (Binned Sample).

Speed Limit (mph)	Downstream Ramp Distance (ft)			Upstream Ramp Distance (ft)		
	Mean	Std. Dev.	Range	Mean	Std. Dev.	Range
60	1241	967	80-6460	1333	913	45-6110
65	1115	1004	80-9120	1313	1056	55-8670
70	1902	1592	115-9120	1989	1676	45-8670
Total	1530	1364	80-9120	1646	1404	45-8670

Table 17. Percentage Distribution of Ramp Type (Binned Sample).

Speed Limit (mph)	Downstream Ramp		Upstream Ramp	
	Entrance	Exit	Entrance	Exit
60	11.87	14.84	14.26	12.45
65	16.20	8.57	9.11	15.66
70	29.27	19.25	17.93	30.59

Table 18. Percentage Distribution of Binned Sample by Year and Speed Limit.

Year	Speed Limit (mph)			Total
	60	65	70	
2015	0.95	0.85	0.00	1.80
2016	4.32	2.93	8.35	15.60
2017	5.38	4.41	8.18	17.97
2018	7.17	7.03	10.01	24.22
2019	4.66	5.05	10.58	20.29
2020	4.19	4.41	11.53	20.12
Total	26.67	24.69	48.64	100.00

Table 19. Percentage Distribution of Binned Sample by Number of Lanes and Speed Limit.

Number of Lanes	Speed Limit (mph)			Total
	60	65	70	
2	4.61	3.94	20.46	29.01
3	17.73	18.61	9.69	46.03
4	4.33	2.14	18.49	24.96
Total	26.67	24.69	48.64	100.00

The overall average speed per year and PSL is shown in Figure 7 and listed in Table 20. Overall, the speeds were fairly similar for a 70-mph road between 2016 and 2019. The potential impacts of the pandemic stay-at-home restrictions (for both businesses and schools), including lower vehicle volumes and less enforcement, can be seen in the 2020 data where overage operating speeds were notably higher for each PSL group. When focusing on 2015 to 2019, the curves for 60- and 65-mph speed limits show an upward trend of higher operating speeds for later years, while the data for 70-mph roads show similar average driving speeds for each year.

Because of the apparent difference in operating speeds for the time period where pandemic stay-at-home restrictions were in place, the research evaluations did not include the 2020 speed data.

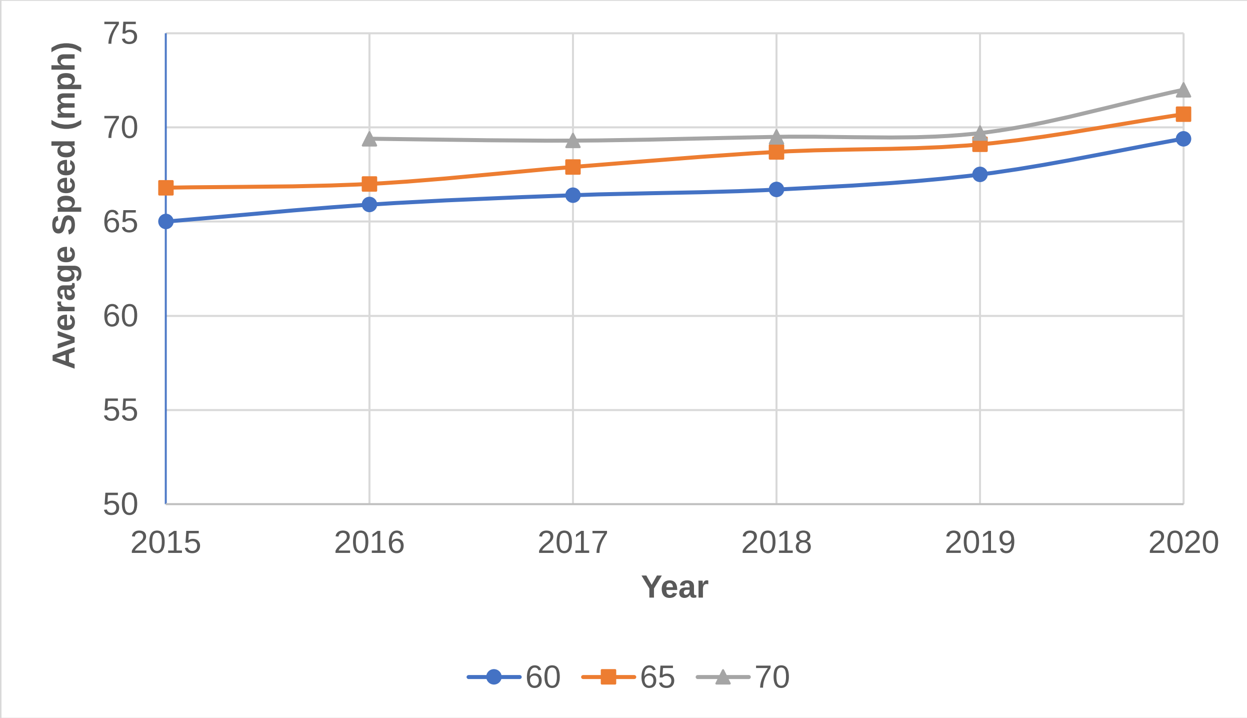


Figure 7. Average Operating Speed by Year and PSL.

Table 20. Average Operating Speed by Year and PSL for Binned Sample.

Year	PSL (mph)		
	60	**65**	**70**
2015	65.0	66.8	No sites
2016	65.9	67.0	69.4
2017	66.4	67.9	69.3
2018	66.7	68.7	69.5
2019	67.5	69.1	69.7
2020	69.4	70.7	72.0
Total	67.0	68.7	70.1
Speed increase between 2016 and 2019	1.6	2.1	0.3

EVALUATION—FREEWAY QUESTION 1

The change in environmental speed limits can be used to address Freeway Research Question 1. The research team consulted with Fort Worth's traffic operations special projects coordinator and learned that the district's records showed the PSL signs were replaced in July 2015. Speed data for May 2015 and May 2016 were compared to identify the amount of operating speed change after the 5-mph speed limit increase.

The sites with data in either 2015 or 2016 were assigned to the following groups:

- Control(60-60) = the detector location had a 60-mph speed limit for both 2015 and 2016.
- Control(65-65) = the detector location had a 65-mph speed limit for both 2015 and 2016.
- Treat(60-65) = the detector location had a 60-mph speed limit in 2015 and a 65-mph speed limit in 2016.
- Treat(60-70) = the detector location had a 60-mph speed limit in 2015 and a 70-mph speed limit in 2016.
- Treat(65-70) = the detector location had a 65-mph speed limit in 2015 and a 70-mph speed limit in 2016.

Because of construction or data availability for a detector, there could be sites that were considered in one year but not the other. Table 21 lists the number of sites per year considered in this analysis.

Table 21. Number of Sites in Before-After Analysis.

Before-After Groups	Number Sites, 2015	Number Sites, 2016
Control(60-60)	45	57
Control(65-65)	10	13
Treat(60-65)	47	35
Treat(60-70)	43	43
Treat(65-70)	47	45
Grand Total	192	193

Table 22 shows the count (sample size) and two major operating speed measures (mean operating speed and standard deviation of operating speed) for each group. The table shows that the after year (2016) has more data entries compared to the before year (2015). For treatment sites with a 5-mph PSL increase, all groups experienced higher average operating speeds in the after year, and the standard deviations of the operating speeds in the after years are lower compared to the before years. For control site groups, while the mean speed is higher, the differences are negligible in values (0.02 mph for 60-mph control group and 0.04 for the 65-mph control group).

Table 22. Count of Readings and Different Operating Speed Measures by Treatment and Control Group in Before-After Period.

Group	N 2015	N 2016	Mean Speed 2015	Mean Speed 2016	Standard Dev. of Speed 2015	Standard Dev. of Speed 2016
Control(60-60)	2782	39,501	65.47	65.49	4.66	4.19
Control(65-65)	1670	60,15	66.20	66.24	3.51	3.49
Treat(60-65)	4922	22,853	64.38	66.79	5.95	4.71
Treat(60-70)	2531	35,773	64.70	67.62	5.25	3.87
Treat(65-70)	6840	39,618	66.83	70.85	5.06	3.70

Table 23 lists three additional operating speed measures (85th percentile speed, or Spd85, percentages over 5 mph from PSL, and percentages over 10 mph from PSL). It was found that 85th percentile speed was not significantly different in the treatment groups during the before and after periods. In the before period for the treatment group, a significant portion of the vehicles (22 to 43 percent) drove 5 mph over the PSL. For the after period for the treatment group, this proportion was comparatively lower (1 to 20 percent). A similar observation was seen in the statistics for 10 mph over the PSL. In the after years for the treatment group, a very negligible percentage of vehicles sped more than 10 mph over the PSL. For the control group, these measures do not notably vary between the before and after periods.

Table 23. Different Operating Speed Measures by Treatment and Control Group in Before-After Period.

Group	Spd85 2015	Spd85 2016	% Over 5 mph 2015	% Over 5 mph 2016	% Over 10 mph 2015	% Over 10 mph 2016
Control(60-60)	70.00	70.00	57.33	55.22	10.89	9.54
Control(65-65)	69.00	69.00	9.46	9.01	0.12	0.08
Treat(60-65)	71.00	71.00	42.89	19.09	18.61	0.42
Treat(60-70)	71.00	71.00	39.87	1.15	16.08	0.01
Treat(65-70)	72.00	74.00	22.02	6.17	6.42	0.35

Table 24 provides the statistical comparison between the before and after mean operating speeds. Within the sections with PSL increases (treatment group), the average operating speed saw an increase. The average operating speed increased between 2.4 and 4.0 mph compared to the 5-mph increase in the PSL or 2.9 mph for the 10-mph increase in the PSL. These operating speed increases were statistically significant. The control groups saw a negligible (in value) and statistically insignificant increase in average operating speed. The change in average operating speed was only 0.02 to 0.04 mph for those roadway segments with no change in the PSL.

Table 24. Average Speed Change by Treatment and Control Group.

Group	Before Mean Speed (mph)	After Mean Speed (mph)	Change (mph)	t-score	95% CI	p-value
Control(60-60)	65.47	65.49	0.02	0.25	[−0.05, 0.04]	0.81
Control(65-65)	66.20	66.24	0.04	0.41	[−0.07, 0.04]	0.68
Treat(60-65)	64.38	66.79	2.41	26.67	[0.42, 0.48]	<0.001
Treat(60-70)	64.70	67.62	2.92	27.44	[0.58, 0.68]	<0.001
Treat(65-70)	66.83	70.85	4.02	62.95	[0.88, 0.94]	<0.001

EVALUATION—FREEWAY QUESTION 2 AND QUESTION 3

Panel Model Using Binned Freeway Database

The format of the available data fit a panel database structure; therefore, the research team decided to use a mixed effect statistical model with nested random effects. This model specification makes an explicit distinction between variables considered as either a fixed feature of the facility (for example, cross-sectional elements) or as variables with a more transient nature (for example, hourly fluctuations). Given this distinction, there are variables that fall on a gray area; for example, AADT was treated as a fixed effect, even though it is not exactly a fixed feature of the facility, because it represents a measurable objective variable equally defined for each facility under study. Similarly, weekly variations in speed were treated as random effects even though they generally tended to form some pattern, but that pattern was highly localized and would vary across detector locations in response to local conditions and the location of each detector relative to specific land uses that generate or attract certain types of traffic at different hours.

Therefore, in the model specification the research team assigned an initial definition of fixed and random effects for the variables that would clearly fall under each category. Additionally, the research team tested (based on the Akaike information criterion, a measure of model entropy) if additional key variables would be more suitable to be modeled as either a fixed or a random effect. **Equation 1** shows the general form of the model specification.

$$Average.Speed_{ijkl} = \boldsymbol{X}' \cdot \boldsymbol{\beta} + Z_i + Z_{ij} + Z_{ijk} + Z_{ijkl} + \varepsilon_{ijkl} \qquad \textbf{Equation 1}$$

Where:

$Average.Speed_{ijkl}$	=	Average 15-min binned speed for the i^{th} Hwy_Cor, j^{th} Link_Name, k^{th} Year, and l^{th} level for GroupDays.
$\boldsymbol{X}$	=	Vector of fixed-effects.
$\boldsymbol{\beta}$	=	Vector of fixed-effects coefficients.
$Z_i, Z_{ij}, Z_{ijk}, and\ Z_{ijkl}$	=	Random effects (or random parameters) at a given level of aggregation.
ε_{ijkl}	=	Residual error.

When handling time series data, it is important to explicitly consider the likely codependence between observations close in time. The mixed-effects framework used in this research allows the implementation of error correlation structures as needed, see Pinheiro and Bates for additional information on the framework (*73*). The modeling structure selected allows for three types of data features explicitly: (a) variables treated as fixed effects, which are expected to have “global” effects that are valid for every unit of analysis; (b) variables treated as random parameters, which can account for clusters or hierarchical structures in the data, as well as for localized variation patterns within those hierarchical structures; and (c) time-dependency in adjacent errors (or residuals) at the lower level of the dataset hierarchical structure. The methods implemented are those widely accepted and used in time series modeling originally proposed by Box et al. (*74*) and Tiao and Box (*75*). For this particular application, the research team selected the simplest autoregressive moving average specification on the series of residuals (not on the response variable, as typically discussed in the literature) which establishes that for a given 15-min period of analysis t:

$$\varepsilon(t) = \rho \cdot \varepsilon(t-1) + \varepsilon_0(t) \qquad \textbf{Equation 2}$$

In other words, the residual for period t is expressed as the prior residual scaled by a constant factor plus an independent remainder $\varepsilon_0(t)$. After several rounds of model selection within the model structure in **Equation 1**, the research team arrived at the specification shown in Equation 3.

The coefficients were estimated using R, open statistical software and packages (*76*, *77*, *78*).

$$\begin{aligned} Average.Speed_{ijkl} &= \beta_0 + \beta_1 \cdot \ln(AggTotalVol + 0.5) + \beta_2 \cdot SL_{Rf60} + \beta_3 \\ &\cdot L_{shld_{wid_{Rf4}}} + \beta_4 \cdot R_{shld_{wid_{Rf10}}} \\ &- \left(I_{DN,EN}\beta_{DN,EN} + I_{DN,EX}\beta_{DN,EX}\right)\ln(d_{DN} + 0.5) \\ &- \left(I_{UP,EN}\beta_{UP,EN} + I_{UP,EX}\beta_{UP,EX}\right)\ln(d_{UP} + 0.5) + Z_{0_i} + Z_{0_{ij}} \\ &+ Z_{0_{ijk}} + Z_{0_{ijkl}} + \varepsilon_{ijkl} \end{aligned} \qquad \textbf{Equation 3}$$

Where:

AggTotalVol	=	15-min volume.
$Average.Speed_{ijkl}$	=	Average 15-min binned speed for the i[th] Hwy_Cor, j[th] Link_Name, k[th] Year, and l[th] level for GroupDays.
β_n	=	N[th] fixed effect coefficient.
β_0	=	Global model intercept (at the fixed-effects level).
$I_{DN,EN}$	=	Indicator variable for downstream entrance ramp (= 1 if the next downstream ramp is an entrance, 0 otherwise).
$I_{DN,EX}$	=	Indicator variable for downstream exit ramp (= 1 if the next downstream ramp is an exit, 0 otherwise).
$I_{UP,EN}$	=	Indicator variable for upstream entrance ramp (= 1 if the next upstream ramp is an entrance, 0 otherwise).
$I_{UP,EX}$	=	Indicator variable for upstream exit ramp (= 1 if the next upstream ramp is an exit, 0 otherwise).
$\beta_{DN,EN}$	=	Calibration coefficient for downstream entrance ramp.
$\beta_{DN,EX}$	=	Calibration coefficient for downstream exit ramp.
$\beta_{UP,EN}$	=	Calibration coefficient for upstream entrance ramp.
$\beta_{UP,EX}$	=	Calibration coefficient for upstream exit ramp.
d_{DN}	=	Distance to next downstream ramp (ft).
d_{UP}	=	Distance to next upstream ramp (ft).
$R_{shld_{wid_{Rf10}}}$	=	Right shoulder width (ft) with respect to a 10-ft shoulder. A 10-ft shoulder would have a value of 0, while a 11-ft shoulder would have a value of 1, etc. for this variable.

$L_{shld_{wid_{Rf4}}}$	=	Left should width (ft) with respect to a 4-ft shoulder. A 4-ft shoulder would have a value of 0, while a 4-ft shoulder would have a value of 1, etc. for this variable.
SL_{Rf60}	=	Speed limit (mph) with respect to 60 mph (i.e., a 65-mph speed would have a value of 5 mph in this database).
$Z_{0_{ijkl}}$	=	Local model intercept for l^{th} GroupDays (second level of temporal aggregation).
$Z_{0_{ijk}}$	=	Local model intercept for k^{th} Year for j-th Link_Name (first level of temporal aggregation).
Z_{0_i}	=	Local model intercept for i^{th} Hwy_Cor (first level of spatial aggregation).
$Z_{0_{ij}}$	=	Local model intercept for j^{th} Link_Name (second level of spatial aggregation).

Table 25 shows the estimates for the fixed effects part of the model that used the binned database (i.e., 15-min period data where all three consecutive 5-min periods were available). The results have direct implications in understanding the relationships between operational speed and other key variables found relevant in the final model. The following sections describe those implications in more detail.

Fixed Effects Coefficients

From the fixed-effects coefficient estimates (see Table 25) the model indicates the following:

- Operating speed decreases with increasing 15-min volume. A 50 percent increase in volume is associated with a speed reduction of 0.40 mph (−0.99083 × ln(1.5) = −0.40175) or a reduction of 0.69 mph if the volume doubles (−0.99083 × ln(2) = −0.68679).
- Operating speed increases with increasing speed limits. For each 5-mph increase in the PSL, the operating speed increases by 1.6325 mph (0.3265 × 5 = 1.6325); for example, a 10-mph increase in posted speed going from a 60-mph freeway to a 70-mph freeway would have an operating speed increase of 3.265 mph, with all other characteristics staying the same (0.3265 × 10 = 3.265).

Table 25. Model Parameter Estimates.

Fixed Effects						
Parameter	**Variable**	**Estimate**	**Std. Err**	**DF**	**t-value**	**p-value**
β_0	Base speed (intercept)	64.77454	2.056911	709613	31.49118	<1e-04
β_1	15-min volume	−0.99083	0.007735	709613	−128.093	<1e-04
β_2	Speed limit relative to 60 mph	0.3265	0.030277	741	10.7839	<1e-04
β_3	Left shoulder relative to 4 ft	0.14591	0.063545	212	2.29608	0.0226
β_4	Right shoulder relative to 10 ft	0.13854	0.070469	212	1.96591	0.0506
$\beta_{DN,EN}$	Distance to closest downstream ramp, entrance	−0.46489	0.20609	212	−2.25577	0.0251
$\beta_{DN,EX}$	Distance to closest downstream ramp, exit	−0.38102	0.220111	212	−1.73104	0.0849
$\beta_{UP,EN}$	Distance to closest upstream ramp, entrance	−0.43942	0.175141	212	−2.50893	0.0129
$\beta_{UP,EX}$	Distance to closest upstream ramp, exit	−0.51354	0.166343	212	−3.08727	0.0023
Random Effects and Residuals						
Parameters	**Variable**	**Standard Deviation**				
Z_{0_i}	Hwy_Cor	1.341091				
$Z_{0_{ij}}$	Link_Name	2.152584				
$Z_{0_{ijk}}$	Year	1.88937				
$Z_{0_{ijkl}}$	GroupDays	1.144867				
$\varepsilon_{0_{ijkl}}$	Independent Residual	1.958449				
ρ	Autocorrelation parameter	+0.61001				

- Operating speed increases with a wider left shoulder. For an additional foot of left shoulder, the operating speed increases by 0.14591 (0.14591 × 1.0 = −0. 14591).
- For this analysis, the relationship between speed and the right shoulder was similar to that found for left shoulders. For an additional foot of right shoulder, the operating speed increases by 0.13854 (0.13854 × 1.0 = −0.13854).
- As expected, operating speeds are higher when the distances to upstream and downstream right-side ramps are longer (statistically significant). Observation between speed and left-side ramps cannot be made as this database did not contain locations where the closest upstream or downstream ramp was on the left-side. These locations were removed due to the small number of sites with that geometric feature. Speeds are increasing with greater distances even though the coefficient has a

negative sign because the model format as shown in Equation 3 includes a negative sign prior to the coefficient.

- If the closest downstream ramp is an entrance ramp and the distance is 100 ft, the operating speed is estimated to be higher by 2.14 mph (2.143 = 0.46489 × ln(100 + 0.5)), compared to a point at the ramp. If the closest downstream entrance ramp is 1,000 ft, the operating speed is estimated to be higher by 3.21 mph (3.212 = 0.46489 × ln(1000 + 0.5)), compared to a point at the ramp.
- When the closest downstream ramp is an exit ramp and the distance is 100 ft, the operating speed is estimated to be higher by 1.76 mph (1.757 = 0.38102 × ln(100 + 0.5)), compared to a point at the ramp. When the downstream exit ramp is 1,000 ft, the operating speed is estimated to be higher by 2.63 mph (2.632 = 0.38102 × ln(1000 + 0.5)), compared to a point at the ramp.
- When the closest upstream ramp is an entrance ramp and is 100 ft distance, the operating speed is estimated to be higher by 2.03 mph (2.026 = 0.43942 × ln(100 + 0.5)), compared to a point at the ramp. If the upstream entrance ramp is 1,000 ft, the operating speed is estimated to be 3.04 mph higher (3.036 = 0.43942 × ln(1000 + 0.5)), compared to a point at the ramp.
- This analysis found upstream exit ramps most influential on operating speed, compared to other ramp types. When the upstream ramp is an exit ramp and is located 100 ft from the sensor, the operating speed is estimated to be higher by 2.37 mph (2.368 = 0.51354 × ln(100 + 0.5)), compared to a point at the ramp. As with other ramp types, speeds are higher when the upstream exit ramp is a greater distance away from the sensor. For example, if the upstream exit ramp is 1,000 ft, the operating speed is estimated to be higher by 3.55 mph (3.548 = 0.51354 × ln(1000 + 0.5)), compared to a point at the ramp.

The fixed effects are the part of the model that can be interpreted more directly. The following sections describe the results from other model components and their implications.

Random-Effects Coefficients

In the model estimation, the random-effects coefficients are estimated for each unit of nested aggregation as described when defining the model. However, interpreting the individual values of those estimates is generally not relevant since the estimate is specific to a given location or given period at a given location. It is of interest, however, to provide some descriptive statistics on the random-effects estimates since they describe general trends in the data not explicitly captured in the fixed-effects part of the model. The model in this research has nested random effects with two tiers of spatial aggregation and two of temporal aggregation as described next.

Spatial Random Effects

The first two levels of aggregation are spatial: first by corridor, and second by specific detector location within a corridor. Figure 8 shows the histogram of the adjustments per corridor applied by the model in the first level of aggregation. It can be seen that a large proportion of corridors have adjustments smaller than 1 mph with all but one having adjustments less than 2 mph.

Figure 9 shows the histogram of adjustments per detector location, which the model applies in addition to the corridor adjustment. It can be seen from Figure 9 that the amount of variation captured by the detector location–specific random effect is larger than by corridor; the approximate range of these adjustments is (−6 mph, 4 mph), compared with the approximate range for corridor adjustments of (−3 mph, 2 mph).

Temporal Random Effects

In order to capture yearly trends at specific locations, the model provides an adjustment each year with data at each detector location under study. These yearly adjustments are applied in addition to the two spatial adjustments shown in the prior section. Figure 10 shows boxplots of all yearly adjustments that show a trend of mean speed increasing with each year. Additionally, when calculating 95 percent confidence intervals around the means of these adjustments, it is clear that the trend cannot be discarded as random noise (see Figure 10). From 2015 to 2019, average speeds on Fort Worth freeways have increased by 1.4 mph.

Finally, in the last level of aggregation, the model applies an adjustment per day of the week at each detector location per year of data in the analysis. The value coded for day of the week was as follows: 1 for Monday, 3 for either Tuesday, Wednesday, or Thursday, 5 for Friday, 6 for Saturday, and 7 for Sunday. Figure 11 shows the trend of this effect for a random sample of 20 detector locations.

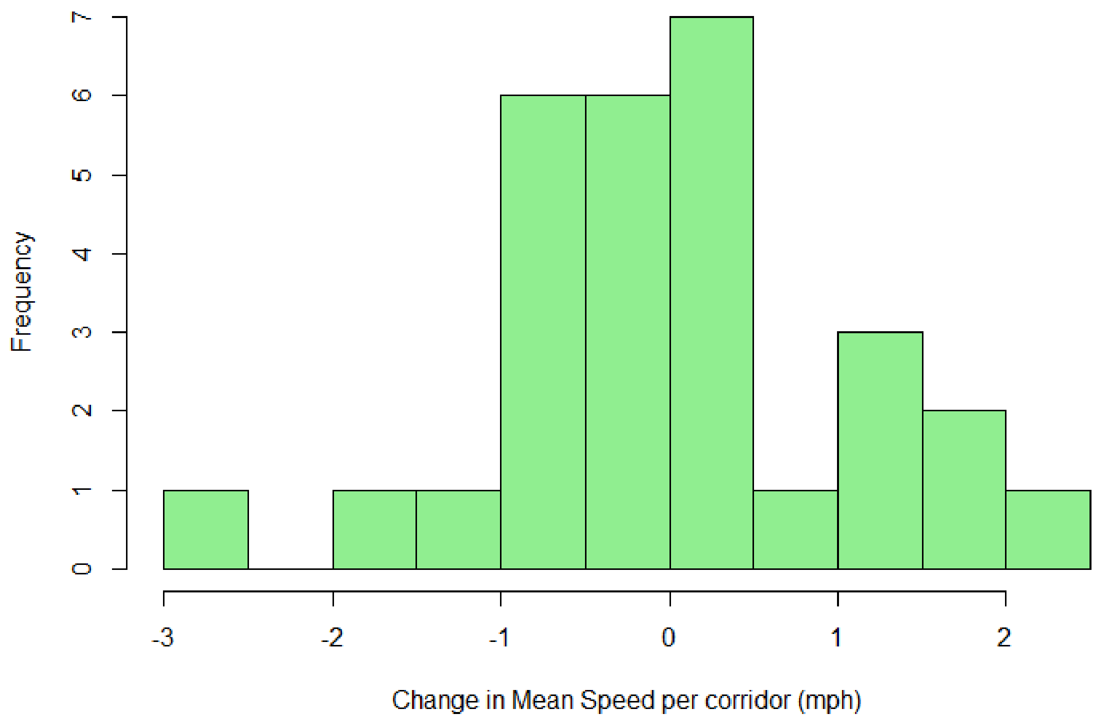


Figure 8. Histogram of Adjustment per Corridor.

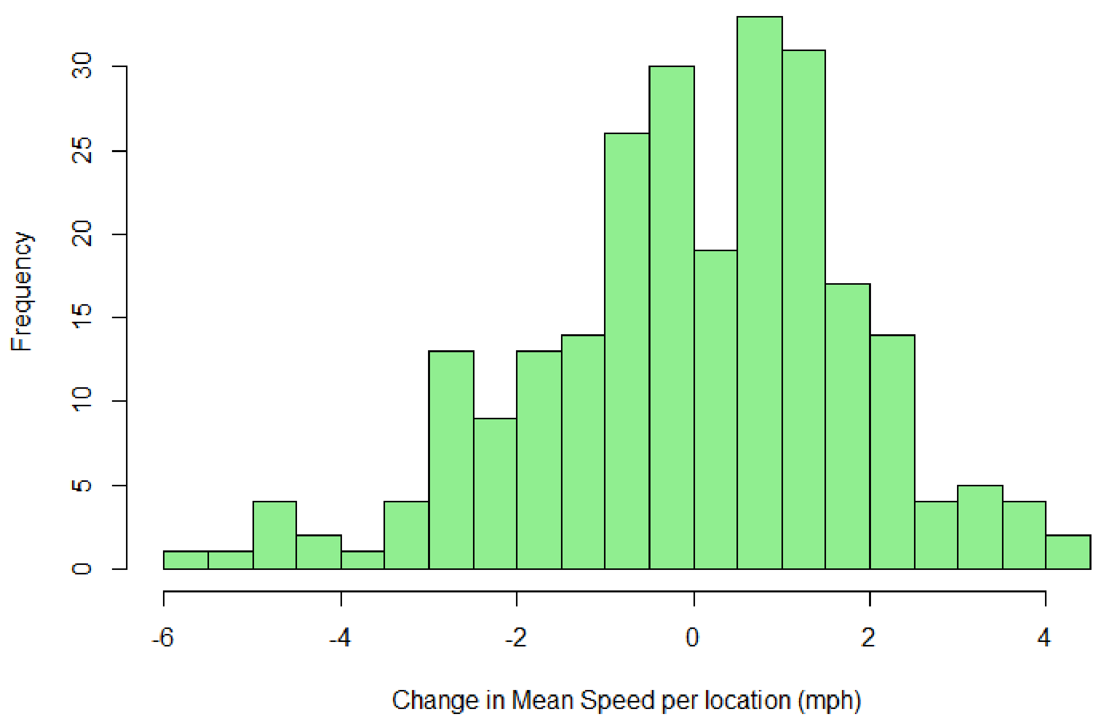


Figure 9. Histogram of Adjustment per Location.

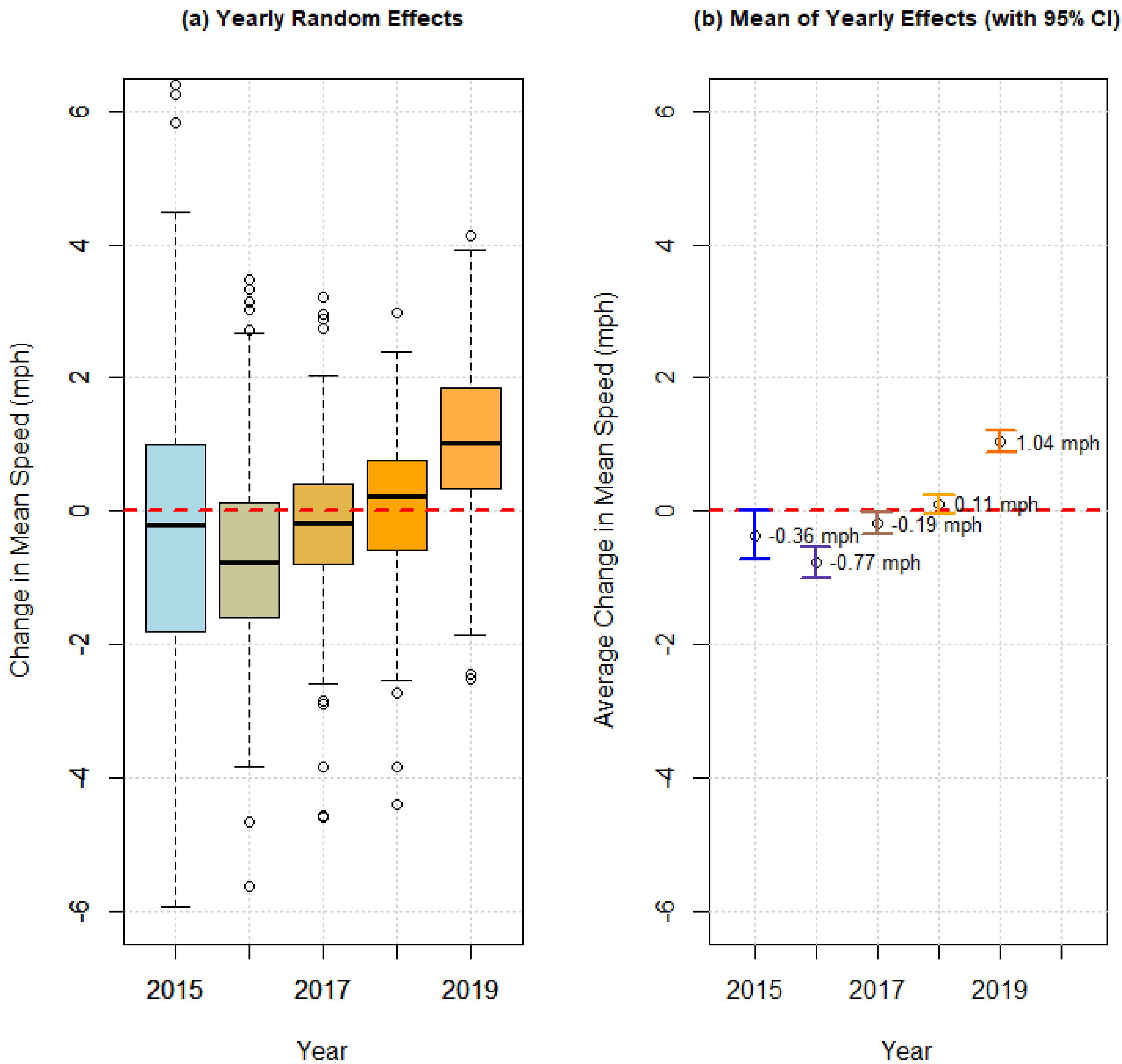
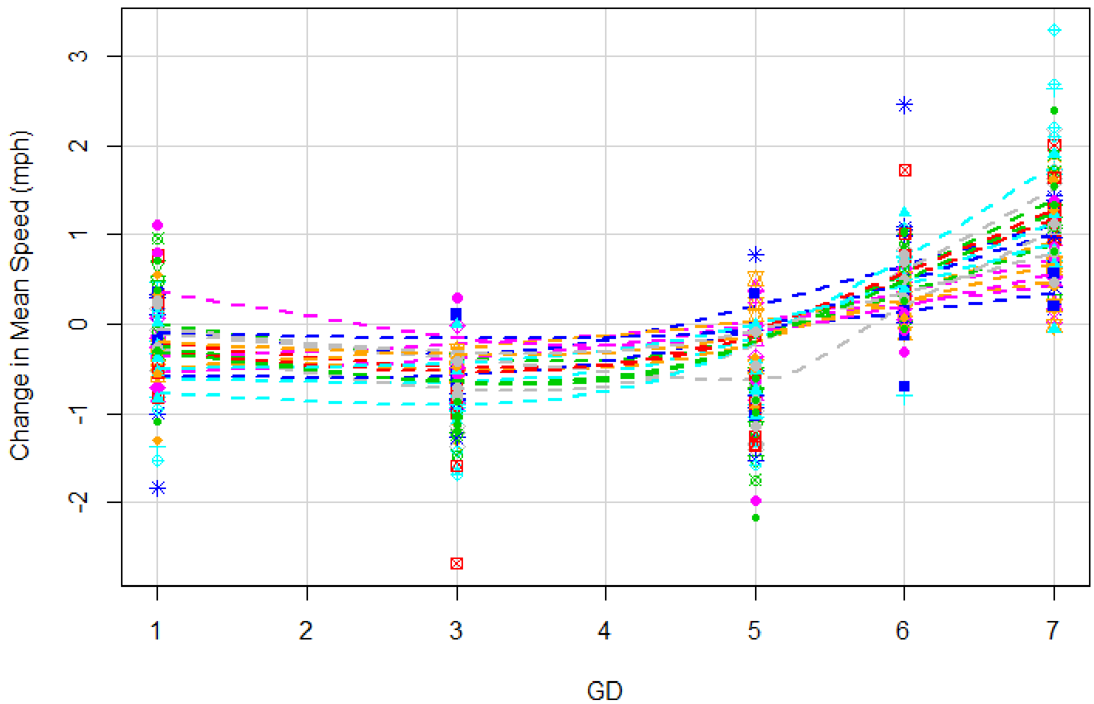


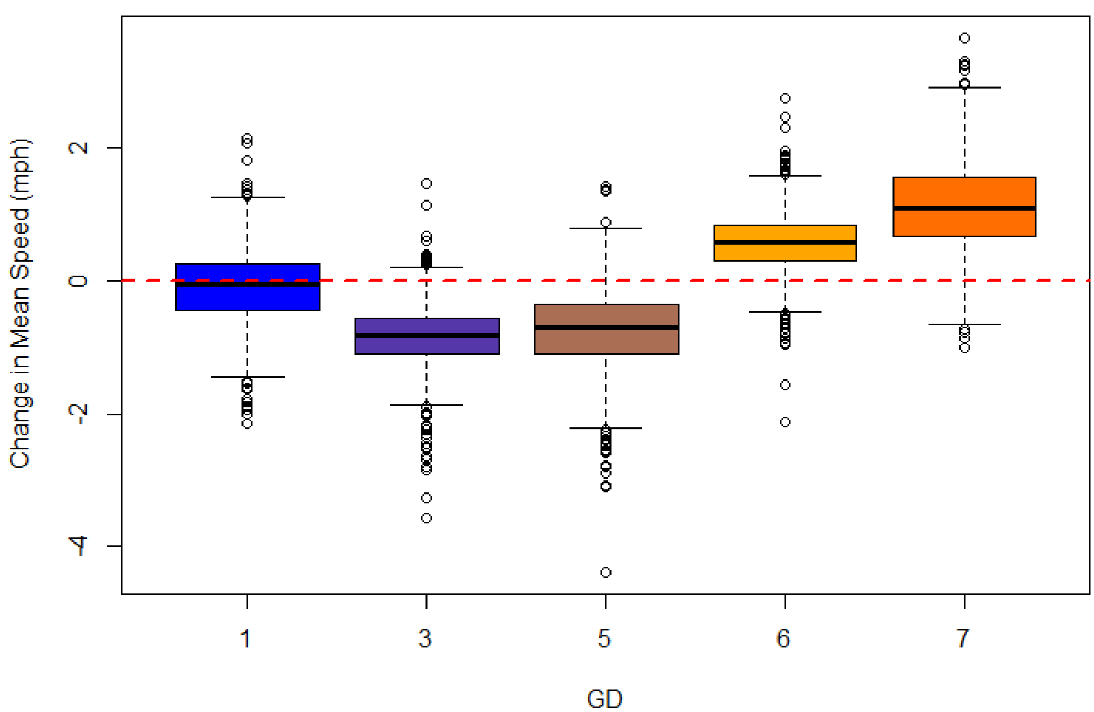
Figure 10. Example of Trend for Increase in Speed with Increasing Years.

It can be seen that the speed adjustments are relatively flat for the first four days of the week (i.e., comparable baseline speeds) and then it consistently increases from Friday to Sunday. When plotting all weekday random effects (see Figure 12), a similar pattern emerges. However, in this later plot it is clear that Monday tends to have faster speeds compared to Tuesday through Friday. After adjusting for other variables, Saturday and Sunday remain the days with faster speeds.



Note: 1 = Monday, 3 = either Tuesday, Wednesday, or Thursday, 5 = Friday, 6 = Saturday, and 7 = Sunday.

Figure 11. Trend for Day of Week.



Note: 1 = Monday, 3 = either Tuesday, Wednesday, or Thursday, 5 = Friday, 6 = Saturday, and 7 = Sunday (different colors are present; however, they are provided to help the reader see the differences between the boxplots).

Figure 12. Weekday Random Effects.

Relative Contribution of Different Factors to the Variability of Operating Speed

To gain perspective on the factors that explain the variability observed in the key variable (i.e., operating speed), this section quantifies the contribution of said factors to the operating speed variability, as estimated by the model described in the previous section. This model provides an explicit account of how the factors of interest relate to the operational speed, and therefore, it is possible to quantify their systematic variation. The total variability by all explanatory factors in the model combined with the residual variability that remains unexplained by the model should amount to the total variability in the response variable.

Table 26 summarizes the breakdown of the variation in the response variable by level of aggregation according to the model. The fourth column of Table 26 (percent of incremental explained variance) shows the percent of variation associated with each explanatory factor in the model. Only 4.2 percent (0.664866 mph^2) of the total variability in the response variable (15.7648 mph^2) can be explained by the variation in 15-min volumes. Although this percentage appears somewhat small, as a reminder, the dataset was based on uncongested traffic conditions as previously described.

For PSLs, which are a focus of this analysis, 12.0 percent (1.898861 mph^2) of the total variation in operational speed can be attributed to the differences in speed limits. In other words, the range of variability that can be attributed to the PSL and not to other factors is expectedly small. Indeed, although the range of the PSL in the model dataset is 10 mph (i.e., from 60 mph to 70 mph), it can be seen in Table 25 that the intercept of the model (64.77 mph) represents the base speed at 60 mph. If the speed limit were to increase to 70 mph (by 10 mph, which is the range in the model dataset) that would amount to a modest but measurable increase in mean speed to 68.04 mph (or a 3.265 mph increase calculated as $3.265 = 0.3265 \times [70-60]$). Other variables describing freeway geometric configuration (i.e., shoulder width and relative location of ramps) are associated with a 6.8 percent of the operational speed variation (1.0780 mph^2).

Jointly, the factors in the fixed effects (i.e., 15-min volume, speed limit, and geometrics) explain 23 percent of the total variation in operational speed in the dataset (3.641727 mph2). The model attributes a comparable amount of variation (3.982365 mph^2 or 25.3 percent) to other unaccounted factors at the detector location (i.e., Link_Name variable) level. This amount of variance is captured as the variation of the Link_Name specific random effects. Because these random effects are gross adjustments of the model to the data per detector location, the interpretation indicates that a significant amount of variation (25.3 percent) exists from detector location to detector location, such that it is not explained by any of the other variables in the model.

Table 26. Variation in Response Variables by Level of Aggregation.

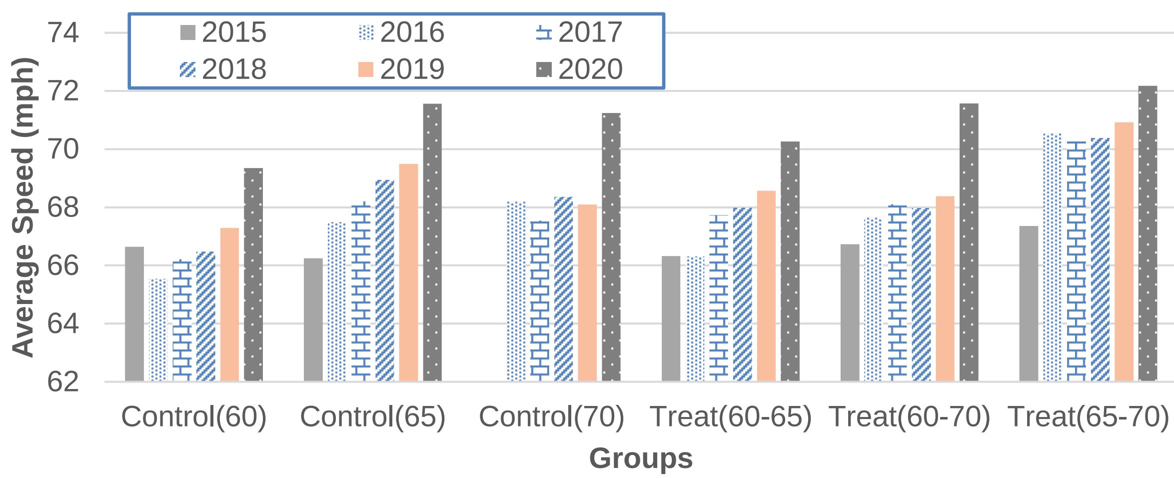
Explanatory Factor (i.e., variables)	**Cumulative Variance (mph^2)**	**Incremental Explained Variance (mph^2)**	**Percent of Incremental Explained Variance (percent)**	**Standard Deviation of Speed (cumulative) (mph)**	**Expected Range of Variation (95% Coverage Interval) (mph)**
15-min Volume	0.664866	0.664866	4.2%	0.815393	+/− 1.6
Speed Limit	2.563727	1.898861	12.0%	1.601164	+/− 3.14
Geometrics	3.641726	1.078	6.8%	1.908331	+/− 3.74
Hwy_Cor	3.891189	0.249462	1.6%	1.97261	+/− 3.87
Link_Name	7.873553	3.982365	25.3%	2.805985	+/− 5.5
Year	10.49177	2.618212	16.6%	3.2391	+/− 6.35
GroupDays	11.64669	1.154925	7.3%	3.412725	+/− 6.69
Residuals	15.76482	4.118126	26.1%	3.970493	+/− 7.78

A 16.6 percent (2.618212 mph^2) of variation in operational speed is associated with the yearly increasing trend observed at the Link_Name level. In comparison, less than half that amount of variation (7.3 percent or 1.154925 mph^2) can be attributed to differences in speeds by day of the week. The smallest amount of variation in the grouping structure was found to be linked to Hwy_Cor, explaining only 1.6 percent (0.249462 mph^2) of the total variation.

Finally, 26.1 percent of the variation in the operational speed was captured in the model residuals (4.118126 mph^2), which means that the remaining 73.9 percent of speed variation is explained by the fixed and random effects combined.

Other Possible Contributions to Operating Speeds in Fort Worth

The previous evaluation explored what roadway or site variables affect operating speed and whether operating speeds are consistently increasing (or decreasing) over time on Fort Worth's urban freeways. Researchers used available speed detector data from TxDOT's Fort Worth TMC, TransVision. Operating speeds were averaged into 15-min intervals for 243 detector locations within "control" or "treated" groups. Treated detector locations had a 5 or 10 mph PSL change between 2015 and 2016, while the control group represented detector locations with constant speed limits (either 60, 65, or 70 mph). Figure 13 shows the average operating speeds between 2015 and 2020 by before and after groups.



Where the groups included the following:

- Control(60) = the detector location had a 60-mph PSL for all years.
- Control(65) = the detector location had a 65-mph PSL for all years.
- Control(70) = the detector location had a 70-mph PSL for 2016 to 2020 (none of the sites in this database had a 70-mph speed limit during 2015).
- Treat(60-65) = the detector location had 60-mph PSL in 2015 and a 65-mph PSL in other years.
- Treat(60-70) = the detector location had 60-mph PSL in 2015 and a 70-mph PSL in other years.
- Treat(65-70) = the detector location had 65-mph PSL in 2015 and a 70-mph PSL in other years.

Figure 13. Average Freeway Operating Speeds by Year for Control or Treated Groups.

Researchers observed speed creep, defined as an incremental increase in operating speed over time, between 2016 and 2019 for the 60 mph and 65 mph control detector locations as well as the Treat(60-65) detector locations. There appears to be either no or minimal speed creep in the 70-mph control detector location or the Treat(60-70) and Treat(65-70) detector locations.

Hauer (*79*) argues that speed creeps, or "evolves," over time but it is not clear as to why. He suggests some possible reasons such as the cycle of applying the 85th percentile to set speed limits that results in increases in the posted speed limit along with most motorists driving faster than the PSL, most drivers thinking they are better than average drivers and attempting to drive faster than the average, speed spillover or adaptation phenomenon, or greater prevalence of wider roads, which are associated with higher speeds. Hauer provides an example of the average operating speed for Montana rural interstates that saw an increase in average operating speed between 1996 and 1998 when the base rule (reasonable and prudent) existed. The average speed value had become fairly consistent around 1998, when the posted speed limit became 70 mph, and remained so until 2007, which was the limit of the study.

The research team explored several possible explanations for why operating speed are different across the years in Fort Worth.

Enforcement Activity

One possible explanation, at least in part, for the increase in operating speeds is reduced enforcement activity. Researchers investigated available enforcement speeding citation data from the Department of Public Safety (DPS) and city and county police departments. Figure 14 shows there was an 11 percent decrease in speeding citations by municipalities and a 25 percent decrease by DPS between 2016 and 2019.

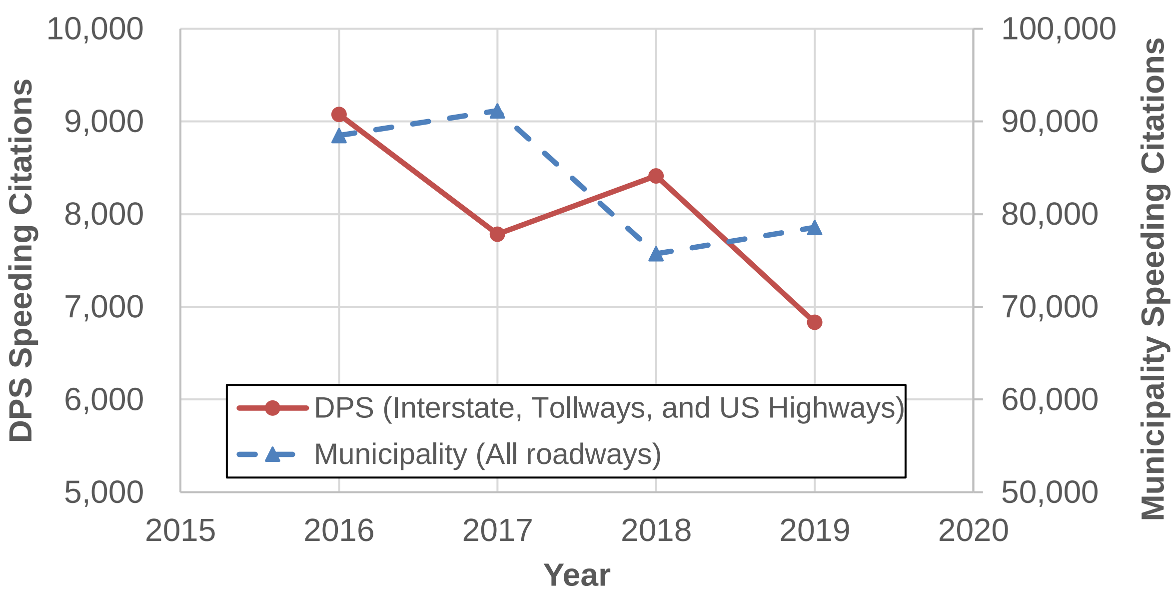
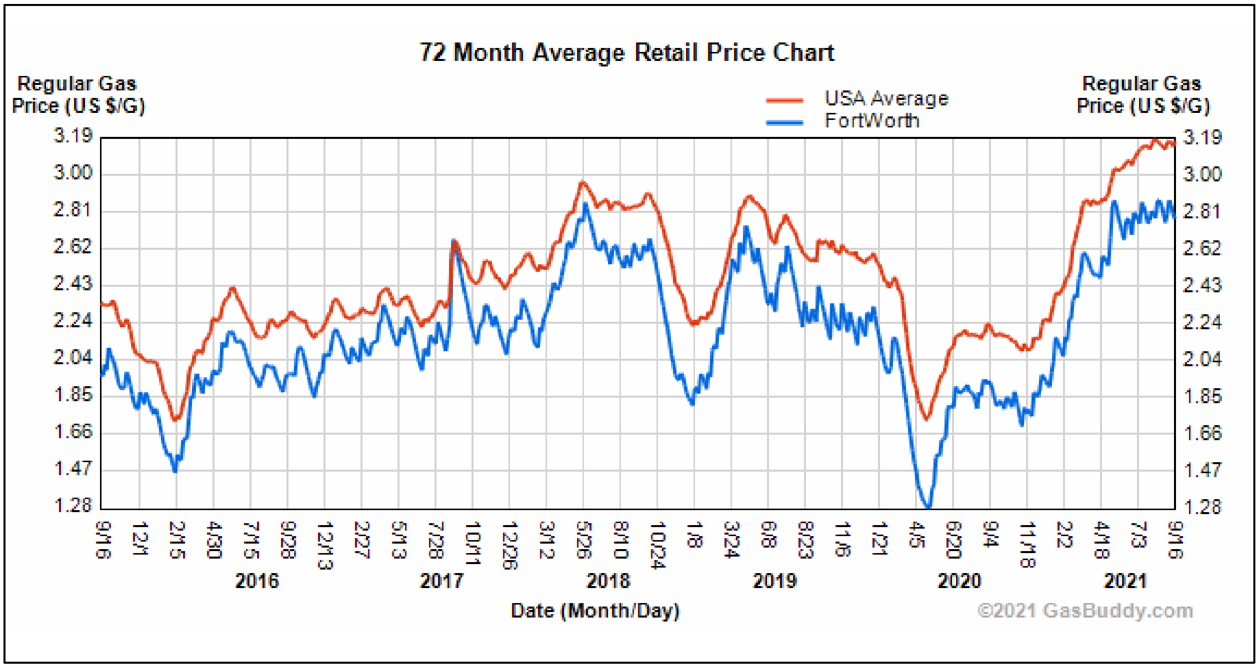


Figure 14. Tarrant County Speeding Citations.

Fuel Prices

Another possible explanation is the significant fluctuations in fuel prices. Researchers gathered available fuel prices from GasBuddy.com. The hypothesis was if fuel prices were low or reduced to low enough levels, then motorist may be more apt to speed because they would not be as concerned about "burning" their fuel. Figure 15 shows that except for Q4 in 2018 and Q1 in 2019, fuel prices slightly increased between 2016 and 2019. Unfortunately, this did not explain why speed creep occurred.



Source: https://www.gasbuddy.com/charts.

Figure 15. Average Fuel Prices (United States vs. Fort Worth, TX).

Location within System

Researchers also investigated which detector locations experienced speed creep to explore if where the detector is located within the freeway system could explain the pattern. Researchers used each detector location–specific random y-intercept in the regression model developed in this study. The team compiled this y-intercept value (i.e., slope) for each detector location and year. Then researchers used the least square fit method to calculate the linear regression of the y-intercept values between 2016 and 2019 (i.e., the time period when the PSL did not vary for the specific detector location). The resulting value indicates how much speed creep occurred overall at the detector location. A more negative value means that the detector location's adjustment in the model is more toward a lower speed as compared to the baseline (2016), and a more positive value means more toward a higher speed. Thus, the detector locations with the most positive numbers are the ones where operating speed increased the most and are not otherwise explained in the model for a given year at given detector location. Researchers developed three slope ranges based on the distribution of the results. There were 46 detector locations with slopes greater than 1.164 (i.e., experienced speed creep). These detector locations are shown with red icons in Figure 16.

Table 27 and Table 28 list the top 10 control detector locations and the top 10 treated detector locations with speed creep, respectively. These detector locations tended to be on the circumferential freeways, such as IH 20 and IH 820 (west side), and within close proximity to interchanges. There was also a cluster of detector locations on SH 360, between SH 183 and IH 30.

Table 27. Top 10 Control Detector Locations with Speed Creep.

No.	Cor_Link	DIR	Slope	PinName	Before-After Categories
1	I820.Trinity.SB.DET-M-link1.SB	SB	5.82	IH820-16-SB	Control(60)
2	SH360.Brown Blvd-W-link1.SB	SB	2.66	SH360-07-SB	Control(60)
3	SH121.Minnis.NB-S-link2.NB	NB	2.34	SH121-06-NB	Control(65)
4	SH199.FM 1886.EB-S-link1.WB	WB	2.14	SH199-01-WB	Control(60)
5	I20.Cooper.EB-S-link2.EB	EB	2.04	IH20-23-EB	Control(70)
6	SH360.Six Flags-W-link1.SB	SB	2.00	SH360-06-SB	Control(60)
7	I820.Ramey.NB-E-link2.NB	NB	1.84	IH820-19-NB	Control(60)
8	SH121.Haltom Rd.SB-M-link2.NB	NB	1.79	SH121-04-NB	Control(65)
9	I20.SH360.EB-S-link1.WB	WB	1.75	IH20-28-WB	Control(70)
10	I30.Collins.WB.DET-M-link1.WB	WB	1.63	IH30-22-WB	Control(60)

Table 28. Top 10 Treated Detector Locations with Speed Creep.

No	Cor_Link	DIR	Slope	PinName	Before-After Categories
1	I35W.Westport Pkwy.NB-E-link2.NB	NB	3.67	IH35W-26-NB	Treat(65-70)
2	I820.Old Decatur Rd.WB-N-link2.EB	EB	3.33	IH820-12-EB	Treat(60-65)
3	I820.Old Decatur Rd.WB-N-link1.WB	WB	2.84	IH820-12-WB	Treat(60-65)
4	I35W.FM916.NB-E-link2.NB	NB	2.68	IH35W-01-NB	Treat(65-70)
5	I35W.Dickson.SB-W-link1.SB	SB	1.92	IH35W-15-SB	Treat(60-70)
6	I820.Mark IV Pkwy.WB-N-link1.WB	WB	1.88	IH820-14-WB	Treat(60-65)
7	I35W.Rosedale.SB-W-link1.SB	SB	1.71	IH35W-17-SB	Treat(60-70)
8	I20.Bowen.WB-N-link2.EB	EB	1.64	IH20-22-EB	Treat(60-70)
9	I820.Mark IV Pkwy.WB-N-link2.EB	EB	1.62	IH820-14-EB	Treat(60-65)
10	SH360.Riverside.DET-W-link2.NB	NB	1.57	SH360-09-NB	Treat(60-65)

Consumer Price Index

Finally, researchers investigated if motorist behavior could be linked to the economy. The thought was there may be less congestion if the economy was poor (less jobs and commerce), thus allowing drivers to speed more or drive closer to their desired speed. The Consumer Price Index (CPI) is "a measure of the average change over time in the prices paid by urban consumers for a market basket of consumer goods and services. Indexes are available for the U.S. and various geographic areas. Average price data for select utility, automotive fuel, and food items are also available" (*80*). Figure 17 shows Dallas–Fort Worth's CPI increased between 2016 and

May 2018, then decreased through 2019. Thus, the CPI was mixed and does not appear to provide insights as to why speed creep may have occurred on Fort Worth's urban freeways.

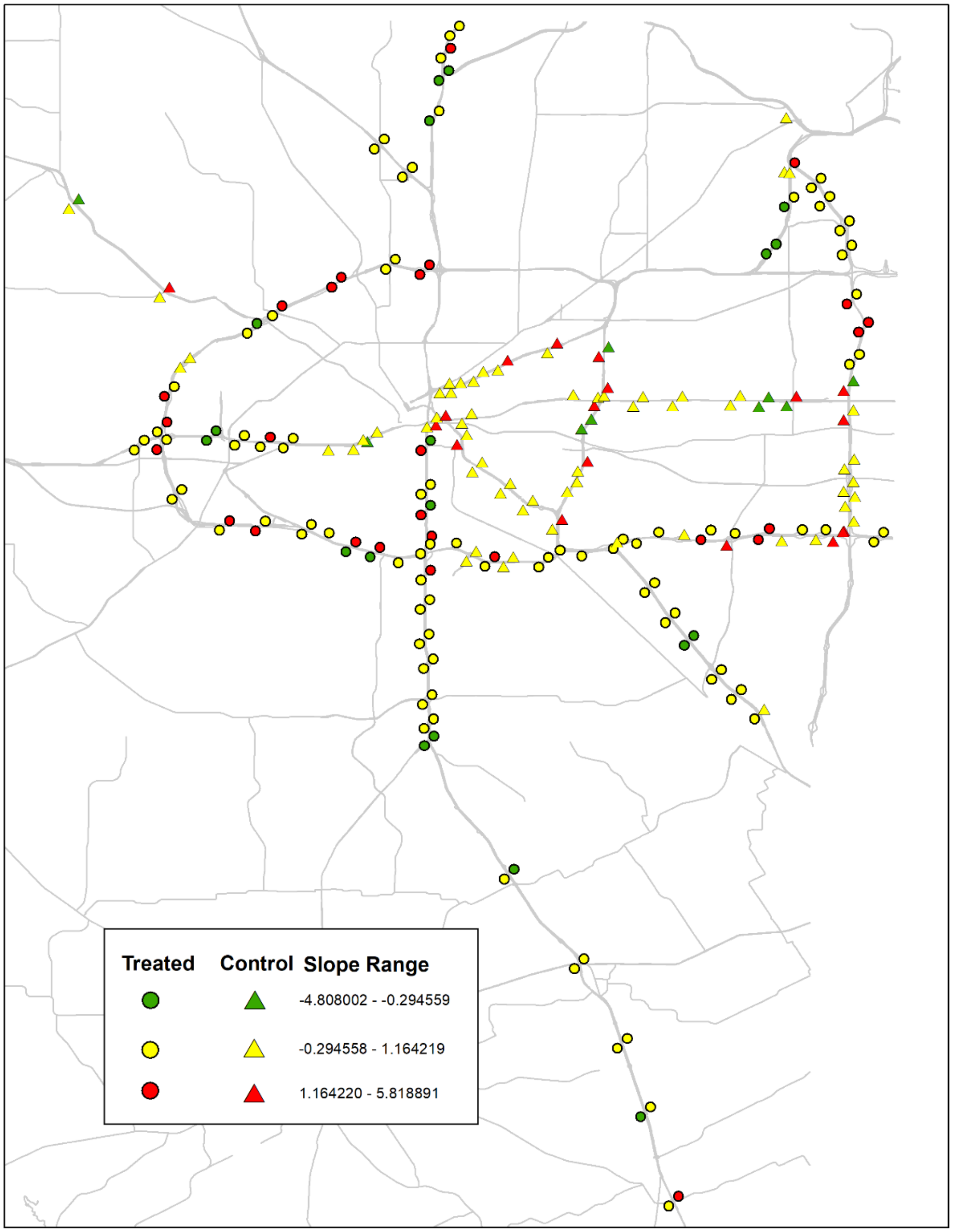
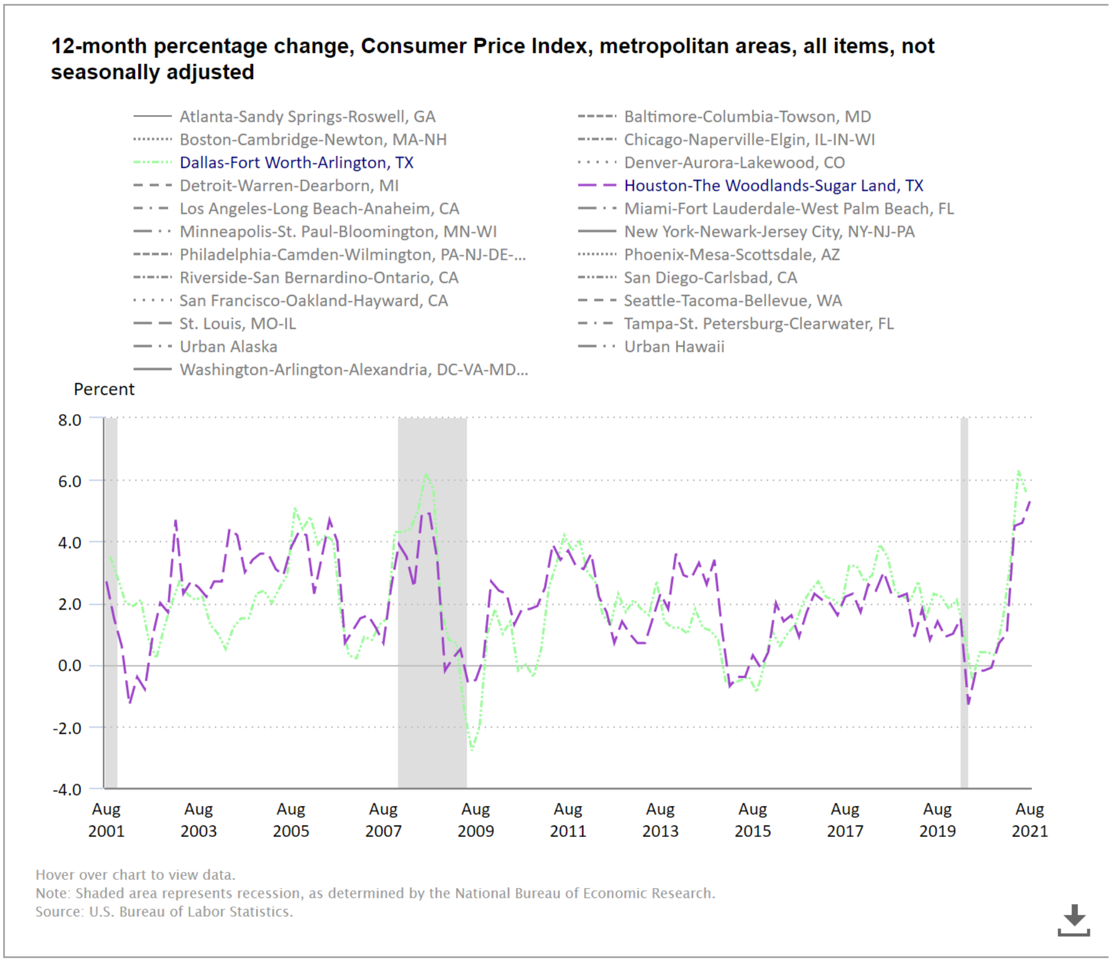


Figure 16. Tarrant County Detector Locations with Speed Creep.



Source: https://www.bls.gov/charts/consumer-price-index/consumer-price-index-by-metro-area.htm.

Figure 17. Consumer Price Index for Dallas–Fort Worth vs. Houston, TX.

EVALUATION—ANOTHER LOOK AT FREEWAY QUESTION 2 AND QUESTION 3 WHEN INCLUDING CITATIONS IN THE ANALYSIS

Resources became available late in the project which allowed the research team to conduct an additional analysis where citation data could be considered within the statistical model.

Panel Model using Binned Freeway Database and Including Citation Data

The format of the equation when considering citations is shown in **Equation 4**. The coefficients were estimated using R, open statistical software and packages (76, 77, 78).

$$Average.Speed_{ijkl} = \beta_0 + \beta_1 \cdot \ln(AggTotalVol + 0.5) + \beta_2 \cdot SL_{Rf60} + \beta_3 \cdot L_{shld_{wid_{Rf4}}} + \beta_4 \cdot R_{shld_{wid_{Rf10}}} + \beta_4 \cdot \ln(Mun.Citations/78586) + \beta_5 \cdot \ln(DPS.Citations/6833) - \beta_{ramp\_type} \cdot \ln(Ramp\_dist + 0.5) + Z_{0_i} + Z_{0_{ij}} + Z_{0_{ijk}} + \varepsilon_{ijk}$$ **Equation 4**

Where:

$Average.Speed_{ijkl}$	=	Average 15-min binned speed for the ith Link_Name, jth Year, and kth level for GroupDays.
AggTotalVol	=	15-min volume.
β_n	=	N-th fixed effect coefficient.
β_0	=	Global model intercept (at the fixed-effects level).
β_{ramp_type}	=	One of four coefficients for the different ramp types in the dataset (Upstream Entry, Upstream Exit, Downstream Entry, and Downstream Exit).
$Ramp\_dist$	=	One of four variables in the dataset indicating the distance to one of the four ramp types in the dataset (Upstream Entrance, Upstream Exit, Downstream Entrance, and Downstream Exit).
$R_{shld_{wid_{Rf10}}}$	=	Right shoulder width (ft) with respect to a 10-ft shoulder. A 10-ft shoulder would have a value of 0, while a 11-ft shoulder would have a value of 1, etc. for this variable.
$L_{shld_{wid_{Rf4}}}$	=	Left should width (ft) with respect to a 4-ft shoulder. A 4-ft shoulder would have a value of 0, while a 4-ft shoulder would have a value of 1, etc. for this variable.
SL_{Rf60}	=	Speed limit (mph) with respect to 60 mph (i.e., a 65-mph speed would have a value of 5 mph in this database).
Mun.Citations	=	Total number of yearly citations issued by municipalities within the county on all types of roads
DPS.Citations	=	Total number of yearly citations issued by DPS within the county freeways
Z_{0_i}	=	Local model intercept for i-th Link_Name (level of spatial aggregation).
$Z_{0_{ij}}$	=	Local model intercept for j-th Year for i-th Link_Name (first level of temporal aggregation).
$Z_{0_{ijk}}$	=	Local model intercept for k-th GroupDays for j-th Year for i-th Link_Name (second level of temporal aggregation).

It should be noted that the number of citations is passed to the model divided by the number in 2019, considered a reference year for the analysis. Table 29 shows the estimates for the fixed effects part of the model that used the binned database (i.e., 15-min period data where all three consecutive 5-min periods were available). The results have direct implications in understanding the relationships between operational speed and other key variables found relevant in the final model. The following sections describe those implications in more detail.

Table 29. Model Parameter Estimates after Adding Citation Data Using Freeway Speed Data between 2016 and 2019.

Fixed Effects						
Parameter	**Variable**	**Estimate**	**Std. Err**	**DF**	**t-value**	**p-value**
β_0	Base Speed (intercept)	65.3979	1.9216	694010	34.0330	<1e-04
β_1	15-min Volume	-1.0132	0.0079	694010	-127.733	<1e-04
β_2	Speed Limit relative to 60 mph	0.1898	0.0409	587	4.6362	<1e-04
β_3	Left Shoulder relative to 4 ft	0.1232	0.0620	239	1.9885	0.0479
β_4	Right Shoulder relative to 10 ft	0.1146	0.0698	239	1.6417	0.1020
β_5	Number of municipal citations in a year	-4.4433	0.6854	587	-6.4825	<1e-04
β_6	Number of DPS citations in a year	-5.8184	0.5160	587	-11.2758	<1e-04
$\beta_{Down\_Ramp\_typeEN}$	Distance to closest downstream ramp, entrance	-0.6325	0.2001	239	-3.1615	0.0018
$\beta_{Down\_Ramp\_typeEX}$	Distance to closest downstream ramp, exit	-0.5526	0.2139	239	-2.5835	0.0104
$\beta_{Up\_Ramp\_typeEN}$	Distance to closest upstream ramp, entrance	-0.5315	0.1795	239	-2.9610	0.0034
$\beta_{Up\_Ramp\_typeEX}$	Distance to closest upstream ramp, exit	-0.6085	0.1695	239	-3.5893	0.0004
Random Effects and Residuals						
Parameters	Variable	Standard Deviation				
Z_{0_i}	Link_Name	2.478064				
$Z_{0_{ij}}$	Year	1.354728				
$Z_{0_{ijk}}$	GroupDays	1.070744				
$\varepsilon_{0_{ijk}}$	Independent Residual	2.023818				
ρ	Autocorrelation parameter	+0.6412				

Fixed Effects Coefficients

From the fixed-effects coefficient estimates (see Table 29) the model indicates the following:

- Operating speed decreases with increasing 15-min volume in non-congested conditions. A 50 percent increase in volume is associated with a reduction of 0.41 mph (-1.013*ln(1.5)=-0.4108) in average operating speed, or a reduction of 0.70 mph if the volume doubles (-1.013*ln(2)=-0.7023).
- Operating speed increases with increasing speed limit. For each 5 mph increase in the PSL, the average operating speed increases by 0.95 mph (0.1898*5=0.949), or an increase of 1.90 mph for a 10-mph increase in posted speed, say going from a 60-mph freeway to a 70-mph freeway, all other characteristics staying the same (0.1898*10=1.898).
- Operating speed increases with wider left shoulder. For an additional foot of left shoulder, the average operating speed increases by 0.12 mph (0.1232*1.0=0.01232).
- Operating speed increases with wider right shoulder. For an additional foot of right shoulder, the average operating speed increases by 0.11 mph (0.1146*1.0=0.1146).
- Number of yearly citations was found to have an impact on operating speeds. For example, a 20 percent increase in DPS citations is expected to result in a 1.06 mph decrease in operating speed (calculated as -5.818*ln(1.2)=-1.061).

As expected, operating speeds are higher when the distances to upstream and downstream right-side ramps are longer (statistically significant). It should be noted that this finding does not apply to left-side ramps, as this database did not contain locations where the closest upstream or downstream ramp was on the left side. They were removed due to the small number of sites with that geometric feature. Speeds are increasing with greater distances even though the coefficient has a negative sign because the model format as shown in **Equation 4** includes a negative sign prior to the coefficient. For example, if the closest downstream ramp is an entrance ramp and the distance is 100 ft, the operating speed is estimated to be higher by 2.92 mph (2.9159 = 0.6325*ln(100+0.5)), compared to a point just at the ramp. If the closest downstream entrance ramp is 1000 ft, the operating speed is estimated to be higher by 4.27 mph (4.3695 = 0.6325*ln(1000+0.5)), compared to a point just at the ramp.

The fixed effects are the part of the model that can be interpreted more directly. The following sections describe the results from other model components and their implications.

Random Effects Coefficients

In the model estimation, the random-effects coefficients are estimated for each unit of nested aggregation as described when defining the model. However, interpreting the individual values of those estimates is generally not relevant as the estimate is specific to a given location or given period at a given location. It is of interest, however, to provide some descriptive statistics on the random-effect estimates as they describe general trends in the data not explicitly captured in the fixed-effects part of the model. The model in this research has nested random effects with one tier of spatial aggregation and two tiers of temporal aggregation as described next.

Spatial Random Effects

The first level of aggregation is spatial by specific detector location within a freeway corridor. Figure 18 shows the histogram of the adjustments per detector location, which the model applies in addition to the fixed effects. It can be seen from Figure 18 that the amount of variation captured by the detector location-specific random effect is significant: the approximate range of these adjustments is [-6 mph, 4 mph].

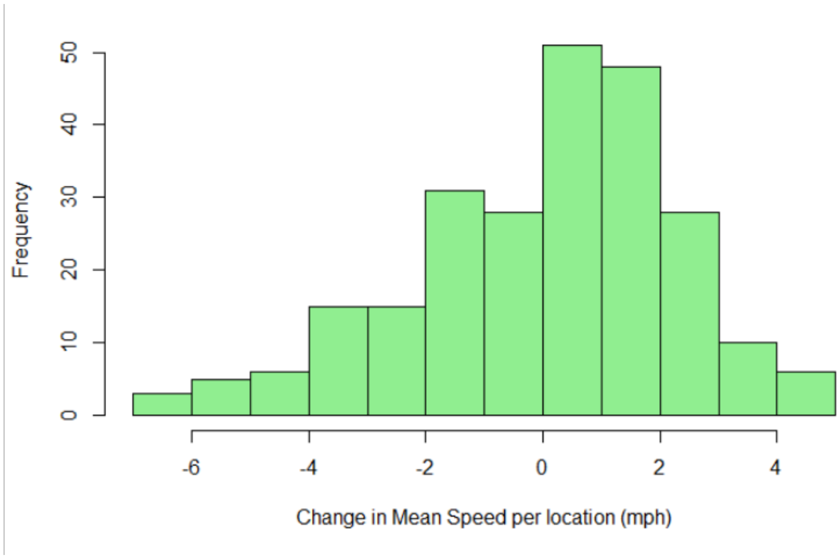
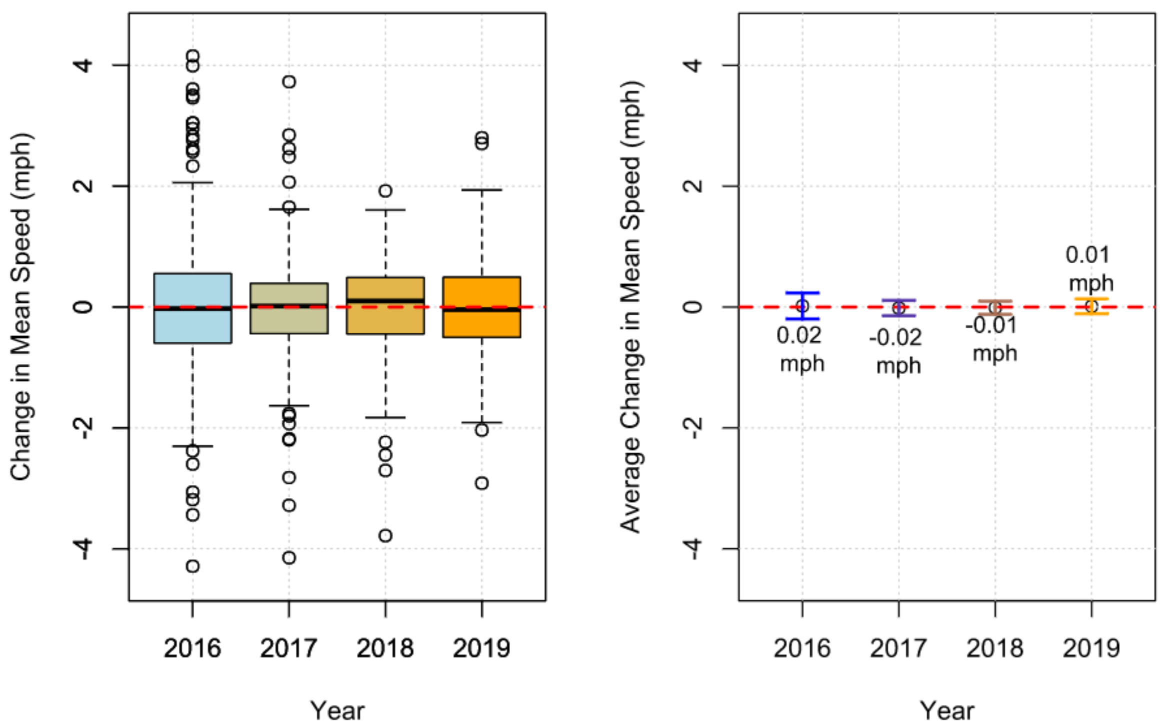


Figure 18. Histogram of Adjustment per Detector Location for Model that Includes Citation Data.

Temporal Random Effects

In order to capture yearly trends at specific locations, the model provides an adjustment per each year with data at each detector location under study. These yearly adjustments are applied in addition to the spatial adjustment discussed in the prior section. Figure 19 shows boxplots of all yearly adjustments versus year which do not suggest a trend that mean speed varies with increasing year, other things equal. Additionally, when calculating 95 percent confidence intervals around the means of these adjustments, all the intervals contain zero, confirming the absence of a trend by year (see Figure 19).



(a) Yearly Random Effects **(b) Mean of Yearly Effects (with 95% CI)**

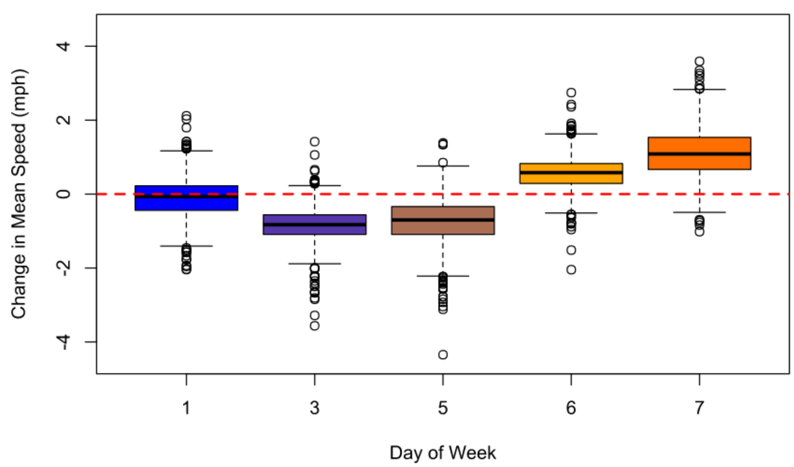
Figure 19. Random Effects by Year for Model that Includes Citation Data.

Finally, in the last level of aggregation, the model applies an adjustment per day of the week at each detector location per year of data in the analysis. It can be seen that the speed adjustments drop from the initial baseline on Monday and remain relatively flat for Tuesday through Friday (i.e., comparable baseline speeds) and then it consistently increases from Saturday to Sunday. When plotting all week-day random effects (see Figure 20), a pattern of being relatively similar speeds during weekdays and higher speeds on weekend. Monday tends to have faster speeds compared to Tuesday through Friday. Saturday and Sunday remain the days with fastest speeds, after adjusting for other variables.

The Relative Contribution of Different Factors to the Variability of Operating Speed

To gain perspective of the factors that explain the variability observed in the key variables this section quantifies the contribution of said factors to the operating speed variability, as estimated by the model described in the previous section. This model provides an explicit account of how the factors of interest relate with the operational speed and therefore, it is possible to quantify their systematic variation. The total variability by all explanatory factors in the model, combined with the residual variability that remains unexplained by the model, should amount to the total variability in the response variable.

Table 30 summarizes the breakdown of the variation in the response variable by level of aggregation according to the model. The fourth column of Table 30 (percent of incremental explained variance) shows the percent of variation in operational speed associated with each explanatory factor in the model. Only 4.4 percent (0.6920 mph^2) of the total variability in the response variable (15.3867 mph^2) can be explained by the variation in 15-min volumes. Although this percentage appears somewhat small, as a reminder, the dataset was based on uncongested traffic conditions as previously described. The finding demonstrates that even in uncongested conditions, speeds are affected by traffic density and proximity to other vehicles.



Note: 1=Monday, 3=either Tuesday, Wednesday, or Thursday, 5=Friday, 6=Saturday, and 7=Sunday (different colors are present; however, they are provided to help the reader to see the differences between the boxplots).

Figure 20. Weekday Random Effects for Model that Includes Citation Data.

Table 30. Variation in Response Variables by Level of Aggregation for Model that Includes Citation Data.

Explanatory Factor (i.e., variables)	Cumulative Variance (mph2)	Incremental Explained Variance (mph2)	Percent of Incremental Explained Variance (percent)	Standard Deviation of Speed (cumulative) (mph)	Expected range of variation (95% coverage Interval) (mph)
15-min Volume	0.6920	0.6920	4.4%	0.8319	+/- 1.63
Speed Limit	1.3322	0.6402	4.1%	1.1542	+/- 2.26
Geometrics	2.5132	1.1810	7.5%	1.5853	+/- 3.11
Citations	3.0845	0.5713	3.6%	1.7563	+/- 3.44
Link_Name	8.4188	5.3343	33.8%	2.9015	+/- 5.69
Year	10.0881	1.6693	10.6%	3.1762	+/- 6.23
GroupDays	11.2243	1.1362	7.2%	3.3503	+/- 6.57
Residuals	15.3867	4.1624	26.4%	3.9226	+/- 7.69

For PSLs, 4.1 percent (1.3322 mph^2) of the total variation in operational speed can be attributed to the operational differences at different speed limits according to the analysis. In other words, the range of variability that can be attributed to PSL and not to other factors is expectedly small. Other variables describing freeway geometric configuration (i.e., shoulder widths and relative location of ramps) are associated with 7.5 percent of the operational speed variation (1.1810 mph^2).

Although Table 30 indicates that the impact of citations on operational speeds is clear, intuitive, and statistically significant, the corresponding share of explained speed variability is smaller than the amount explained by PSL: 3.6 percent or 0.5713 mph^2.

Jointly, the factors in the fixed effects (i.e., 15-min volume, speed limit, geometrics, and citations) explain 20.05 percent of the total variation in operational speed in the dataset (3.0845 mph^2). In contrast, the model attributes a larger amount of variation (5.3343 mph^2 or 33.8 percent) to other unaccounted factors at the detector location (i.e., Link_Name variable) level. This amount of variance is captured as the variation of the Link_Name specific random effects. Because these random effects are gross adjustments of the model to the data per detector location, it follows that a significant amount of variation (33.8 percent) exists from detector location to detector location, such that it is not explained by any of the other variables in the model.

10.6 percent (or 1.6693 mph^2) of variation in operational speed is associated with the differences by year at the Link_Name level. In comparison, 7.2 percent or 1.1362 mph^2 can be attributed to differences in speeds by day of the week.

Finally, 26.4 percent of the variation in the operational speed was captured in the model residuals (4.1624 mph^2) , which means that the remaining 73.6 percent of speed variation is explained by the fixed and random effects combined. Because the residual variation represents variation not explicitly accounted for by any of the model parameters nor the aggregation structure, the interpretation of this result is that operating speed varies by 26.4 percent at each site due to other factors not explicitly considered in this study (e.g., differences in driver speed preference, lane changing behavior, etc.).

CHAPTER 6: EVALUATION OF SPEEDS ON RURAL, EX-URBAN, AND SUBURBAN HIGHWAYS

The primary goal of the evaluation using rural and suburban highway sites was to consider the long-term potential changes in operating speeds for that functional classification of Texas roadways.

RESEARCH QUESTIONS

The following two research questions guided the development and analysis of the database:

- Rural, Suburban, Ex-Urban Highways Research Question 1: What is the relationship of the speed limit sign to operating speed per development level (suburban, ex-urban, rural) with consideration of other roadway characteristics?
- Rural, Suburban, Ex-Urban Highways Research Question 2: Is operating speed increasing over time for these non-access control highways?

SITE SELECTION AND DATA RESOURCES

Following the speed dialog with TxDOT San Antonio District (SAT) staff (see Chapter 4), TxDOT provided a listing of 38 locations where speed zones had changed for on-system roadways over the previous three years. Researchers compared these locations with SAT roadway sections where historical speed data were available through the National Performance Management Research Data Set (NPMRDS). While NPMRDS data were available for 10 of the 38 sections, most of those sections were along access-controlled highways. Since the long-term relationship between posted and operating speed on access-controlled highways was being analyzed using historical speed data from the TxDOT Fort Worth District (see Chapter 5), the SAT access-controlled sites were not used further in this research investigation.

The remaining 28 SAT roadway sections with recent speed limit changes were filtered to identify higher-speed roadways that were not access controlled and whose speed limit change was not associated with speed limit adjustment for a long-term construction work zone. Ultimately, 10 roadway sections remained for detailed speed data analysis. These 10 roadways are listed in Table 31 and shown overlaid on a San Antonio region map in Figure 21. Also provided in Table 31 are the number of historical speed sampling sites for each roadway section.

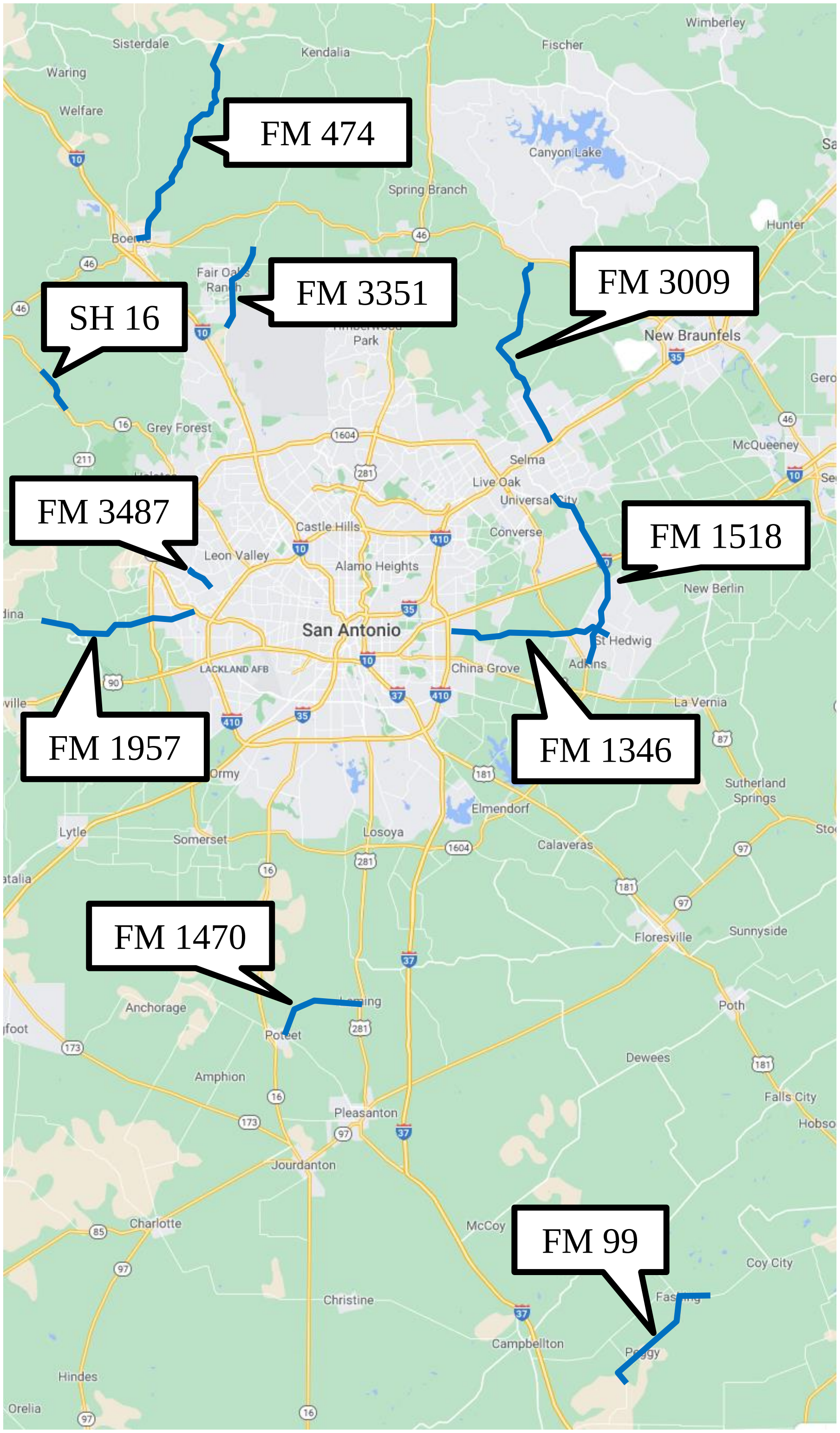


Figure 21. SAT Speed Study Roadway Sections.

Table 31. SAT Speed Study Roadway Sections.

Roadway	Location Description	Length (miles)	Number of Speed Data Sites
FM 99	Eastern Atascosa County	8.8	7
FM 474	Boerne to SH 46	15.4	42
FM 1346	Loop 410 East to St. Hedwig	9.8	5
FM 1470	US 281 to Poteet	6.4	15
FM 1518	Randolph AFB to Loop 1604 East	11.8	28
FM 1957	SH 151 to (Bexar) County Road 381	8.3	44
FM 3009	IH 10 East to SH 46	13.6	51
FM 3351	Fair Oaks to SH 46	3.4	9
FM 3487	FM 471 to Old Grissom Road	1.1	11
SH 16	Northwest of junction with SH 211	2.0	4

Selected Sites

TxDOT SAT staff provided historical speed sampling data from past speed studies for all 10 SAT roadways, which were primarily arterial highways in suburban or rural areas. Full data sets for each roadway were provided, not just the sections where the recent speed limit change was made. From this full dataset, the research team documented all locations where past speed study data sampling occurred along all 10 roadways. The team employed a spreadsheet to digitally record all individual vehicle speed measurements collected for each speed study and appended site and study details including speed study location, date of speed sampling, direction of vehicles, and existing PSL. In total, the rural SAT speed dataset included 216 speed sampling sites and over 25,000 speed measurements.

Speed Data

All SAT speed study field sampling data were recorded on TxDOT's "Radar Motor Vehicle Speed" tally sheet (TxDOT Form 1882, see Figure 4). The layout of the sheet provides for field study of both directions of travel along the study roadway and uses a count/tally method to identify the 85th percentile speed. Researchers transferred the information from each tally sheet to a spreadsheet and developed an index system to maintain the relationship between each site's speed data set and descriptive data. A full list of the pertinent data stored for each tally sheet/study site included:

- Roadway name.
- Date of field speed sampling.
- Time of field speed sampling.

- Location (brief narrative description).
- Existing speed limit value (if provided).
- Travel direction for speed sample datasets.
- All speed measurements (both directions of travel).

To better associate speed field study site data with roadway conditions and to help establish whether any historical speed study field data were collected at the same or "close by" location, the researchers determined if sites could be "grouped." The researchers started the process by translating each tally sheet's narrative location description into Global Positioning System latitude/longitude coordinates. Using these coordinates, the research team then developed a GIS geodatabase of the field speed study locations using Environmental Systems Research Institute's ArcGIS Desktop GIS platform. The geographic locations of the SAT speed samples are provided in Figure 22, and the figure inset provides an example of speed sampling sites that were "grouped" based on proximity.

Roadway Data

The research team identified a logical study corridor for each speed study. In general, the corridor was set to be 1 mile on either side of the location of the speed study. Researchers would review each corridor to determine if there was a roadway element within one mile of the speed study site that could influence or alter motorist speed. For example, if a sharp horizontal curve or intersection traffic control (such as a four-way/all-way stop, traffic signal, or railroad crossing) was present then that location and its description was recorded rather than the (default) 1-mile limit. Researchers recorded the distance between the speed sampling site and the speed-influencing factor for locations where the 1-mile (default) limit was not applicable.

The research team also recorded additional roadway factors with the potential to influence motorist speed for each road segment upstream and downstream of each speed sampling site within each sampling site's boundary/limits. These factors include:

- The number of non-residential access points within the site's limits on each side of the roadway.
- The presence of a passing lane (if any).
- Median presence and type (none, TWLTL, [painted] buffer, grass).

- The number of through lanes (both directions of travel).
- Roadway cross section categorization (two-lane undivided, four-lane undivided, four-lane divided, etc.).
- Primary horizontal geometry (tangent section, horizontal curve, etc.).
- Existing PSL (most recent available, with year of speed limit information noted as available from Google Maps).
- PSL at time of field study speed sampling (if available from Google Maps photo archives or the TxDOT SAT historical speed study).

Note that the primary tools used by the research team to develop this speed sampling site analysis database were the Google Earth™ and Google Maps online applications. Researchers retrieved data from Google Maps and directly recorded their observations and roadway-descriptive data into the research database.

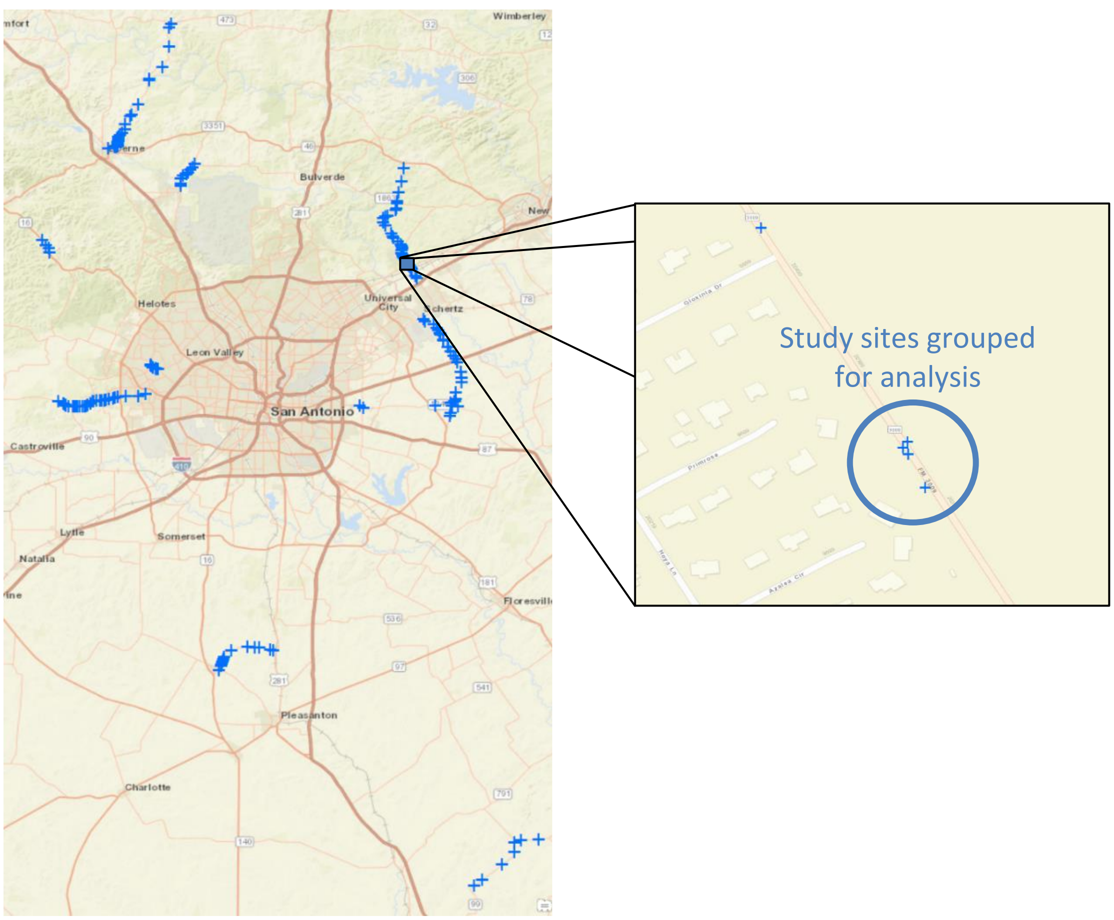


Figure 22. SAT Speed Sampling Locations (216 Sites).

Site Variables

The variables considered in the statistical analysis are listed in Table 32. The segment length value was used to generate the signal and access density values considered in the statistical analysis. Segment length represents the length of the segment between two points that could influence operating speed, typically intersections or sharp horizontal curves, or a 2-mile maximum.

Several additional variables available from the TxDOT Roadway-Highway Inventory (RHiNo) database were also considered and explored but are not listed in Table 32 since the variables listed in Table 32 reflect those variables that had the most potential of being significant in the statistical evaluation. The roadway characteristic variables reflected the year of the speed study. Because some of the speed studies were conducted at the same location, it was important that the roadway geometric variables considered conditions present during the year of the speed study rather than current conditions.

To investigate the research question of whether operating speeds were increasing over time, sites where speeds had been measured more than once within the dataset were identified. These pairs of speed studies were identified and assigned a unique pair number. Table 33 lists the additional variables created for that investigation.

Assembled Databases

Of the data provided to the research team by the San Antonio District, sites were dropped from the study for the following reasons:

- The PSL for the year of the speed study could not be determined either through TxDOT notes or using Google Earth historical street view.
- Historical aerial view of the site was not available; therefore, the roadway site characteristics such as number of lanes or driveway density could not be collected.
- The research team was not confident of the location of the speed study as the description provided would have placed the study in a tight horizontal curve or at an intersection.
- Low number of speed readings for the speed study.

Table 32. Description of Variables Considered in Analysis.

Variables	Description
AccessDensity(YOS)	Number of access points/miles for section during year of study (YOS).
ADT(YOS)	Average daily traffic (ADT) for year of study, estimated from RHiNo's 2019 ADT and growth factor (INCREASE_FCT).
Count	Number of vehicles included in speed statistic of average speed. Reflects free-flow cars. The research team assumed the provided speed studies only included free-flow cars. For data collected in 2021 by the research team, only those readings with a vehicle length of 20 ft or less and gaps greater than 3 sec were included in the average speed calculation.
CrossSection(YOS)	Cross section at speed count location in year of study, where 2U = 2 lane undivided, 3T = 3 lane with center two-way left-turn lane, 4D = 4 lane divided, 4U = 4 lane undivided, 5T = 5 lane with center two-way left-turn lane, 6D = 6 lane divided, and 7T = 7 lane with center two-way left-turn lane.
Devel(YOS)	Type of roadway context during the year of the speed study: rural, ex-urban, or suburban.
Horz(YOS)	Horizontal alignment during year of study: tangent = straight, HC = some horizontal curvature.
Hwy_Dir_Bun	Unique value for each bundle of sites. Reflects the Hwy, highway number, Dir, direction vehicles were traveling, (e.g., NB, EB, SB, or WB), and Bun, bundle number reflecting sites in similar geographical location on a roadway.
LANE_WIDTH	Lane width in feet.
MedianType(YOS)	Median type at speed count location during year of study used to generate cross section: none, TWLTL, raised, left-turn lane.
Popu2010	Census American Community Survey, 2010 population for block-group level.
PSL(YOS)	Posed speed limit for year of study.
RB_WID	Roadbed width, includes shoulder width and surface widths (ft).
S_WID_O	Shoulder-width-outside from RHiNo.
ShoCur(YOS)	Shoulders or curb and gutter during year of study: Curb = curb and gutter present for majority of study segment (more than about 80 percent of segment), Shou = curb and gutter not present for majority of study segment (no more than 20 percent of segment), Mix = both curb and gutter and shoulder (about even mix).
Sidwlk(YOS)	Sidewalks during year of study: Yes = sidewalk present through most of study segment or present for more than about 80 percent of segment, No = sidewalk not present within study segment or present for less than about 20 percent of segment, Mix = sidewalk only present for a portion of the study segment (between 20 and 80 percent of segment).
SigDen(YOS)	Signal density during year of study calculated as #Sig1mi(YOS)/Dis#Sig
Site_Index_Dir	Unique value for each study site. Reflects the Site (including highway number and speed study number along that route), Index (whether the data were collected by TxDOT or the research team), and Dir (direction vehicles were traveling; e.g., NB, EB, SB, or WB).
SpdAve	Average speed (mph).
ThrLaneBothDir	Number of through lanes in both directions of travel for year of study; value used to generate cross section.
TRK_AADT_P	Truck-AADT-pct; percent of trucks in AADT 00.0 to 99.9.
Year(YOS)	Year of speed study.

Table 33. Description of Additional Variables Considered in Analysis on Speed Changing Over Time.

Variables	Description
ChgAccDen[P_B]	Change in access density between the pair of studies.
ChgSpdAve[P_B]	Change in average speed between the pair of studies.
ChgPSL[P_B]	Change in PSL between the pair of studies.
ChgSigDen[P_B]	Change in signal density between the pair of studies.
PairNum	Unique value assigned to a pair of studies where speed data were collected in the same location during different years.
YrsSince1st[P_B]	Number of years between the pair of studies.

Most of the speed studies done in the 1980s and several done in the 1990s were removed because the PSL or the roadway characteristics could not be determined or confirmed. The resulting assembled rural highway database included speed data for 383 sites.

Based on the literature, different roadway characteristics would be influential depending upon the roadway context; therefore, the research team categorized each site within the database into one of following three development levels: suburban, ex-urban, or rural.

Table 34 shows the distribution of sites by cross section and development level, while Table 35 shows the distribution by PSL. The rural sites were either two-lane undivided or two-lanes with a TWLTL with speed limits of 50 to 70 mph but most being 60 mph. The ex-urban sites had more development along with more nearby driveways as compared to the rural sites. Another example of how a roadway would be considered ex-urban rather than rural or suburban was when a subdivision was present on one side of the roadway but not on the other. Ex-urban development was considered to be in transition from rural to suburban conditions. The ex-urban sites for this database also had similar cross sections as the rural sites—either two-lane undivided or two-lanes with a TWLTL—but had a larger range of PSLs. As shown in Table 35, the PSLs ranged from 40 mph to 65 mph. The suburban group included lower PSLs (35 to 60 mph) and a much larger range of cross sections including roads with 6 through lanes and a TWLTL (7T, see Table 34). Descriptive statistics for the database are listed in Table 36.

A second database was developed to explore the question about speed changes over time. Those locations that had a speed study conducted in two different time periods were identified, resulting in 139 pairs being available.

Table 34. Number of Sites per Development Level and Cross Section.

Cross Section (YOS)	Rural	Ex-Urban	Suburban	Grand Total
2U	133	118	54	305
3T	8	16	32	56
4D	0	0	8	8
4U	0	0	2	2
5T	0	0	4	4
6D	0	0	4	4
7T	0	0	4	4
Grand Total	**141**	**134**	**108**	**383**

Table 35. Number of Sites per Development Level and PSL Present at the Year of Study.

PSL (YOS)	Rural	Ex-Urban	Suburban	Grand Total
35	0	0	19	19
40	0	4	7	11
45	0	29	30	59
50	2	16	10	28
55	37	45	32	114
60	77	38	10	125
65	7	2	0	9
70	18	0	0	18
Grand Total	**141**	**134**	**108**	**383**

Table 36. Descriptive Statistics.

Stat[a]	Devel (YOS)[b]	SpdAve	PSL (YOS)	Access Density (YOS)	SigDen (YOS)	S_WID_O	RB_WID	TRK_AADT_P	ADT (YOS)
Min	Rural	42.4	50	0.0	0.0	0.0	20	3.0	318
Max	Rural	65.4	70	10.8	0.0	10.0	54	17.6	15,801
Average	Rural	55.7	60	3.1	0.0	2.8	30	8.0	5,791
SD	Rural	4.5	5	2.3	0.0	2.9	8	4.5	3,712
25%	Rural	52.9	55	1.5	0.0	1.0	26	3.7	2,292
75%	Rural	58.9	60	4.8	0.0	4.0	32	10.9	7,906
Min	Ex-urban	34.3	40	0.0	0.0	0.0	24	3.0	888
Max	Ex-urban	60.4	65	17.5	1.4	10.0	58	16.0	31,411
Average	Ex-urban	50.0	53	5.1	0.2	5.0	38	5.9	9,842
SD	Ex-urban	5.1	6	4.6	0.4	3.6	12	2.7	6,850
25%	Ex-urban	47.2	50	1.6	0.0	1.0	26	3.8	4,484
75%	Ex-urban	52.6	60	6.3	0.0	8.0	45	6.3	16,181
Min	Suburban	31.5	35	0.0	0.0	0.0	26	1.3	3,821
Max	Suburban	56.8	60	28.4	4.0	10.0	92	9.0	39,716
Average	Suburban	44.7	48	10.7	0.8	4.5	43	5.8	14,733
SD	Suburban	6.2	8.1	7.8	1.0	4.0	20	1.9	10,454
25%	Suburban	38.9	45	4.1	0.0	1.0	26	4.4	4,728
75%	Suburban	49.1	55	13.8	1.0	8.0	58	6.3	19,433

Note: [a] Stat = statistic. [b] See Table 32 for description of variables.

EVALUATION—RURAL, EX-URBAN, SUBURBAN HIGHWAYS QUESTION 1

The question for the initial evaluation was "what is the relationship of the value on the speed limit sign to operating speed (i.e., PSL(YOS) to SpdAve) per development (suburban, ex-urban, rural) with consideration of other roadway characteristics?" To account for potential correlations in observations corresponding to the same Hwy_Dir_Bun, the research team employed a mixed effect linear model including Hwy_Dir_Bun as a random effect and including PSL(YOS) and roadway geometry variables as fixed effects.

Rural

For the rural category, the PSL was significant along with outside shoulder width and the roadbed width (see Table 37). Figure 23 provides the actual by predicted plot. As expected, higher operating speeds were associated with higher PSLs and wider shoulders. Wider roadbed widths were associated with lower average speeds. The coefficients can be used in a prediction equation:

$$\hat{y} = 23.9793 + 0.5928 \times \text{PSL(YOS)} + 0.8494 \times \text{S\_WID\_O} - 0.2003 \times \text{RB\_WID} \quad \textbf{Equation 5}$$

Where:

$\hat{y}$ = predicted value of SpdAve.

Table 37. Parameter Estimates for Rural Roads.

Term	**Estimate**	**Std Error**	**DFDen**	**t Ratio**	**Prob>|t|**
Intercept	23.979316	3.964491	128.4	6.05	<.0001*
PSL(YOS)	0.5927624	0.059078	129.9	10.03	<.0001*
S_WID_O	0.8493639	0.206595	131.5	4.11	<.0001*
RB_WID	−0.200271	0.075236	131.3	−2.66	0.0087*

Note: RSquare = 0.665185, Rsquare Adj = 0.657633, Root Mean Square Error = 2.858307, Mean of Response = 55.91387, and Observations (or Sum Wgts) = 137. * = significance level of < 0.05.

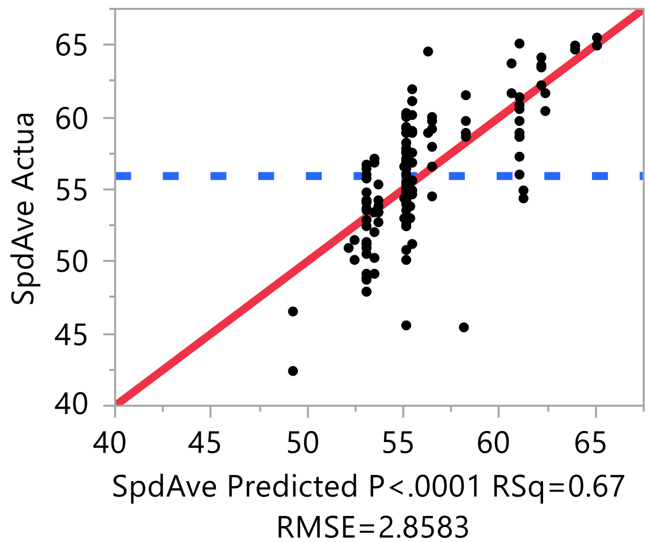


Figure 23. Actual by Predicted Plot for Average Speed on Rural Roads.

Ex-Urban

For the ex-urban category, the PSL was significant along with the presence of a horizontal curve, access density, signal density, outside shoulder width, and the roadbed width (see Table 38). Figure 24 provides the actual by predicted plot. Lower average speeds were associated with the presence of a horizontal curve, higher access or signal density, and wider outside roadbed widths. Higher average speeds were associated with higher PSLs and wider outside shoulder widths. The predicted average speed on ex-urban facilities can be calculated from:

$$\begin{aligned}\hat{y} = 27.17704 &+ 0.4737 \times \mathrm{PSL(YOS)} - 1.2339 \times \boldsymbol{I}[\mathrm{Horz(YOS)=HC}] \\ &+ 1.2339 \times \boldsymbol{I}[\mathrm{Horz(YOS)=tangent}] \\ &- 0.1711 \times \mathrm{AccessDensity(YOS)} - 2.4007 \times \mathrm{SigDen(YOS)} \\ &+ 0.5520 \times \mathrm{S\_WID\_O} - 0.1262 \times \mathrm{RB\_WID}\end{aligned} \qquad \textbf{Equation 6}$$

Where:

$\hat{y}$ = predicted value of SpdAve.

I[.] = indicator function that takes a value of 1 if the condition inside [ ] is satisfied and 0 otherwise.

Table 38. Parameter Estimates for Ex-Urban Roads.

Term	Estimate	Std Error	DFDen	t Ratio	Prob>|t|
Intercept	27.177035	3.381231	116.5	8.04	<.0001*
PSL(YOS)	0.4737209	0.056077	113.7	8.45	<.0001*
Horz(YOS)[HC]	−1.2339	0.636235	90.37	−1.94	0.0556
AccessDensity(YOS)	−0.171073	0.074713	101.9	−2.29	0.0241*
SigDen(YOS)	−2.400671	0.726045	127.8	−3.31	0.0012*
S_WID_O	0.5519553	0.180011	113.6	3.07	0.0027*
RB_WID	−0.126226	0.055114	113.9	−2.29	0.0238*

Note: Rsquare = 0.824428, Rsquare Adj = 0.816387, Root Mean Square Error = 2.678016, Mean of Response = 50.00072, and Observations (or Sum Wgts) = 138. * = significance level of < 0.05.

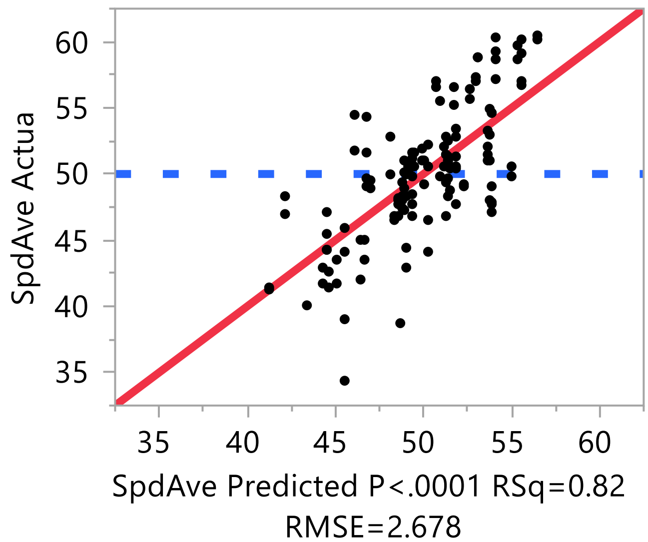


Figure 24. Actual by Predicted Plot for Average Speed on Ex-Urban Roads.

Suburban

More of the roadway variables were significant within the suburban category, as shown in Table 39 for the parameter estimates and in Table 40 for the fixed effects. Figure 25 provides the actual by predicted plot. As expected, the PSL was significant with higher operating speeds. The type of cross section was significant for suburban roads. As shown in Figure 26, the widest cross sections, 6D and 7T, were associated with the highest average speeds. Other significant categorical variables included the presence of a horizontal curve (higher speeds on a tangent) and a sidewalk (higher speeds when sidewalk was not present). While the findings for the variable categorizing shoulder versus curb was significant, the Tukey test (see Table 41) showed interesting results; the least square means differences indicated that the least square means for mixed and curb were not significantly different and the least square means for curb and shoulder were not significantly different.

Table 39. Parameter Estimates for Suburban Roads.

Term	Estimate	Std Error	DFDen	t Ratio	Prob>|t|
Intercept	17.161246	3.945005	90.81	4.35	<.0001*
PSL(YOS)	0.6348452	0.065804	91	9.65	<.0001*
CrossSection(YOS)[2U]	−7.577492	1.67147	84.98	−4.53	<.0001*
CrossSection(YOS)[3T]	−5.581676	1.951269	86.86	−2.86	0.0053*
CrossSection(YOS)[4D]	−0.515376	1.661839	89.26	−0.31	0.7572
CrossSection(YOS)[4U]	−9.844534	2.264114	81.99	−4.35	<.0001*
CrossSection(YOS)[5T]	−0.051244	1.739817	87.92	−0.03	0.9766
CrossSection(YOS)[6D]	12.831536	3.404372	87.24	3.77	0.0003*
Horz(YOS)[HC]	−1.864419	1.377903	85.83	−1.35	0.1796
AccessDensity(YOS)	−0.246931	0.057663	80.83	−4.28	<.0001*
Sidwlk(YOS)[No]	1.9304819	0.589577	88.95	3.27	0.0015*
ShoCur(YOS)[Curb]	0.566128	1.248406	90.97	0.45	0.6513
ShoCur(YOS)[Mix]	1.6504325	0.674609	90.94	2.45	0.0163*
SigDen(YOS)	−1.190365	0.783723	90.69	−1.52	0.1323
S_WID_O	0.5611395	0.209101	85.5	2.68	0.0087*
TRK_AADT_P	0.8513088	0.358631	80.01	2.37	0.0200*
ADT in 1,000	−0.228381	0.068666	86.1	−3.33	0.0013*

Note: Rsquare = 0.948202, Rsquare Adj = 0.939095, Root Mean Square Error 1.900296, Mean of Response = 44.71481, and Observations (or Sum Wgts) = 108. * = significance level of < 0.05.

Table 40. Fixed Effects Test for Suburban Roads.

Source	Nparm	DF	DFDen	F Ratio	Prob > F
PSL(YOS)	1	1	91	93.0737	<.0001*
CrossSection(YOS)	6	6	87.18	6.7813	<.0001*
Horz(YOS)	1	1	85.83	1.8308	0.1796
AccessDensity(YOS)	1	1	80.83	18.3379	<.0001*
Sidwlk(YOS)	1	1	88.95	10.7214	0.0015*
ShoCur(YOS)	2	2	90.18	5.6140	0.0050*
SigDen(YOS)	1	1	90.69	2.3069	0.1323
S_WID_O	1	1	85.5	7.2016	0.0087*
TRK_AADT_P	1	1	80.01	5.6348	0.0200*
ADT in 1,000	1	1	86.1	11.0620	0.0013*

Note: * = significance level of < 0.05.

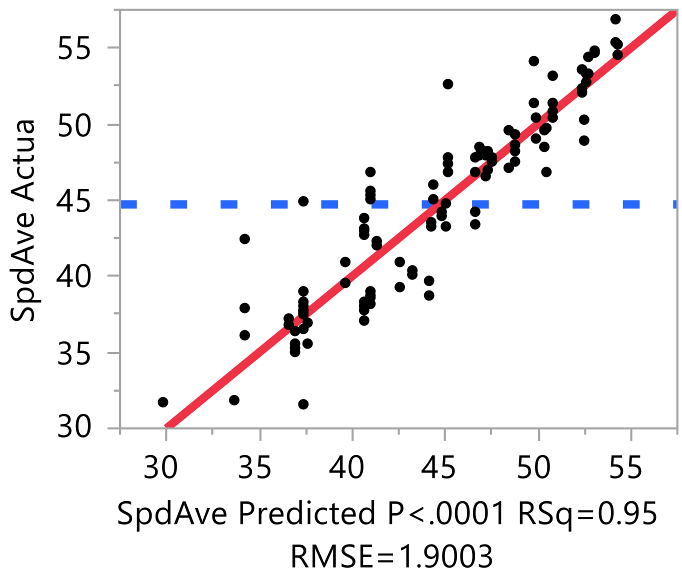


Figure 25. Actual by Predicted Plot for Average Speed on Suburban Roads.

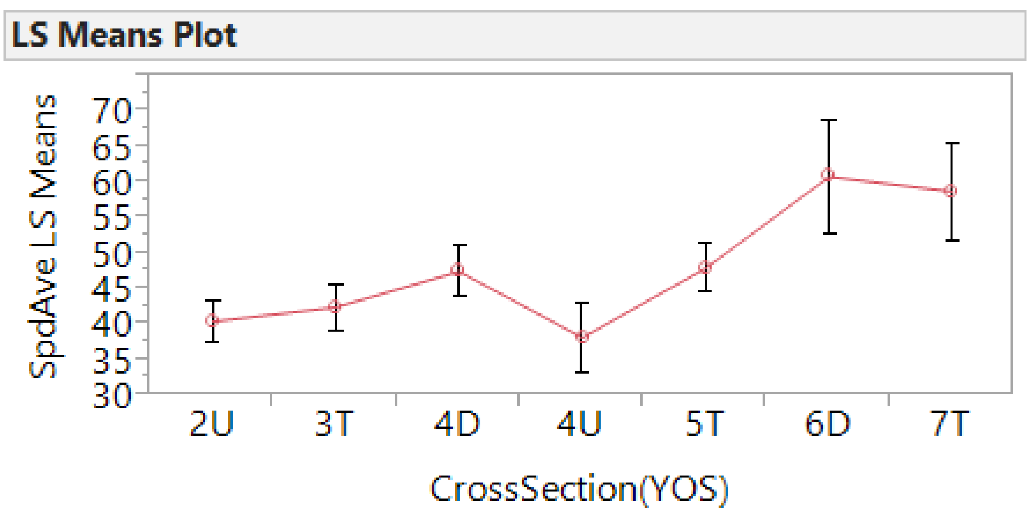


Figure 26. Least Square Means Plot for Suburban Cross Sections.

Table 41. Least Square Means Differences Tukey Honest Significance Test for the ShoCur Variable for Suburban Roads.

Level	A	B	Least Sq Mean
Mix	A	—	49.669625
Curb	A	B	48.585320
Shou	—	B	45.802632

Note: — = not applicable. α = 0.050. Levels not connected by the same letter are significantly different.

Discussion of Results for Rural, Suburban, Ex-Urban Research Question 1

Table 42 provides a comparison of the significance levels by development, while Table 43 shows the effect estimates. In all cases, the PSL present during the year of the study was statistically significant with similar coefficients (range of 0.47 for ex-urban to 0.63 for suburban). The outside shoulder width was significant, with a range of coefficients of similar magnitude (0.56 to 0.78). Access density was significant for suburban and ex-urban with similar coefficient magnitudes (−0.18 to −0.27) but not significant for rural roads. Signal density was expected to be significant for the more developed areas and have similar coefficient magnitudes; however, it was not significant for the suburban arterial included in this dataset and had a greater coefficient for ex-urban roads. Truck AADT and vehicle ADT were only significant for suburban arterials with lower average speed when the road had higher vehicle ADTs but higher average speed for higher truck percentage. These variables were not significant for ex-urban or rural roads.

Table 42. Comparison of Significance Level Results by Development.

Source	Suburban Prob > F	Ex-Urban Prob > F	Rural Prob > F
Rsquare Adj	0.939095	0.824428	0.665185
PSL(YOS)	<.0001*	<.0001*	<.0001*
CrossSection(YOS)	<.0001*	NI	NI
Horz(YOS)[HC]	0.1796	0.0556*	NI
AccessDensity(YOS)	<.0001*	0.0241*	NI
Sidwlk(YOS)[No]	0.0015*	NI	NI
ShoCur(YOS)	0.0050*	NI	NI
SigDen(YOS)	0.1323	0.0012*	NI
S_WID_O	0.0087*	0.0027*	<.0001*
RB_WID	NI	0.0238*	0.0087*
TRK_AADT_P	0.0200*	NI	NI
ADT in 1,000	0.0013*	NI	NI

Note: NI = variable not included in the model. Shaded cells = variable significant. * = significance level of < 0.05.

Table 43. Comparison of Effect Estimate Results by Development.

Source	Suburban	Ex-Urban	Rural
PSL(YOS)	0.6348452	0.4737209	0.5927624
CrossSection(YOS)	Multiple levels	NI	NI
Horz(YOS)[HC]	−1.864419	−1.2339	NI
AccessDensity(YOS)	−0.246931	−0.171073	NI
Sidwlk(YOS)[No]	1.9304819	NI	NI
ShoCur(YOS)	Multiple levels	NI	NI
SigDen(YOS)	−1.190365	−2.400671	NI
S_WID_O	0.5611395	0.5519553	0.8493639
RB_WID	NI	−0.126226	−0.200271
TRK_AADT_P	0.8513088	NI	NI
ADT in 1,000	−0.228381	NI	NI

Note: NI = variable not included in the model. Shaded cells = variable significant.

Analysis Based on Change in Average Speed

ChgSpdAve[P_B] (denoted by ChgSpdAve hereafter) was used as a measure of the change in average speed over time between a pair of sites. Several new variables were created for this evaluation and are listed in Table 33. When assessing the average speed change over time, it is important to adjust for the effects of other co-varying variables over time to avoid potential confounding. A review of the data showed that it would be better to perform the analysis separately for the change in development (to avoid confounding between change in development and change in speed over time), for the following groups:

- Change from Ex-Urban = site was ex-urban in before period and is suburban in after period, 16 pairs.
- Change from Rural = site was rural in before period and is ex-urban in after period, 24 pairs.
- Same Devel = site was the same development in both before and after periods, 99 pairs.

Figure 27 provides an overview of the changes in these variables for when the site had the same development type during both time periods, had changed from rural to ex-urban over the time period, or changed from ex-urban to suburban. A separate analysis was performed per change in development; see Table 44 for when the development changed from ex-urban to suburban, Table 45 for when development changed from rural to ex-urban, and Table 46 for when the development did not change. The variable representing the number of years since the first study at the site (YrsSince1st[P_B]) was significant when the development changed from rural to ex-urban and when the development type did not change. In both cases the estimate was negative, which indicates that the speeds decreased over time. A theory was that speed will increase over time especially if the PSL is set using the 85th percentile speed. This dataset, however, indicates that as a region develops and becomes more suburban, speeds decrease.

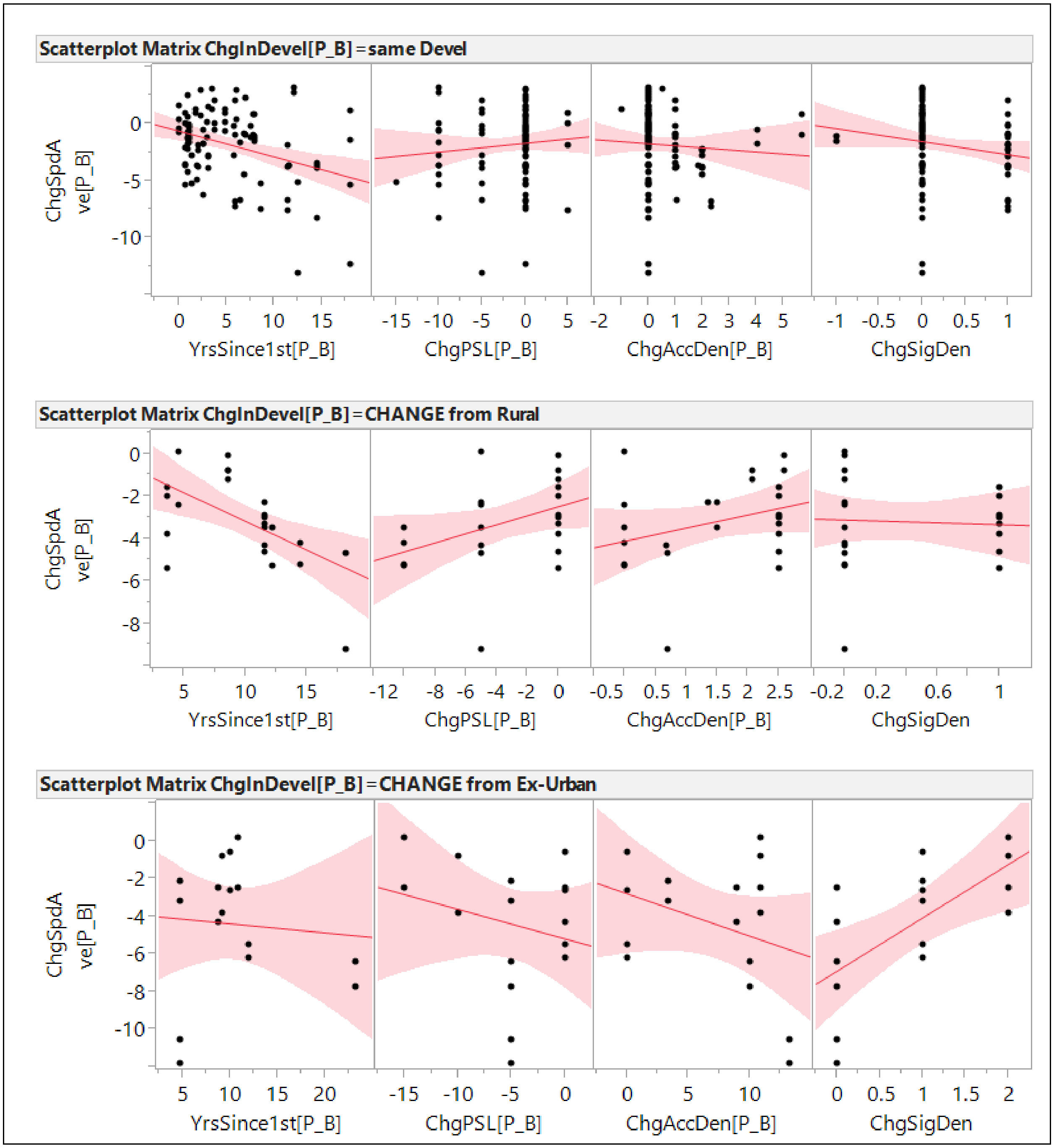


Figure 27. Scatterplots for Changes between Pairs.

Table 44. Parameter Estimates for ChgSpdAve[P_B] When Development Is Changing from Ex-Urban to Suburban.

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	37.34685	18.13437	2.06	0.0664
YrsSince1st[P_B]	−0.326769	0.189755	−1.72	0.1158
ChgPSL[P_B]	−0.749142	0.483025	−1.55	0.1520
ChgAccDen[P_B]	−2.35253	0.958335	−2.45	0.0340*
ChgSigDen	−18.68321	9.171776	−2.04	0.0690
ChgInCS[P_B][CHANGE in CS]	17.765819	7.300336	2.43	0.0352*

Note: RSquare = 0.692712, RSquare Adj = 0.539068, Root Mean Square Error = 2.334992, Mean of Response = −4.39375, and Observations (or Sum Wgts) = 16. * = significance level of < 0.05.

Table 45. Parameter Estimates for ChgSpdAve[P_B] When Development Is Changing from Rural to Ex-Urban.

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	−0.426732	1.918058	−0.22	0.8263
YrsSince1st[P_B]	−0.290576	0.089098	−3.26	0.0041*
ChgPSL[P_B]	0.0494409	0.241201	0.20	0.8398
ChgAccDen[P_B]	0.8353751	0.859063	0.97	0.3431
ChgSigDen	−2.778325	0.921106	−3.02	0.0071*

Note: RSquare = 0.550899, RSquare Adj = 0.456351, Root Mean Square Error = 1.526782, Mean of Response = −3.17917, and Observations (or Sum Wgts) = 24. * = significance level of < 0.05.

Table 46. Parameter Estimates for ChgSpdAve[P_B] When Development Is Not Changing.

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	−0.494315	0.681163	−0.73	0.4698
YrsSince1st[P_B]	−0.22073	0.064128	−3.44	0.0009*
ChgPSL[P_B]	0.0368166	0.078038	0.47	0.6382
ChgAccDen[P_B]	0.1454835	0.316145	0.46	0.6465
ChgSigDen	−1.062212	0.89789	−1.18	0.2398
ChgInCS[P_B][CHANGE in CS]	−0.207321	0.551231	−0.38	0.7077

Note: RSquare = 0.154347, RSquare Adj = 0.108882, Root Mean Square Error = 2.923935, Mean of Response = −1.78687, and Observations (or Sum Wgts) = 99. * = significance level of < 0.05.

Analysis Based on Average Speed

In this analysis, average speed (SpdAve) rather than the change in the average speed was modeled. When assessing the effect of time on average speed, it is important to adjust for the effects of other variables that affect average speed. These variables may also vary over space and/or time. The value of the variable at the time of the speed study was used in the model. PSL, AccessDen, SigDen, CrossSection, and Devel vary over space (location) and over time for some pairs (PairNum), while Horz, SidWlk, ShoCur, RB_WID, TRK_AADT_P, and ADT in 1,000 vary only over location in this dataset. PairNum is included as a random effect in the model to account for repeated measures for SpdAve at the same location.

Table 47 provides the parameter estimates, while Table 48 shows the fixed effects test for sites included in the pair of speed studies analysis. As expected, most of the variables were significant except for the following: presence of sidewalk, ADT in 1,000, and Year(YOS). Figure 28 shows a plot of the predicted to actual average speed.

Table 47. Parameter Estimates for SpdAve for 278 Sites Included in the Pair of Speed Studies Analysis.

Term	Estimate	Std Error	DFDen	t Ratio	Prob>|t|
Intercept	85.237944	60.90133	223.5	1.40	0.1630
PSL(YOS)	0.470212	0.040791	254.4	11.53	<.0001*
CrossSection(YOS)[2U]	6.1345028	2.911502	135.6	2.11	0.0370*
CrossSection(YOS)[3T]	2.898623	2.450835	131	1.18	0.2391
CrossSection(YOS)[5T]	17.305338	3.371506	188.3	5.13	<.0001*
CrossSection(YOS)[6D]	−11.24176	4.304894	159.9	−2.61	0.0099*
Devel(YOS)[Ex-Urban]	0.5212712	0.301018	259	1.73	0.0845
Devel(YOS)[Rural]	1.1243963	0.457779	240.3	2.46	0.0148*
AccessDen(YOS)rev	-0.193343	0.061012	166.2	−3.17	0.0018*
SigDen(YOS)	−2.377919	0.605501	214	−3.93	0.0001*
Horz(YOS)[HC]	−1.999334	0.539858	133.1	−3.70	0.0003*
Sidwlk(YOS)[No]	−0.833642	0.581807	244	−1.43	0.1532
ShoCur(YOS)[Curb]	2.6745203	0.993815	237.2	2.69	0.0076*
ShoCur(YOS)[Mix]	−1.570395	0.593001	238	−2.65	0.0086*
S_WID_O	−0.771694	0.278035	135.2	−2.78	0.0063*
RB_WID	0.3462849	0.079348	137.5	4.36	<.0001*
TRK_AADT_P	−0.451325	0.093286	128.6	−4.84	<.0001*
ADT in 1,000	−0.060309	0.053226	137.9	−1.13	0.2592
Year(YOS)	−0.035311	0.030195	219.7	−1.17	0.2435

Note: RSquare = 0.916044, RSquare Adj = 0.910209, Root Mean Square Error = 2.125564, Mean of Response = 48.21115, and Observations (or Sum Wgts) = 278. * = significance level of < 0.05.

Table 48. Fixed Effects Test for Sites Included in the Pair of Speed Studies Analysis.

Source	Nparm	DF	DFDen	F Ratio	Prob > F
PSL(YOS)	1	1	254.4	132.8768	<.0001*
CrossSection(YOS)	4	4	204.6	11.0028	<.0001*
Devel(YOS)	2	2	244.2	4.3437	0.0140*
AccessDen(YOS)rev	1	1	166.2	10.0423	0.0018*
SigDen(YOS)	1	1	214	15.4228	0.0001*
Horz(YOS)	1	1	133.1	13.7155	0.0003*
Sidwlk(YOS)	1	1	244	2.0531	0.1532
ShoCur(YOS)	2	2	239.6	4.8079	0.0090*
S_WID_O	1	1	135.2	7.7036	0.0063*
RB_WID	1	1	137.5	19.0458	<.0001*
TRK_AADT_P	1	1	128.6	23.4071	<.0001*
ADT in 1,000	1	1	137.9	1.2838	0.2592
Year(YOS)	1	1	219.7	1.3676	0.2435

Note: * = significance level of < 0.05.

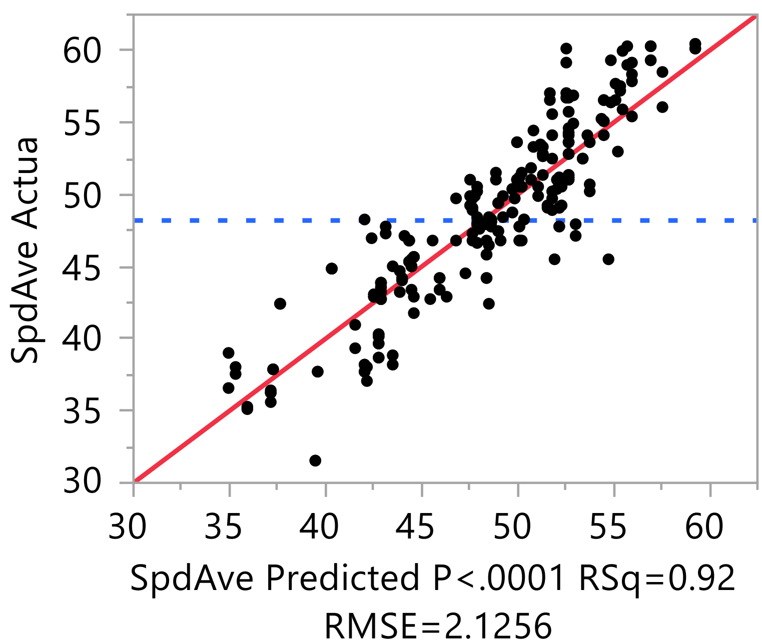


Figure 28. Actual by Predicted Plot for Average Speed for Sites Included in the Pair of Speed Studies Analysis.

Discussion on Results for Rural, Ex-Urban, and Suburban Research Question 2

There does not seem to be any significant relationship between SpdAve and time (Year[YOS]). Although a negative association is observed (the coefficient for Year[YOS] is −0.035311), it appears to be insignificant both statistically and practically.

CHAPTER 7: CONCLUSIONS AND RECOMMENDATIONS

BACKGROUND

PSLs are a highly complex issue involving engineering, human factors, and political and societal concerns. Within Texas, the TxMUTCD (*2*) and TxDOT's *Procedures for Establishing Speed Zones* (*1*) are the primary reference documents used. On a national level, recent research as part of NCHRP Project 17-76 (*4*), along with calls to change how speed limit are set, especially for city streets, have generated extensive discussion on how speed limits are and should be set.

A review of the literature identified several factors associated with operating speed including the following: PSL, AADT, truck AADT, access density, roadside development, horizontal alignment, lane width, median type, median width, number of lanes, presence of a passing lane, shoulder width, vertical alignment, and time of day.

DISTRICT SPEED DIALOGS

Dialogs between the research team and the districts on speed were held using web-based conferences. All 11 planned discussions were scheduled with district staff via web conferencing and were completed between March and December 2020. The insights gained from the speed dialogs generated the following emphasis areas for consideration when developing the educational materials:

- Update "Setting Speed Limits" pamphlet for <u>use with citizens</u>. The relationship between speed limits and safety should be clarified in this updated document, including the expected safety impacts of speed limit changes.
- Develop speed limit setting procedure material for <u>use with municipalities</u>.
- Develop a graphic illustrating the entire process between request and posting of a revised speed limit. The graphic will help to demonstrate the number of decision points, interactions, and who is involved. This graphic will be considered for the pamphlet developed for municipalities.
- Review, and perhaps expand, the section of the TxDOT website specifically devoted to speed limits (*81*). This web-based information should echo the suggested content for the anticipated revised public information pamphlets on speed limits.

The district discussions also identified the following desirable future research efforts to improve TxDOT speed management practices:

- Develop a guide on conducting speed studies with examples for different types of equipment and for different roadway classifications.
- Create tool(s) to help organize district speed study programs, including tracking the status of each study and outcome. Preference is that the tool be map-based and can pull information from other TxDOT databases, such as values for shoulder width, etc. A comprehensive tool could even incorporate the ability to store the speed data collected in conjunction with each speed study and provide a strip map, or equivalent, as an official record of each speed study's outcome.
- Create tool(s) to automate the decision process for selecting the recommend PSL that can also be used as part of the needed documentation. Such a tool has the potential to increase consistency statewide between the roadway environment and posted speed, as well as resolve inconsistencies that can evolve over time in the application of engineering judgment for speed studies as responsible staff change positions at TxDOT.

SPEEDS ON FREEWAYS

The evaluations of speeds on Texas freeways used data from 243 sensors located in Fort Worth. The data represented operating speeds during daytime and clear weather conditions (no rain within 1 hour of the speed reading). Speeds were removed from the database if construction was present, an incident had occurred 10 min prior to the speed reading or ended within 20 min after the speed reading, the nearby ramp was on the left-side, and if the segment had five or more general purpose lanes or a managed lane. To focus on free-flow type of conditions, speeds were removed if the operating speed was less than 53 or more than 90 mph or if the vehicle count would suggest a flow greater than 3,000 veh/hr/lane. The goal was to develop a database that contained operating speeds most likely affected by the PSL sign. Almost 900,000 15-min average speed readings were considered. Because the speeds were notably higher during 2020 with the pandemic restrictions, only data from 2015 to 2019 were considered.

The initial evaluation explored how much average operating speeds increased on those segments where the speed limit was raised from 60 to 65 mph, 60 to 70 mph, or 65 to 70 mph. In all cases, the average operating speed increased. The average operating speed increased between 2.4 to 4.0 mph as compared to the 5-mph increase in PSL or 2.9 mph for the 10-mph increase in PSL. These operating speed increases were statistically significant. The change in average operating speed for the control groups was only 0.02 to 0.04 mph where the speed limit was either 60 or 65 mph in both the before and after periods.

The next evaluation identified the variables associated with variations in average operating speed. For this dataset, the geometric variables with a significant relationship with operating speed included left and right shoulder widths, distance to downstream and upstream ramp, and type of ramp (entrance or exit). Even though the speed data reflected lower volume conditions, the 15-min volume variable was also significant. With respect to operating speeds and PSLs, as expected, freeway operating speeds were faster on the freeways with higher PSL. For this database, the segments with 65 mph PSL had average operating speeds that were about 1.63 mph faster. The segments with 70 mph PSL had average operating speeds that were about 3.26 mph faster.

In order to capture yearly trends at specific locations, the model included a variable to reflect the year of the data (2015, 2016, 2017, 2018, or 2019). The initial results showed a trend of mean speed increasing with each year. The research team attempted to identify reasons for the increase such as fuel prices (lower fuel prices could result in higher speeds), location within the freeway network (perhaps speeds are lower near major interchanges), and consumer price index (lower speed with higher index). The number of speeding citations issued during the 2016 to 2019 period decreased, which could be a reason that speeds increased over the same period. Additional resources became available for the project, so the research team was able to conduct a second statistical analysis that included the citation data. Following are the key conclusions and recommendations from that evaluation:

1. The most significant amount of operating speed variation was found to be unidentified localized factors representing 33.8 percent of variability due to differences from detector location to detector location. The researchers theorize that possible sources could be local attractors, traffic generators including those associated with heavy truck traffic, facility types connecting to and from the nearby ramps, or driver’s familiarity or trip purpose.
2. The next most important source of speed variation was found at the spot of speed location (26.4 percent of total variation represented in the residuals). Differences between driver

speed preferences, vehicle types, and number and characteristics of lane changing maneuvers are examples of transient events that were not identified nor explicitly accounted for in the model that should affect the speed measured from period of analysis to period of analysis and thus captured in this source of variation.

3. Yearly shifts in speeds at a given location was found the third most relevant source of speed variation (10.6 percent). These yearly shifts could be explained by economic fluctuations and other factors that might change from year to year, including, perhaps, the local population being more willing to operate at higher speeds or drivers becoming more familiar with the area.
4. Geometry was found as the fourth most influential factor affecting operating speed, as it was estimated that it explains about 7.5 percent of the speed variation in this dataset.
5. Weekly patterns at specific sites were found as the fifth most influential factor on operating speed, accounting for 7.2 percent of the total speed variation.
6. Differences in volume between 15-min periods only accounted for 4.4 percent of total speed variation. The research team expected this variable to have minimal impact as periods with high volume were removed from the dataset.
7. Second to last, varying posted speed limit values was found to affect the operating speed only by 4.1 percent. The range of posted speed limits included in the dataset was 60, 65, and 70 mph.
8. Finally, the level of enforcement was found to impact operating speeds significantly with more citations being associated with lower expected speeds. However, the size of that effect and the range of citation levels represented in the data only account for 3.6 percent of the total variation in operational speed.

Citations together with PSL and geometry represent the range of influence that engineering, law enforcement, and traffic management can influence operating speed. This study estimates that a strategy that entails modifying geometry, changing the PSL, and varying the level of law enforcement presence within the ranges included in this study may impact freeway operational speeds up to 6.2 mph (depending upon existing conditions along with the changes in the geometry, PSL, and enforcement).

SPEEDS ON HIGHWAYS

The evaluation of speeds on a sample of Texas non-access-controlled highways used speed zones conducted by TxDOT and by the research team within the past 20 years. The resulting database included 383 sites that were grouped into three development levels: rural, ex-urban, and suburban. A second database was developed to explore the question about speed changes over time. Those locations that had a speed study conducted in two different time periods were identified, resulting in 139 pairs being available. For all three development levels, PSL was significant. In other words, the statistical evaluations showed that average operating speeds have a relationship with PSL where drivers operate at higher operating speeds with higher posted limits.

For the rural category, outside shoulder width and the roadbed width were significant. For the ex-urban category, the presence of a horizontal curve, access density, signal density, outside shoulder width, and the roadbed width were also significant. The suburban roadways had several significant variables in addition to PSL including roadway cross section, presence of horizontal curve, access density, presence of sidewalk, presence of shoulder or curb and gutter, shoulder width, vehicle volume, and truck volume.

The second question explored whether operating speed was increasing over time. The results of the analyses revealed that there does not seem to be any significant relationship between average speed and time (year since previous study) for rural, ex-urban, or suburban highways. While a negative association was observed (i.e., speeds were less in later years), the coefficient (−0.035311) was insignificant and not of practical value. If assuming 10 years had elapsed since an initial study, the new operating speed would only be 0.3 mph less. While it is logical to think that operating speeds could increase as the PSL increases for a highway segment, for this set of sites the roadway and development changes resulted in most sites having lower PSLs and operating speeds rather than increased PSLs and operating speeds over time.

FUTURE RESEARCH NEEDS

The dialogues with the districts identified several suggestions and needs with regards to PSLs from the districts. They suggested that the material on the TxDOT website on speed limits could be updated using findings from this project. The districts would also like tools that could help them better organize and manage speed studies, including tools that would be map based and could automatically obtain values for key variables, such as shoulder width, from existing TxDOT databases. The tool should be designed to serve as the official record of each speed study outcome.

With regards to the freeway analysis, comparing the amount of influence between detector location and PSL, a recommendation would be that design and area-wide traffic management are important, but that a significant amount of effort needs to be devoted to looking at localized factors at specific sites, which can be more influential than design and operations management. Another recommendation would be to examine what other factors by location and by year within location might be systematic and could be explicitly measured with additional variables in the analysis. Factors associated with location or years at a given location amount to 40.4 percent of speed variation in the dataset, but the researchers were unable to identify these specific factors with the resources available in the project.

Regarding enforcement, it should be noted that the account for law enforcement presence in the current analysis was as yearly levels of citations for the overall study area, both in all municipal roads and in freeways by DPS. Future work should consider additional efforts to account for law enforcement with more sensitivity to the locations and periods of time with law enforcement presence. Expectedly, an analysis with such an account of this important factor could help explain some of the variability currently found as uncharacterized operational differences from location to location and from year to year.

Another research need is to identify the impacts of techniques that can be used to manage speed. These techniques could include speed feedback signs or increased enforcement, among others. The effectiveness of these techniques should be identified, and the results communicated to practitioners.

APPENDIX A: PAMPHLET

SIDE 1

SOME FACTS ABOUT DRIVERS, SPEED, AND SPEED LIMITS

Drivers and the Driving Environment

Numerous factors influence the speed selected by a driver, with the factors and amount varying based on conditions present. The number on the speed limit sign is a clear factor, along with the number of driveways, signals, curves, the widths of road features, and roadside objects. Weather, the day of the week, and natural light levels all play a role in driver speed choice. The amount of enforcement can strongly impact compliance with the posted speed limit.

Speed Limits and Driver Behavior

Changing speed limits can influence driver speed, but not as much as the change shown in the number on the sign. Research has found that a 5-mph speed limit reduction produces about a 1-mph reduction in average driver speed. For rural roads, increasing a speed limit by 10 mph increases average driver speed by only 3 to 5 mph.

Speed Limits and Safety

The speed-crash relationship is complex; research findings differ across studies, datasets, and speed measures. Several studies have identified speed variation (the range of individual driver speeds on the roadway) to have an adverse effect on safety. A recent study using data on city streets showed that crashes were lowest when the posted speed limit was within 5 mph of drivers' average speed. This same study confirmed that greater speed variation is linked to increased crashes. Recent research on high speed roads has also established a link between large speed variations and more severe crashes.

FOR MORE INFORMATION

To learn more about TxDOT and how speed limits are set, contact your local district office, or visit **www.txdot.gov.**

Abilene (325) 676-6800
4250 N. Clack
Abilene, Texas 79601

Amarillo (806) 356-3200
5715 Canyon Drive
Amarillo, Texas 79110

Atlanta (903) 796-2851
701 E Main Street
Atlanta, Texas 75551

Austin (512) 832-7000
7901 N. I-35
Austin, TX 78753

Beaumont (409) 898-5745
8350 Eastex Freeway
Beaumont, Texas 77708-1701

Brownwood (325) 646-2591
2495 Highway 183 North
Brownwood, Texas 76802

Bryan (979) 778-2165
2591 North Earl Rudder Freeway
Bryan, Texas 77803-5190

Childress (940) 937-2571
7599 US 287
Childress, Texas 79201-9705

Corpus Christi (361) 808-2275
1701 S. Padre Island Drive
Corpus Christi, TX 78416

Dallas (214) 320-6100
4777 E. Highway 80
Mesquite, TX 75150-6643

El Paso (915) 790-4204
13301 Gateway West
El Paso, TX 79928-5410

Fort Worth (817) 370-6500
2501 S W Loop 820
Fort Worth, Texas 7613

Houston (713) 802-5000
7600 Washington Avenue
Houston, Texas 77007

Laredo (956) 712-7400
1817 Bob Bullock Loop
Laredo, TX 78043

Lubbock (806) 745-4411
135 Slaton Road
Lubbock, Texas 79404-5201

Lufkin (936) 633-4321
1805 N. Timberland Drive
Lufkin, Texas 75901

Odessa (432) 498-4697
3901 E. Highway 80
Odessa, Texas 79761

Paris (903) 737-9300
1365 N. Main Street
Paris, TX 75460

Pharr (956) 702-6100
600 W. Interstate 2
Pharr, TX 78577

San Angelo (325) 944-1501
4502 Knickerbocker Road
San Angelo, TX 76904

San Antonio (210) 615-1110
4615 NW Loop 410
San Antonio, Texas 78229-0928

Tyler (903) 510-9100
2709 W. Front St.
Tyler, TX 75702

Waco (254) 867-2700
100 S. Loop Drive
Waco, TX 76704-2858

Wichita Falls (940) 720-7700
1601 Southwest Parkway
Wichita Falls, TX 76302

Yoakum (361) 293-4300
403 Huck Street
Yoakum, Texas 77995

Texas Department of Transportation

TTI.TXDOT2115.6389.0122

Texas Department of Transportation

SETTING SPEED LIMITS

Texas Department of Transportation

SIDE 2

EVER WONDER HOW SPEED LIMITS ARE SET?

STEP 1

Speed Limit Change Request:
Anyone can request a speed limit change. This is the first step in TxDOT conducting a speed study investigation to determine if such a change is warranted.

STEP 2

Data Collection and Study:
TxDOT collects field speed data to determine if the change is needed. The local TxDOT engineer also studies driver sightlines, road characteristics, and driveways (along with other speed-related safety concerns) to develop a recommended speed limit.

STEP 3

Recommendation Review:
TxDOT headquarters staff review the recommendation, verify the findings, and ensure consistency in how new speed limits are developed across the state. Once the review is complete, the new speed limit can be adopted.

STEP 4

Legal Framework:
The roadway's governing agency must provide a legal basis to enforce the new speed limit. A city council passes a new municipal ordinance for local streets; the Texas Transportation Commission approves a minute order for state roadways.

STEP 5

Sign Installation:
Once TxDOT staff install the new speed limit signs, the new limit is now enforceable. Though most jurisdictions allow a grace period for issuing warnings, law enforcement can cite violators for speeding any time after installation.

Who decides that this stretch of road should be 45 mph, while the stretch just over the hill is 55 mph? Why an interstate highway crossing west Texas is posted at 80 mph, while the limit on the same highway drops to 65 mph as it approaches the city?

Those speed limits aren't random. We don't pick a number arbitrarily and put it on the signs. There is research behind the process of establishing speed limits, and decades of experience guiding those decisions.

State law establishes the framework for speed management in Texas. Maximum speed limits are set by road type and driving environment; 30 mph for urban districts or streets, 60 mph on non-urban, non-state roadways, and 70 mph on non-urban state or federal roadways.

Some exceptions to these rules are allowed and managed under the authority of the Texas Transportation Commission. Speed limits can be adjusted and changed within these guidelines after being studied using the five-step process shown.

APPENDIX B: FREQUENTLY ASKED QUESTIONS ABOUT REGULATORY SPEED LIMITS

The following are questions frequently asked regarding regulatory speed limits. The answers were developed based on information in the literature along with research team knowledge regarding speed limits. These questions reflect regulatory speed limits and may not apply to work zones, advisory speeds, school zones, and other types of speed limits.

WHO SETS SPEED LIMITS IN TEXAS?

State law—the Texas Transportation Code (the "Code")—establishes the framework for speed management in the State of Texas. The Code generally establishes maximum speed limits based on the type of road and driving environment:

- Urban district or street: 30 mph.
- Alley, beach, or roads adjacent to beaches: 15 mph.
- Numbered state or federal highway outside urban district: 70 mph.
- Non-numbered highways outside urban district: 60 mph.

Exceptions are allowed for speeds greater than 70 mph on select numbered state or federal highways where the Texas Transportation Commission (TTC) deems it reasonable and safe to do so, including speed limits of up to 85 mph on roadways designed for this speed. Within this framework, the posted speed limit is determined by the responsible agency of the road or highway. Speed limits on city streets are managed by the municipal transportation department and established by municipal ordinance. Speed limits on county roads are managed by the county transportation department and established by county commissioners court minute order.

Speed limits on state and federal highways are managed by the Texas Department of Transportation (TxDOT). Speed studies—a type of engineering study—are performed on all state and federal routes on a regular basis and when requested by the public. The process for studying—and potentially changing—a speed limit is shown in the flowchart in Figure 29. If it is determined that a speed limit change is justified, the roadway's location determines the legal steps for adopting the revised speed limit. Outside municipal boundaries, speed limits are established by TTC minute order. For portions of state highways passing through a municipality, the speed limit is established by municipal ordinance.

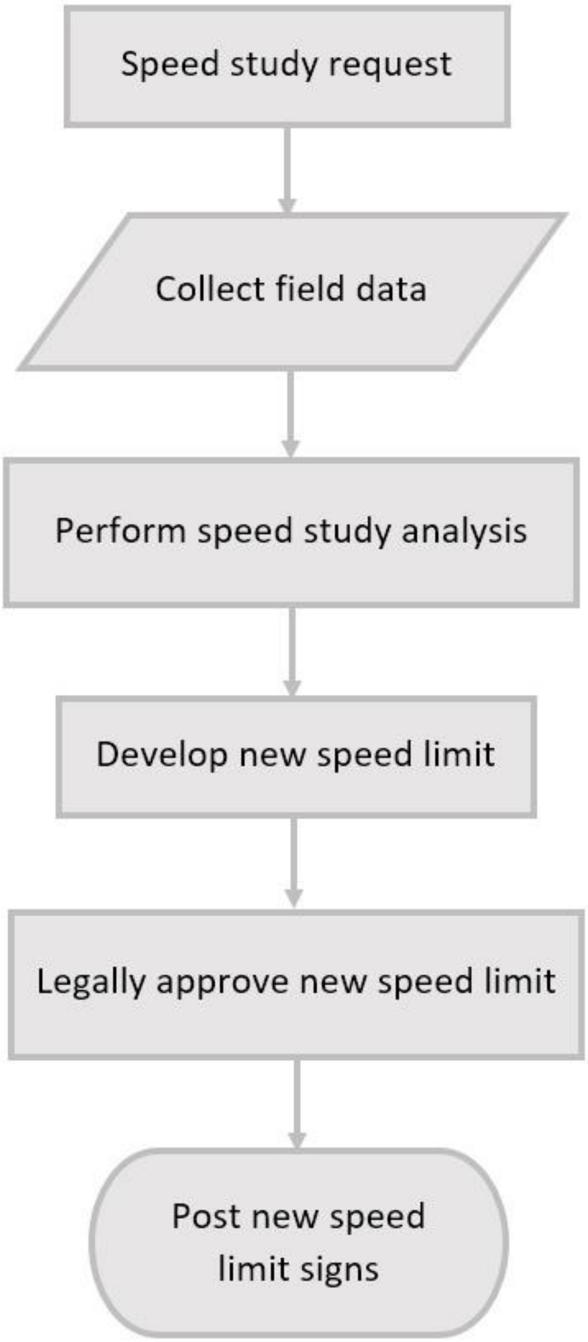


Figure 29. Setting Speed Limit Process.

HOW ARE SPEED LIMITS SET IN TEXAS?

Speed limits in Texas are based on the statutory speed limits outlined in the Code and evaluated by procedures established by TxDOT. The Texas Administrative Code (TAC) requires that speed limits be based on the 85th percentile speed, a value calculated from speed data based on typical engineering practice and that which defines a boundary for excessive speeds. As part of a speed study, the resulting suggested speed limit starts at the 85th percentile speed value and is then adjusted for the design and physical factors that can influence safe operating speeds, including:

- Horizontal and vertical curves.
- Hidden driveways and other roadside developments.
- High driveway density.
- Rural residential or developed areas.
- Lack of striped, improved shoulders.

After all such factors are considered in the speed study, an engineering recommendation is made on whether a speed limit change is necessary. If a change is recommended for a state or federal highway, the revised limit is reviewed by TxDOT staff for consistency in statewide practice and prepared for adoption by either TTC minute order (outside of municipal boundaries) or municipal ordinance (inside of municipal boundaries).

WHAT IS THE MAXIMUM SPEED LIMIT IN TEXAS AND HAS IT CHANGED OVER THE YEARS?

The statutory maximum speed limit in Texas is 75 mph on most roadways on the state highway system, 80 mph on parts of IH 10 and IH 20 in rural west Texas, and up to 85 mph on certain highways that are designed to accommodate travel at the established speed (State Highway 130 is currently the only roadway in this category).

The statutory maximum speed limit for the state highway system was 70 mph in daytime and 65 mph at night until a series of legislative changes occurred starting in 2006. Such changes were made to recognize different conditions on some types of roadways that could justify the posting of higher regulatory speed limits and included:

- 1974: National Maximum Speed Limit (NMSL) Law restricted the maximum permissible vehicle speed limit to 55 mph on all interstate roads in the United States.
- 1995: NMSL repealed.
- 2000: Environmental speed limits implemented in several Texas regions as a method to improve air quality.
- 2003: No new environmental speed limits to be implemented.
- 2006: Rural interstate highways and some other rural highways in sparsely populated counties could be signed as high as 80 mph and 75 mph, respectively.
- 2011: All highways on the state highway system could be signed as high as 75 mph. In addition, the night and truck speed limits were repealed.
- 2012: Highways that were built to exceptionally high design standards and could accommodate travel at higher speeds could be signed up to 85 mph.

WHY DO WE USE 85TH PERCENTILE SPEED AS PART OF SETTING SPEED LIMITS?

The 85th percentile speed has been used as a rule of thumb for setting regulatory speed limits since the 1930s. The concept is based on the principles that most drivers are reasonable and prudent, desire to avoid a crash, and desire to arrive at their destination in the shortest possible time. Historical speed studies have shown that cumulative speed distribution curves often bend at speeds slightly above the 85th percentile, such that there are a small number of notably fast vehicles above this value that are assumed to be driving above a reasonable speed. Using the 85th percentile results in speed limits that are credible to the public and avoids criminalizing too large a proportion of the driving population.

HOW ARE ROADWAY USERS CONSIDERED WHEN SETTING SPEED LIMITS?

The driver often plays a key role in the speed limit setting process since the speeds used toward establishing speed limits are typically measured when traffic is flowing freely. During free-flow conditions, drivers select speeds that they believe optimize the tradeoffs between travel time and risk. Basing the speed limit on the 85th percentile indicates a belief that drivers are pretty good at assessing these tradeoffs and their judgment is trustworthy in establishing a level where drivers who exceed that speed may be cited by law enforcement. While that may be so, additional conditions could exist that do not influence the 85th percentile speed but contribute to crashes. A posted speed limit that is lower than the 85th percentile speed could help to minimize the consequences of those conditions. In addition, the desire to provide roadway corridors that encourage active transportation should be associated with appropriate posted speed limits that consider the safety and mobility needs of pedestrians and bicyclists.

WHY CAN YOU NOT POST A SPEED LIMIT BASED ON AN OPINION OF WHAT IS GOOD FOR A ROAD?

If the speed limit value decision is not based on objective data or accompanied by needed enforcement, education, or infrastructure changes, then target travel speeds may not be achieved. Drivers usually select their operating speed based on their perception of the driving environment and their own needs and preferences rather than actively considering other road users' needs and perspectives.

IS THE 85TH PERCENTILE SPEED APPROPRIATE FOR ALL CONDITIONS?

While the 85th percentile speed is an essential starting point for setting regulatory speed limits, it is not sufficient to account for all site conditions and all roadway users. The 85th percentile speed concept implicitly assumes that drivers are aware of roadway hazards that require them to reduce their speed. This assumption is questionable in some conditions, particularly on roadways with frequent curves or driveways or notable numbers of pedestrians and bicyclists (such as urban streets). Hence, it is necessary to examine and document site conditions and the frequency of vulnerable road users when conducting a speed zone study and adjust the speed limit as needed to account for these conditions. If the speed limit is adjusted notably down from the 85th percentile, it is important to provide education and enforcement to ensure credibility and compliance.

HOW EFFECTIVE IS A LOWER POSTED SPEED LIMIT IN LOWERING OPERATING SPEED?

There is evidence that in some locations a reduction in the posted speed limit will be accompanied by a reduction in average operating speed. This reduction, if present, will not be in the same magnitude as the reduction in posted speed limit. Research has shown that the reduction is 1 mph or less compared to a 5-mph speed limit drop.

HOW MUCH DOES SPEED INCREASE AFTER RAISING THE POSTED SPEED LIMIT?

In one of the most extensive studies in this area, speed limits were changed at 100 sites along non-limited-access highways where the speed limits were either raised or lowered, and speed limits were not changed at 83 control sites. The difference in operating speed at the treated sites after these changes was typically less than 1.5 mph on average. Other research projects have also found that speed limit increases tend to result in increased vehicle speeds, but average speed increases were generally less than half the amount of the actual speed limit increase. 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. 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. In summary, while the research findings indicate a change in the speed limit sign can affect operating speeds, it is not as influential as the magnitude of the speed limit value change.

WHAT AFFECTS OPERATING SPEED?

Numerous factors influence the speed selected by a driver, with the amount of influence varying depending on conditions present. For example, a parent may be driving faster when going to pick up a child from day care to avoid late fees compared to when that parent is returning home after a Saturday morning soccer game.

Research has provided insights, in general, into factors that are associated with higher or lower operating speeds. Factors not related to the design of the road that can influence operating speed include natural light level (day or night), weather (i.e., rain, snow), day of the week, and driver characteristics such as age and gender.

On urban and suburban city streets, operating speeds are lower with a greater number of access points (e.g., driveways or minor streets), signals, horizontal curves, and features associated with urban development such as street furniture. On rural high-speed highways, operating speeds are lower on horizontal curves with small radii and higher access density. Higher operating speeds are associated with more travel lanes, wider lane widths, wider median widths, and wider shoulders. For freeways, increases in the number of vehicles will result in lower operating speeds as expected; however, even when the freeway is considered to be in free-flow conditions, the number of vehicles appears to affect operating speed in addition to the number of lanes and lane and shoulder width. For any roadway type and within any roadway context, higher posted speed limits are associated with higher operating speeds, as to be expected.

WHAT IS THE SAFETY RELATIONSHIP BETWEEN POSTED SPEED LIMITS AND CRASHES?

The speed-crash relationship is often confounded by many other factors (road characteristics, weather, etc.), and as a result the estimated relationship has not been consistent across different research studies. In most studies, speed variation was found to have an adverse effect on safety. The findings on the relationship between average speed (or 85th percentile speed) and crashes have had conflicting results. For example, a negative relationship between average speed and crash frequency/rates was found by some studies, while a positive relationship was found by other studies. Confounding factors have often been cited as possible reasons for such a disputable relationship. The speed-crash relationship cannot be appropriately established without considering the corresponding contexts (such as roadway type, roadway geometry, traffic, etc.), which may confound the relationship between speeds and crashes if not considered. In addition, how different factors interact must be studied.

A recent study (*17*) using city streets found crashes were lowest when the posted speed limit was within 5 mph of the average operating speed. The presence of a median or curb is associated with less crashes, while the number of signalized intersections, traffic volume, and segment length were correlated with more crashes. Another important implication from that research was the confirmation of the relation between the speed variability and crash occurrence for city streets. Increased crash occurrence was observed with larger speed variability. Larger spread/variability in operating speed is indicative of reduced smoothness in operations and higher potential for speed differentials. Another possible explanation is that the associations found could indicate that sites with more speed variability tend to be those with mixed visual cues or prone to ambiguous contextual situations (e.g., wide streets in a residential setting). These mixed visual cues may result in different drivers choosing different speeds, and perhaps by doing so a large proportion of the driving population could be more likely to exceed roadway conditions and thus increase their risk of crashing.

For high-speed highways or freeways, maximum speed limit changes have corresponded to an increase in crashes in some research studies. Speed trends appear to vary by geographic regions and may be influenced by societal factors such as driver age, population density, unemployment rate, median family income, speeding enforcement, and similar factors. Speed variability has been linked to greater crash severity at the higher speed limit thresholds.

WHAT REFERENCE MATERIALS ARE AVAILABLE TO HELP WITH POSTED SPEED LIMITS?

Within Texas, the key reference document for posted speed limits is the *Procedures for Establishing Speed Zones* (*1*) manual.

Procedures for Establishing Speed Zones

- Source: http://onlinemanuals.txdot.gov/txdotmanuals/szn/index.htm.
- Date: last modified August 2015.
- Publisher: TxDOT.
- Description: The purpose of this TxDOT manual is to provide the information and procedures necessary for establishing speed zones and advisory speeds on the state highway system.

The following sources provide additional guidance on posted speed limits.

Posted Speed Limit Setting Procedure and Tool: User Guide and NCHRP 17-76 SLS-Tool

- Source: https://www.trb.org/Main/Blurbs/182038.aspx.
- Date: last modified April 2019.
- Publisher: National Cooperative Highway Research Program (NCHRP).
- Description: NCHRP Project 17-76 investigated the factors that influence operating speed and safety. This knowledge was used to develop guidance and a speed limit setting tool (SLS-Tool) so engineers can make informed decisions about the setting of speed limits.

Speed Management Safety Website

- Source: https://safety.fhwa.dot.gov/speedmgt/.
- Date: last modified April 2019.
- Publisher: Federal Highway Administration (FHWA).
- Description: This website provides links to several publications and tools along with ongoing research.

Speed Management ePrimer for Rural Transition Zones and Town Centers

- Source: https://safety.fhwa.dot.gov/speedmgt/ref_mats/rural_transition_speed_zones.cfm.
- Date: January 2018.
- Publisher: Federal Highway Administration.
- Description: This ePrimer reviews speeding-related safety issues facing rural communities and discusses the basic elements required for data collection, information processing, and countermeasure selection by rural transportation professionals and community decision makers. The ePrimer is presented in six distinct modules developed to allow the reader to move between each to find the desired information without a cover-to-cover reading.

Traffic Calming ePrimer

- Source: https://safety.fhwa.dot.gov/speedmgt/traffic_calm.cfm.
- Date: February 15, 2017.
- Publisher**:** Federal Highway Administration.
- Description: The ePrimer presents a review of traffic calming practices in eight modules. The ePrimer presents:
    - A definition of traffic calming, its purpose, and its relationship to other transportation initiatives (i.e., complete streets and context-sensitive solutions).
    - Illustrations and photographs of 22 types of traffic calming measures.
    - Considerations for their appropriate application, including effects and design and installation specifics.

- Research on the effects of traffic calming measures on mobility and safety for passenger vehicles; emergency response, public transit, and waste collection vehicles; and pedestrians and bicyclists.
- Examples and case studies of both comprehensive traffic calming programs and neighborhood-specific traffic calming plans.
- Case studies that cover effective processes used to plan and define a local traffic calming program or project and assessments of the effects of individual and series traffic calming measures.

Speed Enforcement Program Guidelines

- Source: https://safety.fhwa.dot.gov/speedmgt/ref_mats/fhwasa09028/resources/Speed%20Enforcement%20Program%20Guidelines.pdf#page=1.
- Date: March 2008.
- Publisher: U.S. Department of Transportation, National Highway Traffic Safety Administration.
- Description: The objective of the guidelines is to provide law enforcement personnel and decision makers with tools to establish and maintain an effective speed management program. The guidelines include:
    - Identification of the problem.
    - Legislature, regulation, and policy.
    - Program management, including public outreach.
    - Enforcement countermeasures.
    - Program evaluation.

USLIMITS2

- Source: https://safety.fhwa.dot.gov/uslimits. User Guide for USLIMITS2: https://safety.fhwa.dot.gov/uslimits/documents/appendix-l-user-guide.pdf.
- Date: March 2008 for initial development, December 2017 for updated user guide.
- Publisher: U.S. Department of Transportation, FHWA.

- Description: USLIMITS2 is a web-based tool that was designed to assist practitioners in setting consistent and safe speed limits. It is used to set speed limits for specific segments of roads and can be used on all types of roads (local roads to freeways).

APPENDIX C: COMMON TXDOT IMPLEMENTATION ORDER FOR SPEED MANAGEMENT TECHNIQUES

Speed Management Devices	Change in Speed Limit	Speed Transition Zones in Rural Areas	Rural Highway Speed Management	Suburban Roadway Speed Management	Urban Roadway Speed Management	Collector Roadway Speed Management	Neighborhood Speed Management
Signing Enhancements—Oversize	1	1	1	1	1	—	—
Signing Enhancements—Red Border[a]	1	1	—	—	—	—	—
Speed Feedback Signs[b]	—	—	2	2	2	1	—
Gateway Treatments[c]	—	2	—	—	—	—	—
Transverse Rumble Strips[d]	2	3	—	—	—	—	—
Raised Medians/Islands[e]	—	—	—	3	3	2	—
Traffic Calming (e.g., speed humps/tables)	—	—	—	—	—	—	1
Reduced Lane Width[f]	—	—	—	3	3	2	—
Road Diet (e.g., change cross section)	—	—	—	—	4	2	—
Signal Timing	—	—	—	4	5	—	—
Speed Zone Pavement Markings (w/legends)[g]	—	—	—	—	—	—	—
Optical Speed Bars	—	—	—	—	—	—	—

Note: Numbers in table (1–5) indicate suggested implementation order.
[a] – Usually applied to the first reduced speed sign approaching a speed limit change area or rural community.
[b] – Most effective deployment mode is with speed trailers for several weeks at a time, on a rotating schedule. Coordination with law enforcement substantially increases effectiveness.
[c] – Longer implementation timeline and requires coordination with municipality; TxDOT 2015 guidelines.
[d] – Presents significant noise concern in corridors with residential development.
[e] – Usually applied for access management and requires capital funds expenditure (longer implementation timeline).
[f] – Limited applicability on roadways with bus routes.
[g] – Applied on curve approaches and for school zones, but not for general speed management.
(pink box) – Not a typical TxDOT speed management device or practice; usually applied by municipalities.
(blue box) – Not a typical TxDOT speed management device; rare application of speed bars at high-speed curves.

APPENDIX D: SUGGESTED REVISIONS TO THE *PROCEDURES FOR ESTABLISHING SPEED ZONES* MANUAL

INTRODUCTION AND SCOPE

In its current form, TxDOT's *Procedures for Establishing Speed Zones* manual (*1*) ("Speed Zone Manual" hereinafter) contains the following chapters and appendices:

- Introduction.
- Regulatory and Advisory Speeds.
- Speed Zone Studies.
- Speed Zone Approval.
- Application of Advisory Speeds.
- Forms.
- Glossary.

The findings from Research Project 0-7049 may lead to notable changes to Chapters 3 and 4 and additional minor changes to other parts of the Speed Zone Manual. The most extensive changes will likely occur in Chapter 3, which currently contains these sections:

- Overview.
- Determining the 85th Percentile Speed.
- Developing Strip Maps.
- Speed Zone Design.
- Rechecks of Speed Zones.
- Environmental Speed Limits.

The following sections in this appendix detail anticipated changes to the Speed Zone Manual. It is important to note that these changes would become necessary if TxDOT adopts a framework of quantitative decision rules for setting regulatory speed limits in a manner similar to the framework documented in *NCHRP Web-Only Document 291: Development of a Posted Speed Limit Setting Procedure and Tool* (*17*). This framework calls for using the 85th and 50th percentiles of the free-flow speed distribution for setting regulatory speed limits based on geometric, traffic, and safety conditions at the site.

SUGGESTED REVISIONS TO CHAPTER 3

The current version of Chapter 3 describes the procedures to conduct and document speed zone studies for the purpose of setting regulatory speed limits. This chapter will require revision to provide practitioners with guidance for collecting the needed data to apply any updated decision rules for setting regulatory speed limits. The following paragraphs describe the suggested changes to each section in Chapter 3.

Section 1: Overview

The overview section will need two minor revisions. First, the final paragraph under the "Interim Speed Limits for New or Reconstructed Highways" heading should be revised to replace "an 85th percentile speed study" with "a speed study." This broadened language acknowledges the need to measure more than just the 85th percentile speed (i.e., the pace and the 50th percentile speed may also be needed). Second, the bullet list under the "Scope of Study" heading should be revised as shown in Table 49.

Table 49. Suggested Revisions to Chapter 3 Section 1 Bullet List.

Existing Text	Proposed Change
Determining the 85th percentile speed	Rephrase: "Determining the speed distribution."
Crash study	Delete. The crash study will be subsumed into the documentation of site characteristics.
Developing of strip maps	Rephrase: "Documenting site characteristics."
Speed zone design	No change.
Rechecks of speed zones	No change.

Section 2: Determining the 85th Percentile Speed

The existing section title and language emphasize the 85th percentile free-flow speed because this speed has historically formed the basis for setting regulatory speed limits. Section 4 of Chapter 3 in the Speed Zone Manual provides a list of reasons to set a regulatory speed limit below the 85th percentile speed but does not tie the magnitude of the reduction to a specific percentile in the speed distribution. If TxDOT adopts decision rules to quantify deviations from the 85th percentile speed, these rules would likely account for other parts of the speed distribution, such as the 50th percentile. Additionally, the *Texas Manual on Uniform Traffic Control Devices* (TxMUTCD) (Section 2B.13, paragraph 18) (*2*) acknowledges the pace speed as a factor that may be considered when establishing or re-evaluating regulatory speed limits. The pace speed is the 10-mph range in the free-flow speed distribution that contains the largest number of vehicles. Hence, the research team suggests changing this section title to "Determining the Speed Distribution." Language should be added to this section to acknowledge other parts of the speed distribution, including the pace and the 50th percentile.

Section 3: Developing Strip Maps

The existing Speed Zone Manual provides extensive guidance on preparing strip maps and calls for the following data to be shown on the maps:

- Crossroads and cross streets.
- Limits of the speed zone.
- Adjoining speed zone(s) of connecting map(s).
- Limits of any incorporated city or town.
- Names and approximate limits of the developed area of unincorporated towns.
- Urban districts.
- Schools and school crossings.
- Traffic signals.
- Important traffic generators.
- Ball bank readings.
- Railroad crossings.
- Bridges.

A revised set of decision rules may require a different set of site variables to be collected and documented. Hence, the research team suggests changing this section title to "Documenting Site Characteristics." The research team provides no suggestion for the format of data records (strip map, spreadsheet, forms, diagrams, or other formats as needed). The data record format will depend on the needs of TxDOT and other involved jurisdictions, such as counties and cities. However, the research team does provide general suggestions on the content of the site characteristic documentation. The following data topics need to be documented in a speed zone study:

- Basic data (roadway location, type, and context).
- Geometry (number of lanes, median type, and other variables as needed).

- Traffic control (existing regulatory speed limit, statutory speed limit).
- Crash history (crash locations and severities, number of years of crash data available).
- Jurisdiction (locations of district limits, county lines, city limits, and school zones present on the segment).

Information to be collected as "basic data" includes the roadway type and context. The decision rule framework from *NCHRP Web-Only Document 291* (*17*) includes the following roadway types and contexts:

- Roadway types: freeway, principal arterial, minor arterial, collector, and local.
- Roadway context: rural, rural town, suburban, urban, and urban core.

Section 4: Speed Zone Design

In the existing Speed Zone Manual, two bulleted lists are provided to give reasons to deviate from the 85th percentile speed when setting regulatory speed limits. These bulleted lists are provided under the following two headings:

- Crash rate greater than the statewide average crash rate for similar types of roadways.
- Additional roadway factors.

These two bulleted lists have substantially similar content, with more explanatory material provided in the second list. Table 50 provides a comparison of the contents of the two lists. This comparison shows that TxDOT currently recognizes a list of reasons to set the regulatory speed limit below the 85th percentile speed and that the reasons can relate to crash history, presence of suboptimal geometry, or presence of vulnerable road users (i.e., pedestrians and bicyclists).

Table 50. Bulleted List Contents from Chapter 3 Section 4.

Item	List One	List Two	Notes
Description	List One: crash rate, lower by up to 12 mph	List Two: additional roadway factors, lower by up to 10 mph (typical) or 12 mph (high crash rate)	Notes (from List Two)
Narrow roadway pavement	X	X	e.g., ≤ 20 ft
Horizontal and vertical curves	X	X	Possible limited sight distance
Hidden driveways and other developments	—	X	Possible limited sight distance
High driveway density	X	X	The higher the number of driveways, the higher the potential for encountering entering and turning vehicles
Lack of striped, improved shoulders	X	X	Constricted lateral movement
Crash history	X	X	—
Rural residential or developed areas	—	X	Higher potential for pedestrian and bicycle traffic

Note: — = not applicable. X = content present.

Section 4 should be rewritten to include any updated decision rules adopted by TxDOT. The two bulleted lists mentioned above should be combined into one list that reflects the decision rules. If new decision rules are adopted, they should specify the degree to which the posted regulatory speed limit can deviate from the 85th percentile speed and likely identify other points in the speed distribution (such as the 50th percentile) that may be considered in setting the regulatory speed limit.

Section 5: Rechecks of Speed Zones

The research team suggests no changes to this section.

Section 6: Environmental Speed Limits

The content of this section is outside the scope of Research Project 0-7049.

SUGGESTED REVISIONS TO CHAPTER 4

Chapter 4 of the Speed Zone Manual contains discussion of the process for obtaining approval for speed zones after they have been developed according to the procedures from Chapter 3. This process is not being changed by the 0-7049 guidance. Chapter 4 also contains various references to strip maps. The research team suggests broadening these references so they acknowledge the documentation discussed in the proposed Chapter 3, Section 3 material above. Additionally, the research team suggests providing a flow chart to assist practitioners through the process.

OTHER SUGGESTED REVISIONS

The research team is not proposing specific new content for Appendix A (Forms) but suggests that TxDOT consider its own documentation needs for speed limit data analysis and decision making and develop new forms as needed.

The research team is not proposing specific new content for Appendix B (Glossary) but suggests that TxDOT review the content of the glossary, determine if any existing content is no longer relevant and needs to be removed, determine if new content needs to be added, and make changes accordingly.

There are various places within the Speed Zone Manual where the "Traffic Operations Division" is mentioned. This text should be rephrased as "Traffic Safety Division" to reflect the name change for the division.

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