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Using Vehicle Probe Data to Evaluate Speed Limits

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16. Abstract

When speed limits are set via an engineering speed zone study, the operating speed for a site is needed. This research project investigated whether probe speed data (rather than speeds measured in the field) could reasonably be used in a speed zone study. The idea for using probe speed data is to develop conversion equations that would convert an average yearly speed measure obtained from probe speed data into a speed measure that would represent free-flow conditions for passenger cars. Equations for 85th percentile speed and average speed were created for freeway and non-freeway facilities, each subdivided into urban and rural contexts, and their performances were evaluated. For freeways, the adjusted R-squared values for the regression equations indicate that the independent variables used in the models can explain between 77 and 92 percent of the observed speed variability. Further, the values for the root mean square error implies that, on average, the predicted speeds are off by 2.6 to 2.9 mph, which are lower than the suggested incremental speed limits (5 mph). For non-freeway facilities, the adjusted R-squared values for the regression equations indicate that the independent variables used in the models can explain between 71 and 89 percent of the observed speed variability. The root mean square error implies that, on average, the predicted speeds are off by 2.8 to 3.5 mph. These values are again lower than the suggested incremental speed limits (5 mph) but high enough to potentially affect the outcome of the speed zone study. Further, the research team used the speed zone methodology to generate a suggested speed limit using on-site and predicted speed data. For the freeway test case, 97 percent of the rural study sites and 88 percent of the urban study sites had the same suggested speed limit when using either the on-site or predicted speed data. The rural non-freeway test case also had a high suggested speed limit match (86 percent). For the urban non-freeway test case, only 42 percent of the study sites generated the exact same suggested speed limit; however, if the range was expanded to be within 5 mph, 93 percent of the study sites would be included. In conclusion, the calculated predicted speeds used in the speed zone method generally produce suggested speed limits that are the same or within 5 mph as the suggested speed limits identified using the on-site speed data. Therefore, the potential of using probe speed data exists. Additional required research includes applying the protocol to a select region and reviewing the findings to determine if the results are defensible, identifying how influential various factors are to the outcomes, and identifying how to implement such a process.

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USING VEHICLE PROBE DATA TO EVALUATE SPEED LIMITS

by

Kay Fitzpatrick, Ph.D., P.E., PMP
Senior Research Engineer
Texas A&M Transportation Institute

Boniphace Kutela, Ph.D., P.E., PMP
Associate Research Engineer
Texas A&M Transportation Institute

Eun Sug Park, Ph.D.
Senior Research Scientist
Texas A&M Transportation Institute

Michael P. Pratt, P.E., PTOE
Associate Research Engineer
Texas A&M Transportation Institute

Steven Venglar, P.E.
Research Engineer
Texas A&M Transportation Institute

Minh Le, P.E., PMP
Research Engineer
Texas A&M Transportation Institute

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College Station, Texas 77843-3135

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.

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CHAPTER 1: INTRODUCTION

BACKGROUND

Speed limits are among the most visible and routinely enforced traffic control devices motorists encounter in their everyday driving. They are associated with safety in a broad range of forums, from neighborhood residents concerned with their children's safety to national safety agencies. Recently, the rationale for speed limit setting procedures via speed zone studies used by nearly all engineering practitioners has been called into question, especially with regards to non-freeway conditions. Given this high degree of exposure and scrutiny, speed limits—and the practices and procedures used to develop them, to inform drivers, and to help enforce them—are frequently an area of concern and discussion with a broad range of stakeholders. This research project investigated how to make speed zone studies and speed limit decisions more effective and efficient.

PROJECT OBJECTIVES AND SCOPE

This research project investigated whether quality probe speed data are available for use in speed zone studies. The project included the following specific technical objectives:

- Identify variables that should be considered within a Texas speed limit study.
- Identify available resources within Texas for the variables needed for a Texas speed limit study, especially speed probe, roadway, and crash data.
- Determine whether speed probe data can be used in place of the current approach for collecting speed data, and if so, how the probe data should be adjusted or refined for appropriate use in setting speed limits.
- Establish adjustment factors to convert the typical space mean probe speed data to representative free-flow speed data.
- Develop guidelines and a workshop on how to use the various data streams in evaluating and setting speed limits.

REPORT ORGANIZATION

This report consists of eight chapters. In addition to this introductory chapter, the report contains the following material:

- Chapter 2 provides an overview of the setting of posted speed limits.
- Chapter 3 discusses probe and traditional sources for speed data.
- Chapter 4 presents potential sources that could be used to develop the datasets needed to evaluate the feasibility of using probe data in a speed zone study.
- Chapter 5 describes the building of test cases.
- Chapter 6 presents the findings for the freeway test case.

- Chapter 7 presents the findings for the non-freeway test case.
- Chapter 8 summarizes researchers' findings and provides recommendations for future action.

CHAPTER 2: SETTING OF POSTED SPEED LIMITS

TEXAS DEPARTMENT OF TRANSPORTATION SPEED ZONE METHOD

Within Texas, the *Texas Manual on Uniform Traffic Control Devices* (TxMUTCD) (*1*) and the Texas Department of Transportation's (TxDOT's) *Procedures for Establishing Speed Zones* (*2*) are used in the process of setting speed limits. The TxMUTCD also references the *Traffic Control Devices Handbook* (*3*) regarding criteria on the spacing of speed limit signs. The TxMUTCD was adopted in October 2014. It is currently being updated to reflect changes in the recently approved 2023 *Manual on Uniform Traffic Control Devices* (MUTCD) (*4*).

The 2014 TxMUTCD states that when a speed limit within a speed zone is posted, it should be within 5 mph of the 85th percentile speed of free-flowing traffic. It also states that speed studies for signalized intersection approaches should occur outside the influence area of the traffic control signal, which is generally considered to be approximately 1/2 mile, to avoid obtaining skewed results for the 85th percentile speed. An option statement lists the following factors that may be considered when establishing or reevaluating speed limits: road characteristics including shoulder condition, grade, alignment, and sight distance; the pace; roadside development and environment; parking practices and pedestrian activity; and reported crash experience for at least a 12-month period.

TxDOT' *Procedures for Establishing Speed Zones* (*2*) is also commonly known as the Speed Zone Manual (SZM). It provides greater details regarding the setting of posted speed limits as compared to the information included in the TxMUTCD. Regulatory speed limits are set based on the 85th percentile speed of free-flowing passenger cars and various site-specific considerations, particularly geometry and crash history. The methodology used by TxDOT to set regulatory speed limits is described in the SZM. This methodology requires a speed zone study of vehicles in the field to set or revise regulatory speed limits.

Chapter 3 Section 4 of the SZM provides the following list of criteria that can be used to justify setting a regulatory speed limit below the 85th percentile speed:

- Narrow roadway pavement widths.
- Horizontal and vertical curves.
- Hidden driveways and other developments.
- High driveway density.
- Crash history.
- Rural residential or developed areas.
- Lack of striped, improved shoulders.

The SZM explains that these criteria can justify setting a regulatory speed limit as much as 10 mph below the 85th percentile speed or as much as 12 mph below the 85th percentile speed if the speed zone of interest has a crash rate higher than the statewide average crash rate for similar facilities.

MANUAL ON UNIFORM TRAFFIC CONTROL DEVICES METHOD

The 2014 TxMUTCD (*1*) is based on the 2009 *Manual on Uniform Traffic Control Devices* (*5*). Per the TxMUTCD (*1*), 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:

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

The TxMUTCD is currently being reviewed and revised in consideration of the newly released 2023 MUTCD; until then, the 2014 version is the version to consider. To understand what the revision may include, changes in the 2023 MUTCD are presented below. The new version of the MUTCD (*4*) was released in December 2023. It contains several revisions to the speed limit section. The 2023 MUTCD now includes the following six factors that should be considered by the engineering study:

- Roadway environment (e.g., roadside development, number and frequency of driveways and access points, and land use), functional classification, public transit volume and location or frequency of stops, parking practices, and pedestrian and bicycle facilities and activity.
- Roadway characteristics (e.g., lane widths, shoulder condition, grade, alignment, median type, and sight distance).
- Geographic context (e.g., urban district, rural town center, non-urbanized rural area, or suburban area), and multi-modal trip generation.
- Reported crash experience for at least a 12-month period.
- Speed distribution of free-flowing vehicles including the pace, median (50th percentile), and 85th percentile speeds.
- Review of past speed studies to identify any trends in operating speeds.

NATIONAL DISCUSSIONS ON SETTING POSTED SPEED LIMITS

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 (6). The MUTCD (*4*) and the TxMUTCD (*1*) provide 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 although 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 the factors in the MUTCD along with others such as bicyclist activity or alignment.

On a national level, to address the desire to update the procedures used in setting posted speed limits, a recent National Cooperative Highway Research Program (NCHRP) Project (Project 17-76) investigated the factors that influence operating speeds and 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 spreadsheet-based speed limit setting tool (SLS-Tool). The methodology is documented in NCHRP Report 966 (*7*) and requires the 85th and 50th percentile speeds as inputs to the analysis, along with various site characteristics.

As part of the recent TxDOT Project 0-7049 (*8*), the research team conducted dialogs with TxDOT districts to learn about the practices and procedures being used to set speed limits, developed several products designed to increase the understanding of operating speed and of posted speed limits, 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. The pamphlet and answers to common questions are available in the 0-7049 research report (*8*).

NATIONAL SPEED LIMIT DEBATES

The national speed limit debate increased in 2017 with two publications. In March 2017, the National Association of City Transportation Officials (NACTO) released a policy statement (*9*). One of the action items in that statement would "permit local control of city speed limits." They recommend "state rules or laws that set speed limits at the 85th percentile speed should be repealed." In July 2017, the National Transportation Safety Board (NTSB) published a report on speeding (*Reducing Speeding-Related Crashes Involving Passenger Vehicles*) (*10*) that contained several recommendations for reducing speed-related crashes including two recommendations directed to the Federal Highway Administration (FHWA) for changes to the MUTCD. NTSB recommended that the then 2009 MUTCD (*5*) factors currently listed as optional for all engineering studies be required, that an expert system be require to be used as a validation tool, that the guidance that speed limits in speed zones should be within 5 mph of the 85th percentile speed be removed, and that the safe system approach be incorporated 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 (*11*, *12*). One of the questions from the NCUTCD task force survey was "How would you set speed limits if given the choice?" Responses included rounding to the nearest 5 mph of the 85^{th} 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. These findings along with many discussions within various groups influenced the changes that are now included in the 2023 MUTCD (*4*).

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" (*13*). In addition, the task force also examined alternatives to the 85^{th} percentile method for determining speed limits in California. The California Zero Traffic Fatalities Task Force made several recommendations (*14*), including having a policy that would allow an increased deviation (more than 5 mph) from the 85^{th} percentile speed for high injury networks and areas adjacent to land uses and types of roadways that have high concentrations of vulnerable road users. Activities are also occurring in Oregon to change how speed limits are set in cities and counties.

CITYWIDE SPEED LIMIT DEBATES

Several U.S. cities have recently campaigned to be able to set lower citywide default speed limits. Examples of United State cities that are setting a 25 mph or 20 mph citywide speed limit include Boston, Massachusetts (*15*); New York City, New York (*16*); Seattle, Washington (*17*); Portland, Oregon (*18*); and Austin, Texas (*19*). Other countries are also implementing citywide 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. NACTO recently published a document that provides guidance on the "setting of safe speed limits on urban streets" (*20*).

The California Zero Traffic Fatalities Task Force made several recommendations (*14*), 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.

NCHRP PROJECT 17-76 DEVELOP SPEED LIMIT SETTING PROCEDURE

Given the increased emphasis on context within the profession, the NCHRP 17-76 research team decided that the newly developed procedure should also be sensitive to context. The expanded functional classification system available in NCHRP Report 855 (*21*) was used to develop speed limit setting groups (SLSGs) that reflect logical groups with respect to setting speed limits. For example, freeways, which have very specific geometric design criteria, are present within several roadway type and roadway context combinations. Those roadway type and context combinations were grouped into a limited-access SLSG. Table 1 shows the SLSGs for the various combinations of roadway context and type, including the following four groups:

- Limited access.
- Undeveloped.
- Developed.
- Full access.

The SLS-Procedure was automated into an SLS-Tool using a spreadsheet as the base format. Along with the SLS-Tool is a stand-alone document—*User Guide for Posted Speed Limit Setting Procedure and Tool* (*7*)—that provides information regarding the variables used in the spreadsheet tool, along with general information about the setting of speed limits.

Table 1. Suggested Speed Limit Setting Groups (*6*).

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

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

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

NCHRP Project 17-76 collected insights into how the roadway environment influences operating speed and safety (crashes) through a review of the literature and the collection and analysis of data from two states. Using those insights along with an understanding of different methods being used and currently being considered for the setting of posted speed limits, the research team developed the SLS-Procedure, automated that procedure with the SLS-Tool, and explained both with a user guide (*7*) and a research report (*6*).

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

VARIABLES OF INTEREST FOR TXDOT PROJECT 0-7156

The TxDOT Project 0-7156 aimed to identify variables needed for a speed zone study and that would be needed to evaluate if probe speed data could be used in a speed zone study. The two types of variables of interest to this project included the following:

- Variables that should be considered in a speed zone study (e.g., free-flow speed, crashes, number of driveways, etc.). These variables will be called *speed zone factors*.
- Variables that can explain the variability of the operating speed or speed measures provided by a vendor and collected using probes. In other words, variables that can help to identify a free-flow type of speed from a speed calculated using probe vehicles for a roadway segment. These variables will be called *road factors*.

Multiple factors, including the posted speed limit, can influence a driver’s speed choice. However, the exact relationships may not be clear or conclusively proven. Adding to the challenge of quantifying the relationship is the interaction between these factors and the overall visual scene for the driver. The *look and feel* of the road can communicate an appropriate speed to a driver, although the driver must be willing to accept that message.

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

Several road factors having a relationship to operating speed have been identified in previous literature. These factors will be considered during the development of this study’s test cases, which was a later task in this research project.

Details on how the SLS-Procedure was developed are available in Fitzpatrick et al. (6). That information is not provided here due to space limitations; however, a list of the variables selected for each speed limit setting group can provide the reader with an appreciation of what is being used within the 17-76 SLS-Procedure. Table 2 lists the speed data variables, Table 3 lists the crash data variables, and Table 4 lists the roadway segment input variables needed for the 17-76 SLS-Procedure.

Table 2. Speed Data Input Variables for 17-76 SLS-Procedure (*6*).

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

Notes: ✓ = variables used in SLSG, - = variables not used in SLSG.

Table 3. Crash Data Input Variables (If Available) for 17-76 SLS-Procedure (*6*).

Crash Data Variable	Limited Access	Undeveloped	Developed	Full Access
Number of years of crash data	✓	✓	✓	✓
Annual average daily traffic (two-way total) for crash data period (vehicles/day)	✓	✓	✓	✓
All (KABCO) crashes for crash data period	✓	✓	✓	✓
Fatal and injury (KABC) crashes for crash data period	✓	✓	✓	✓
Average KABCO and KABC crash rates (crashes/100 million vehicle miles traveled) (if not provided, KABCO and KABC crash rates from FHWA's Highway Safety Information System are used)	✓	✓	✓	✓
One-way street direction (yes or no)	-	-	✓	✓
Number of lanes	✓	✓	✓	✓
Median type	-	✓	✓	✓

Notes: ✓ = 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.

Table 4. Roadway Segment Input Variables for 17-76 SLS-Procedure (*6*).

Roadway Segment Variable	Limited Access	Undeveloped	Develope d	Full Access
Annual average daily traffic (two-way total) for crash data period (vehicles/day)	✓	✓	-	-
Adverse alignment present (yes or no)	✓	✓	✓	✓
Angle parking present (no, yes for at least 40% of the segment, or yes for less than 40% of the segment)	-	-	✓	✓
Bicyclist activity (high or not high)	-	-	✓	✓
Design speed (mph)	✓	-	-	-
Directional design-hour truck volume (truck/hour)	✓	-	-	-
Grade (%)	✓	-	-	-
Inside (left) shoulder width (ft)	✓	-	-	-
Lane width (ft)	-	✓	-	-
Developed or full access median type (undivided, two-way left-turn lane, or divided)	-	-	✓	✓
Undeveloped median type (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 (miles)	✓	✓	✓	✓
Shoulder width (ft)	-	✓	-	-
Sidewalk buffer (present or not present)	-	-	✓	✓
Sidewalk presence/width (none, narrow, adequate, or wide)	-	-	✓	✓

Notes: ✓ = variables used in SLSG, - = variables not used in SLSG.

SETTING OF POSTED SPEED LIMITS SUMMARY

The review of the literature identified several studies that have explored the relationships among operating speed, safety, and roadway characteristics, as recently documented in Fitzpatrick at al. (*6*). Consensus is that higher operating speeds (represented in many cases by the posted speed limit) are associated with more severe crashes, as supported by the basic physics of the situation. Few studies are available that examine the relationship between the magnitude of operating speed and the number of crashes, probably primarily due to the difficulties in obtaining actual operating speed data for significant lengths of time and for a significant number of sites. A 2017 study on rural two-lane highways in Israel (*22*) and a 2016 study on two-lane urban roads in the city of Edmonton, Canada (*23*), are notable exceptions. These two studies found that as operating speed increased, the number of crashes also increased.

A review of USLIMITS2 (FHWA's expert system for recommending speed limits in speed zones) (*24*) and similar procedures in Portland, Oregon (*25*), New Zealand (*26*), and Canada (*27*) showed that several of the variables identified in the literature review are also being considered in their procedures. In some cases, the consideration is specific. For example, in USLIMITS2, a precise value for signal or access density (e.g., 4 signals per mile) would change the recommendation. In other cases, the value for the variable is based on engineering judgment (e.g., is parking activity high or not high).

The roadway, traffic control device, and traffic variables that were found to affect speed or crashes were identified and used to develop a list of variables for consideration in the test cases developed as part of the Texas Project 0-7156.

CHAPTER 3: PROBE AND TRADITIONAL SPEED MEASURES

OVERVIEW

The main objective for TxDOT Project 0-7156 was to explore whether probe speed data (for this study, INRIX speed data) can reasonably be used in a TxDOT speed zone study. The suggestion was to use a representative INRIX speed for the corridor and convert that speed value to a representative spot speed. Key questions included the following:

- What is a representative spot speed for a site?
- What is the preferred representative probe speed among the various probe speed measures that are available or can be calculated?

This chapter discusses key elements that need to be considered when developing a prediction equation or protocol to convert a probe speed to a spot speed that is appropriate for a speed zone study.

AVAILABLE AND SUGGESTED PROBE SPEED MEASURES

Several speed measures are available from probe data. The following sections describe what is available along with what should be considered for this study.

Available Probe Speed Measures

Probe speed datasets contain several options for speed values. The values can represent various time periods such as an hour, a week, or the entire year. Examples of hourly speed measures provided by INRIX include the following:

- FFspd is the free-flow mean speed representing the 66th percentile of the 168 hourly speed bins at a given location for the week. The metric is from collected speed data for a segment for each of the 168 hours of the week.

- SpdXX is the average speed for a given hour of the day corresponding to XX, where XX is a number from 00 to 23.

Probe speed data are obtained from multiple sources such as commercial fleets and consumer vehicle data. The probe speed data represent a sample of all vehicles on the road for that time period, rather than measuring each and every vehicle on the road. Because of this data collection approach, the sample size or percentage of all vehicles on the road being measured is not known. Also not known is the mix of vehicle types and how close the reported speed is to a free-flow speed, which is a key characteristic for speed zone studies.

Suggested Probe Speed Measures

Within this project, various speed measures could be considered. For example, can the same time period be represented by the speed measure that was collected on site in the field and in the probe speed data? Such a comparison is of interest to understand how well the probe speed compares to free-flow speed data or compares to speed data that represents all vehicles on the road.

If a specific hour of data is desired for a speed zone study, the technician would need to select that time period and then obtain the probe speed data for that specific hour. The particular time period selected in important. The selection of a specific date (or day of the week) along with hour may result in selecting a time period that is not an accurate representation of the speed pattern for the spot or free-flow conditions for a given corridor. Also, would that same time period be used for all future speed zone studies? An alternative is to use the speed data available for a longer time period, say a week, a month, or a year. This would provide a better representation of long-term conditions at the site.

SPEED MEASUREMENT FOR SPEED ZONE STUDIES

The TxMUTCD states that "speed zones (other than statutory speed limits) shall only be established on the basis of an engineering study that has been performed in accordance with traffic engineering practices. The engineering study shall include an analysis of the current speed distribution of free-flowing vehicles" (*1*, page 57, Section 2B.13, paragraph 01).

Free-Flow Speed Definition and Measurement

Free-flow speed represents the speed that a motorist would travel if there were no congestion, adverse conditions (e.g., bad weather or limited visibility), or traffic control (e.g., traffic control signal or all-way stop control) influencing their movement. Geometric features, such as an isolated sharp horizontal curve or driveways, can also be influence free-flow speed; it is recommended to avoid those potentially impactful features when selecting where to measure the representative spot speed for the corridor.

Part of the challenge when deciding whether the measured speed represents *free flow* for a corridor lies in the decision of selecting the corridor limits and operating speed measurement locations. For example, if a corridor has a high number of driveways and the speed is measured at the only spot not near a driveway, that measured speed may not be truly representative of the entire corridor.

The process for identifying free-flow vehicles depends on the method of data collection selected for the study. When speed data are collected manually, the data collector's judgement is used to select vehicles that are free flowing. If speed data are collected automatically and each observation has an associated time stamp at a sufficient resolution (i.e., with sub-second accuracy), the practitioner can filter the data to identify those vehicles that meet the definition of a free-flow vehicle. For example, if the definition of a free-flow vehicle is a vehicle with at least 3 seconds behind the preceding vehicle in its lane, all observations in a given lane with a time stamp less than 3 seconds after the preceding observation would be filtered. Texas practice, as outlined in the SZM, indicates that 3 seconds is acceptable (*2*, page 3–7). Other researchers have used 5 seconds. Using the SZM method, only cars should be included in the free-flow speed; other vehicle types would need to be filtered from the automatically collected data.

Speed to Represent Large Majority of Drivers

In the SZM, the Value of Speed Zoning section notes the following:

> "Realistic speed zoning will serve to protect the public and to regulate the unreasonable behavior of an individual. Having recognized that normally careful and competent actions of a reasonable person should be considered legal, the Texas Legislature has passed legislation concerning speed zoning in order to assure this protection. If a speed zone is determined by the actions of the majority of drivers on a highway, then it is hoped that speed zoning will facilitate the orderly movement of traffic by increasing driver awareness of a reasonable and prudent speed."

The SZM Value of Speed Zoning section shows the support for basing speed limits on driver behavior. The Guidelines for Selecting Speed Limits section states that speed limits on all roadways should be set based on spot speed studies and the 85th percentile operating speed and then provides a reference on how to conduct speed zone studies. The method to conduct speed zone studies includes requirements for the acceptable location along a corridor (e.g., located midway between signals or 0.2 miles from a signal), the number of vehicles to be included (minimum of 125 cars per direction), and more. The method to determine the 85th percentile speed is used to support the identification of the speed being used by "the large majority of drivers who are reasonable and prudent, do not want to have a crash, and desire to reach their destination in the shortest possible time." The acceptance of probe speed data is increasing, as demonstrated by the greater use of in-vehicle navigation systems (*28*) and the use of the data in national databases, such as the National Performance Management Research Data Set (NPMRDS). Whether these examples prove that probe speed data values provide reasonable representations of most drivers can still be debated.

Speed Data Collection Locations (Segment Versus Spot Speeds)

A TxDOT speed zone study requires the speed of free-flow vehicles measured at a unique and specific location or *spot*. Because INRIX speeds reflect the operating conditions along a segment, INRIX speeds would need to be converted to represent a spot speed. In theory, a simple prediction equation using the INRIX speed value could produce usable values. However, fundamental differences exist between a spot speed used in speed zone study and the INRIX segment speed. Figure 1 illustrates two speed measurement segments compared to two spot speed measurement locations.

The SZM states that "A complete picture of speeds in an area can only be obtained through the proper location of speed check stations. Ideally, speed checks at an infinite number of locations would be desirable; however, since this is not practical, speed check stations must be strategically located to show all the important changes in prevailing speeds" (*2*, Chapter 3, Section 2, pages 3–6). The use of segment speed over spot speed provides the opportunity to give a complete picture of speeds in an area.

A basic challenge with selecting a spot speed location is to pick a location that is away from signals or driveways with many turning movements. The SZM states to locate the speed check station midway between signals or 0.2 miles from any signal, whichever is less. Because of the spacing of signals, achieving the 0.2 miles can be challenging in an urban area.

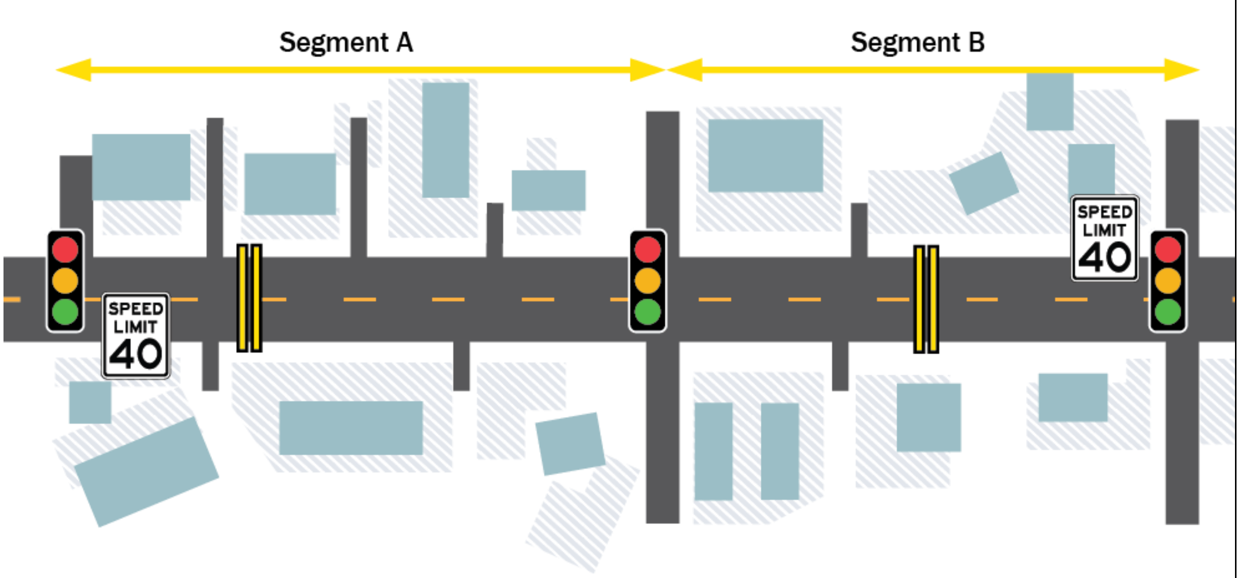
In theory, a speed zone study could use segment speed if the measured vehicles represent free-flow condition and there are no other speed-influencing features on the segment. Speed-influencing features for non-freeway segments can include the following:

- The number of driveways (along with the activity level from the major driveways).
- The number of signals within the segment (along with the signal timing for the road of interest). Signals stop traffic along each approach to provide the opportunity for vehicles on the other approaches to move.
- The length of the segment. Longer segments offer a greater likelihood that a speed limiting feature will exist.

Speed-influencing features for freeway segments can include the following:

- The number of ramps (along with the activity level from these ramps).
- The type of ramps (left or right, along with whether the ramp is from a surface street or between two freeways).
- The length of the segment. Longer segments offer a greater likelihood that a speed limiting feature will exist.

Therefore, a procedure to use segment speed as a free-flow spot speed should consider those characteristics when converting the segment speed to a spot speed.



	Road segments where the segment speed is calculated as the distance between end points divided by the time to travel that distance for a vehicle.
	On-site spot speed measurement such as road tubes recording the speed of a vehicle crossing the spot (tubes). Other equipment can be used to gather spot speeds, such as side-fire radar, lidar guns, etc.
	Traffic control signal.

Figure 1. Examples of Segment and Spot Speeds.

Speed Data Collection Times

A driver's overall operating speed could be influenced by the hour of the day and the month of the year. The hour of the day could serve as a surrogate for hourly volume or typical congestion level, even when the volume appears not to be congested but is high enough to impact driver speed choice. While the collection of free-flow speed data should capture those drivers who are being influenced by the roadway rather than other vehicles, the characteristics of the overall population of drivers may be different for a specific hour of the day. For example, collecting data during the middle of the morning may capture those drivers running errands rather than commuters. Collecting data during the middle of the afternoon may capture more trips related to school-age children. Variations by month of the year may also occur when contrasting data collected during the summer with data collected in the fall or spring because more drivers may be on vacation during the summer months. Data collected during winter months may also reflect the shorter number of daylight hours or colder weather. The month of the year may also be a surrogate for rain.

Traffic volume, especially if congestion is occurring, can be influential because spot speeds should represent free-flow speed while INRIX speeds would represent a random or typical sample of all vehicles. Available volume-related variables that could help convert a segment speed (perhaps not at free flow) into a free-flow spot speed include the following:

- The vehicle volume on the segment during a specific time period.
- The annual vehicle volume for the segment.
- The number of trucks on the segment.
- The K-factor for the segment.

Vehicles to Measure During Speed Data Collection

TxDOT speed zone studies use speed data for free-flow cars measured at a spot, while probe speed data reflect a space mean speed based on travel time and distance for a sample of vehicles. The speed zone study generally captures the speed of 125 passenger cars that are not in a queue as selected by the technician measuring from the roadside.

The probe speed data represent a sample of vehicles on the segment. The number or proportion of vehicles measured is not known; however, probe data vendors have developed checks to indicate whether the measured speed data being reported for a given time period represent existing conditions and if not, a historical speed is reported.

Other Factors Potentially Affecting Speed Measures

The type of vehicle included in the speed measure can affect the speed being used to represent a majority of drivers. Should the measured speed represent heavy trucks, buses, or bicyclists if those users represent a significant portion of the traffic? Currently, the TxDOT procedure only considers passenger cars.

Also affecting the conversion of a segment speed to a spot speed is how the spot speed was calculated. Tube and TxDOT automatic traffic recorder (ATR) data, while representing all vehicles that pass the spot, are frequently binned. For example, the ATR speed data has the number of vehicles grouped into 15 speed categories. Class 1 includes speeds ranging from 0 to 30 mph; each subsequent 5 mph increment between 30 and 90 mph is categorized as a new speed class. The last two categories have different classification criteria. Class 14 includes speeds ranging from 90 to 120 mph, while Class 15 includes speeds over 120 mph. This binned data must be converted to individual data or assumed to reflect the midpoint to be able to calculate the average or 85^{th} percentile speed for a spot. If most of the actual speeds are near one end of the bin, the calculated average or 85^{th} percentile speeds may be too small or too large. Randomly assigning the vehicles to the speeds represented in the bin could help minimize this potential issue.

For segment speeds, the speed is calculated from a sample of vehicles rather than all vehicles. This may be an issue in rural areas where, in theory, fewer vehicles are available for INRIX to sample, resulting in a bias and a poor match between INRIX speeds and the speeds measured on site.

Other debates regarding the setting of speed limits could affect what speed measures should be used (i.e., only the 85^{th} percentile speed or the 85^{th} percentile and average speed). One debate involves the use of driver speed distributions, which some argue should not be used because it may not be compatible with Complete Streets, Vision Zero, Safe System, Active Transportation, Sustainable Transportation, or Transportation Equity policy goals. Such debates are outside the scope of this current TxDOT research project.

CONVERSION EQUATION DEVELOPMENT

One goal of the TxDOT Project 0-7156 was to develop prediction equations that could convert the available INRIX segment speeds into representative spot speeds that could be used within the TxDOT speed zone method. These efforts focused on the following two main comparisons:

- Comparing INRIX and on-site speeds using the same time period (i.e., matching time periods).
- Comparing yearly INRIX speeds to 85^{th} percentile (or average) speeds calculated using all vehicles present for a given time period (1 hour when available, or the entire period for a speed zone study).

Some of the data available were from TxDOT speed zone studies; therefore, the on-site speeds represent free-flow conditions. These sites were used in the matched time period analysis. The TxDOT speed zone study tally sheets provided the speeds of individual vehicles, along with the start and end times for data collection. For freeways, the side-fire radar recorded the speeds of individual vehicles, along with the headways and tailways for each vehicle and each vehicle's length. Free-flow vehicles were identified as having a speed greater than 53 mph and leading and trailing headways exceeding 5 seconds. Only passenger cars (i.e., no heavy trucks) were included when calculating the spot speed measures. Average speeds for both the spot speed and the segment speed were calculated and compared. For most of the sites the matching time period was 1 hour starting at the top of the hour. For the speed zone sites, the start and end times (to the closest 5-minute increment) were used. This effort helped to illustrate if a reasonable relationship could be identified between INRIX segment speeds and on-site spot speeds. It also identified variables that could be of interest.

The comparison of the INRIX speed measures that represented an entire year of data to a sample of speeds measured on site provided the opportunity to consider a greater number of sites and a greater number of hours of data for each site. The databases were assembled to compare the INRIX speed measure to the 85^{th} percentile speed calculated for several site-periods. Site-period speeds were removed from the evaluation when congested conditions were obvious.

When predicting the operating speed at a point, researchers must determine whether to include the posted speed limit for the site in the model. Because posted speed limit has a known association with the measured operating speed (operating speed is used in the speed limit setting procedure), including the posted speed limit may mask the potential influence of other variables. Conversely, including the posted speed limit can provide a surrogate for the general conditions on and near the site. Lower posted speed limits are associated with higher numbers of driveways, sidewalks, and buildings close to the road. Higher posted speed limits are generally associated with larger distances between the edge of the road or between buildings.

CHAPTER 4: AVAILABLE DATASETS

The research team investigated the availability of existing data or datasets, especially with respect to the following:

- Location-based variables, considered as either speed zone factors (e.g., horizontal alignment) or road factors (e.g., number of driveways).
- Operating speed variables measured via probes and on site.

LOCATION DATA

Potential sources of data for location-based variables (either speed zone factors or road factors) included the following:

- TxDOT's Roadway Highway Inventory Network Offload (RHiNO).
- FHWA's Highway Performance Monitoring System (HPMS).
- U.S. Census Bureau's data.
- TxDOT's Crash Records Information System (CRIS).
- Google Earth's aerial or street views.

The databases used in this project's test cases are discussed in Chapter 5.

ON-SITE SPEED DATA

TxDOT Speed Zone Studies

The research team reached out to several TxDOT districts to requested copies of recent speed zone studies for use in this project. The research team obtained data from the following districts: Houston, Fort Worth, and Dallas. A sample of speed studies conducted within the past 5 years were requested. For each speed study, tally sheets and strip maps were requested so that the research team could identify the specific location of the study and calculate both the 85th percentile and average speeds. For one of the districts, several of the speed studies were conducted by contractors who did not provide tally sheets; therefore, the average speed was not available (only the 85th percentile speed is required for TxDOT speed zone studies).

Data from Previous Research Projects

The research team reviewed recent research projects to determine whether speed data from those projects could be used in this project. Chapter 5 details the datasets that could be included.

Automatic Traffic Recorder Data

TxDOT's ATR) data consists of speed data collected using permanent ATR equipment at permanent sites across the State of Texas. The ATR locations are selected by TxDOT's

Transportation Planning and Programming (TPP) and districts in accordance with FHWA's *Traffic Monitoring Guide* (*29*) and approved by TPP. The ATRs collect data in each lane 24 hours a day, 365 days a year. The equipment records traffic volumes as total and as directional traffic for each station. TPP retrieves the data via modem daily (Monday through Sunday) to develop seasonal factors and estimate vehicle miles of travel (VMT). The ATR data are usually preprocessed by the TPP to estimate the VMT, annual average daily traffic (AADT), and K-factor. The hourly volume is analyzed using historical patterns, and some seasonal variation factors are developed. These seasonal variation factors are then applied to accumulative count recorder axle counts to develop AADT values. Figure 2 shows the spatial distribution of the ATR stations across the state. Note that although the ATR stations cover the entire state, fewer stations exist on freeways in the southern portion of the state.

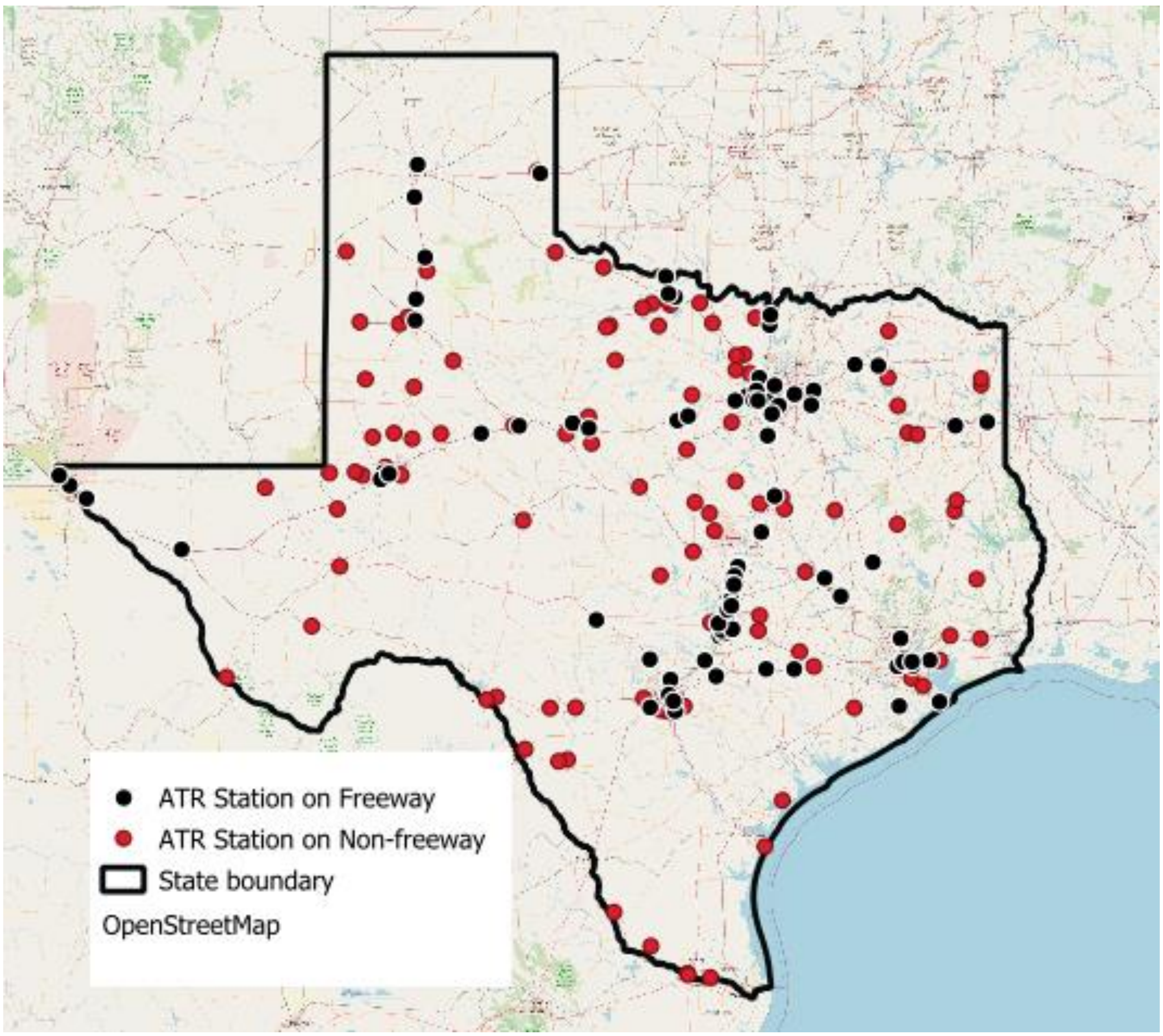


Figure 2. Spatial Distribution of ATR Stations on Freeways and Non-freeways.

PROBE OPERATING SPEED

The research team initially considered available probe operating speed datasets from the following sources:

- INRIX XD contains real-time, highly granular speed data from probe vehicles, crowdsourced devices, connected vehicles, and fixed sensors. Speed data are available for more than one million non-freeway segments by hour or 15-minute period, including free-flow speed.
- NPMRDS provides car, truck, and mixed vehicle travel times via a 5-minute traffic message channel (TMC) based system. Speed data are sourced from global positioning systems and mobile devices in vehicles, including American Trucking Research Institute truck speed data. The data are limited to National Highway System (NHS) roadways.
- Dallas and Fort Worth freeway data is available from the Dallas and Fort Worth District Traffic Management Centers (Daltrans, and TransVision), which have deployed approximately 1,000 roadway smart sensors that continuously monitor and record traffic data. The districts use these sensors, along with other Intelligent Transportation System devices, to monitor almost 633 centerline miles of highways.
- StreetLight collects and reports a variety of mobility data on roadways across the country using anonymized location records from smart devices. Featured data include volumes, origins and destinations, turning movements, and link analysis. Data for average speeds are available, but they are based on origins and destinations of trips and are historical rather than real-time.
- Wejo is a relatively new source of big data, with millions of cars uploading to the cloud about every 3 seconds nationwide. The precision of data is uncertain, and cost is a potential disadvantage (data are reported to be priced per 100 million data points).

Based on the initial reviews, the research team focused on the speed data available from the NPMRDS and INRIX XD. Additional information on these two sources follows.

NPMRDS

The NPMRDS, procured by FHWA, is free to state departments of transportation and metropolitan planning organizations for research. While free, the acquired NPMRDS data are limited to the NHS portion of the state roadway network. In July 2013, FHWA procured the NPMRDS to support its Freight Performance Measurement and Urban Congestion Report programs. The NPMRDS includes probe vehicle-based travel time data (for both passenger and freight vehicles) at 5-minute intervals for all NHS facilities.

The NPMRDS travel times are reported based on TMC segments, with link lengths varying from less than 1 mile to several miles. The NPMRDS is intended for state agencies to measure system performance in meeting new federal performance management requirements. The first version of the NPMRDS was known as *Version 1* or *HERE NPMRDS*. The current version is known as *Version 2* or *INRIX NPMRDS*, which provides data from January 1, 2017. Essentially, INRIX replaced HERE Technologies as the supplier of NPMRDS data under contract to FHWA.

The NPMRDS data consists of a static geographic information systems (GIS) file and a database file. The GIS shapefile, containing static roadway information, is used to relate the travel time information to each TMC segment. The GIS shapefile provides for visualizing and geo-referencing the NPMRDS data to different maps. The TMC file contains TMC segment geometry information. A database contains a set of files including the operating speed of passenger and freight vehicles separately and combined for identified roadways geo-referenced to TMC segment IDs.

INRIX XD™ Speed Data

INRIX provides real-time speed data coverage across the U.S. roadway network. Their highly granular floating vehicle data are combined with traditional real-time traffic flow information, as well as hundreds of market-specific criteria that affect traffic. INRIX compiles and aggregates crowdsourced, passively collected data from a variety of different sources and data resellers, including smartphones, connected cars, fleet telematics, and fixed-sensor networks. They blend these data sources using proprietary algorithms to produce several different traffic data products. Their most popular data product is segment-based traffic speeds. Because of this, they are one of the leading companies in providing real-time traffic speed information. INRIX traffic speeds have been tested and evaluated on major highways, freeways, and arterial streets and found to be accurate for real-time and historical archived use (*30*). Historically, their dataset has been robust for interstates and freeways; however, the addition of the INRIX XD traffic service has added a rich dataset for non-freeways in many locations across the country, incorporating more than a million roadway segments.

INRIX XD Nationwide Average Speed Database

INRIX XD collects both site descriptors and speed data. Speed data are compiled into a nationwide average speed (NAS) database that contains speed data for each individual segment aggregated by hour or by 15-minute periods. The hourly file, commonly described as the *NAS168 file*, contains the collected speed data for each segment for each of the 168 hours of the week. This file can be used for queries to obtain speed data for specific time periods or for the entire week by hour and time of day. The NAS168 file also contains a variable for free-flow speed or reference speed, representing the 67^{th} percentile observed speed for all time periods. Site descriptors include the road or street name; the direction of travel; the starting and ending latitude and longitude for each segment; the location by state, county, and ZIP code; and the segment length. The NAS168 file data for 2019 were requested for use in this effort.

Table 5 lists the field names used in these files and provides a description of the data. Because the NPMRDS covers only NHS roadways, the INRIX XD data has greater potential for this project.

Table 5. INRIX XD Data File Format.

Field Name	Type	Example	Description
Xdsegid	Integer	167115703	Identification number for a particular roadway segment
Dayname	Text	FR	Two-letter abbreviation for the day of the week on which the speed data were collected
Ffspd	Integer	23	Free-flow mean speed representing the 66th percentile of 168 hourly speed bins at a given location for a week
SpdXX	Integer	21	Average speed for a given hour of a day corresponding to XX, where XX is a number from 00 to 23
Road	Text	E VILLA MARIA RD	Roadway name on which the segment is located
Direction	Text	W	Direction of travel (N, S, E, or W) for which the data were recorded
Roadorder	Text	B4-E1	Code showing the order in which the segments are arranged in the data file
Startlat	Float	30.63972	Latitude for the start of the roadway segment
Endlat	Float	30.64354	Latitude for the end of the roadway segment
Startlon	Float	–96.35821	Longitude for the start of the roadway segment
Endlon	Float	–96.35343	Longitude for the end of the roadway segment
State	Text	Texas	State in which the roadway segment is located
County	Text	Brazos	County in which the roadway segment is located
Zipcode	Integer	77802	ZIP code in which the roadway segment is located
Seglength	Float	0.398	Length of the roadway segment in miles

The NAS168 file data obtained by the research team had to first be cleaned. The team learned that, in some cases, the observations for the INRIX speeds for a given day were repeated. Thus, all repeating observations were removed by creating a filter so that each day of the week appeared once for each INRIX segment. The research team also removed all zeros entries, which represented missing data.

Regional Integrated Transportation Information System

The research team collected INRIX XD speed data using the Regional Integrated Transportation Information System (RITIS) website (Figure 3). The input for the speed data query was the INRIX XD segment ID, the start and ending date and time, and the number of days. The research team selected an hourly aggregation of the data.

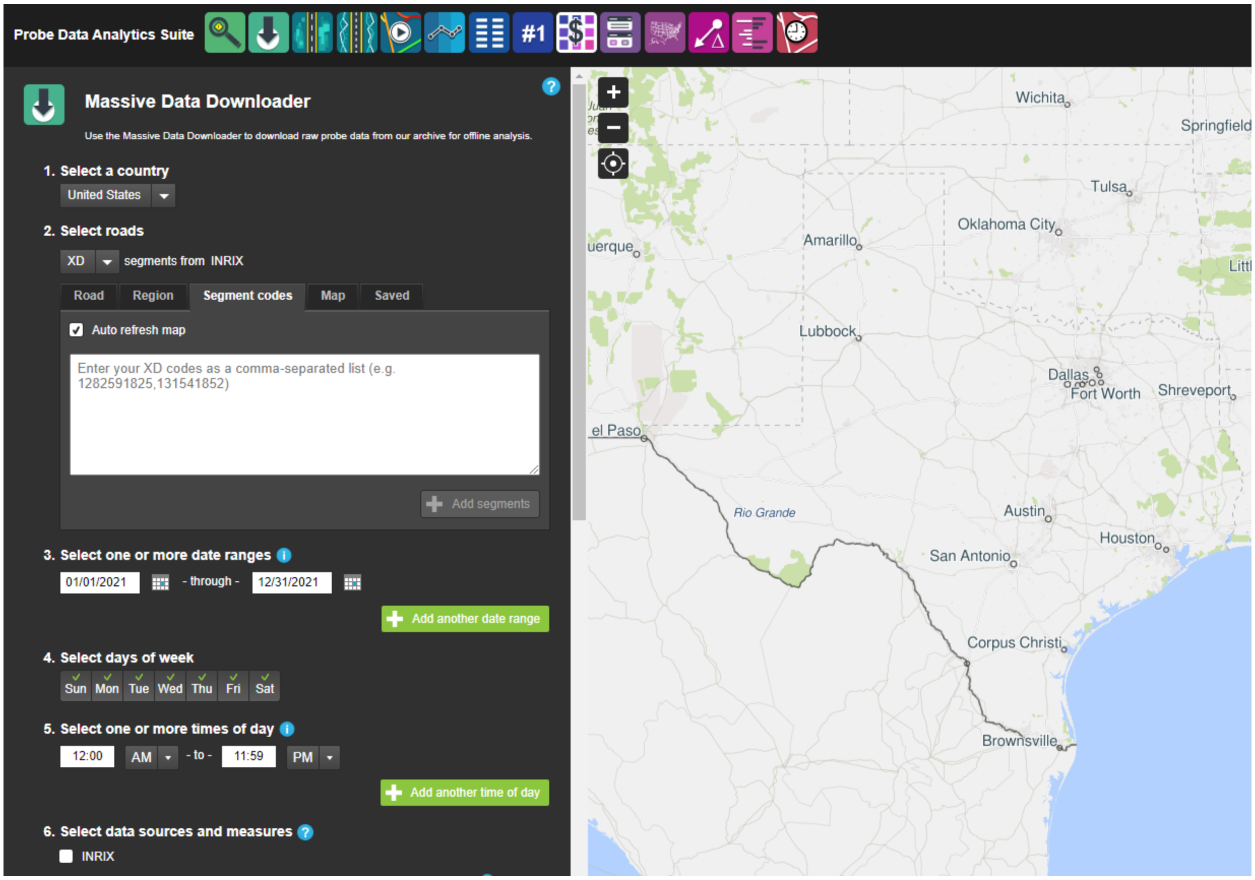


Figure 3. RITIS Website for INRIX XD Speed Data Collection.

INRIX XD Segment Coverage

A total of 408,769 segments were recorded in the INRIX XD segment dataset. Comparatively, a total of 836,658 segments were recorded in TxDOT's RHiNO. Table 6 and Table 7 present descriptive statistics for the segment length and number of lanes, respectively, for the roadway segments contained in the INRIX XD and RHiNO datasets. The segment lengths in the two datasets differs significantly. For instance, the maximum segment length in TxDOT's RHiNO is 44 miles, while the maximum segment length in INRIX XD is 0.99 miles. Further, the median segment length in RHiNO is 0.17, while the median segment length in INRIX XD is 0.42.

Table 6. Descriptive Statistics for Segment Length (in Miles).

Data Source	Minimum	Maximum	Mean	Median	Standard Deviation
RHiNO	0.001	44.24	0.40	0.17	0.77
INRIX XD	0.00	0.99	0.37	0.42	0.27

Table 7. Descriptive Statistics for Number of Lanes.

Data Source	Number of Lanes	Frequency
RHiNO	1	5503
	2	731139
	3	20737
	4	64947
	5	2134
	6	9893
	7	273
	8	1351
	9	125
	10	423
	11	67
	12	44
	13	12
	14	10
INRIX XD	1	288536
	2	81098
	3	31896
	4	5914
	5	1076
	6	221
	7	23
	8	4
	9	1

CHAPTER 5: BUILDING OF TEST CASES

OVERVIEW

The research team identified test cases to compare traditionally collected spot speed data with speed data from probe sources. The vision for this project was to be able to evaluate more than a single speed zone through the use of *big* data—especially big speed data—and to demonstrate that such a speed data resource can assist a district in evaluating multiple sites, where *sites* may reflect a freeway system or an entire county. The goal is to be able to evaluate an entire district or the entire state; however, the process needs to be developed and then proven on a smaller scale. Figure 4 provides an overview of the process to compare speed data from on-road on-site measurements to speed data from probes.

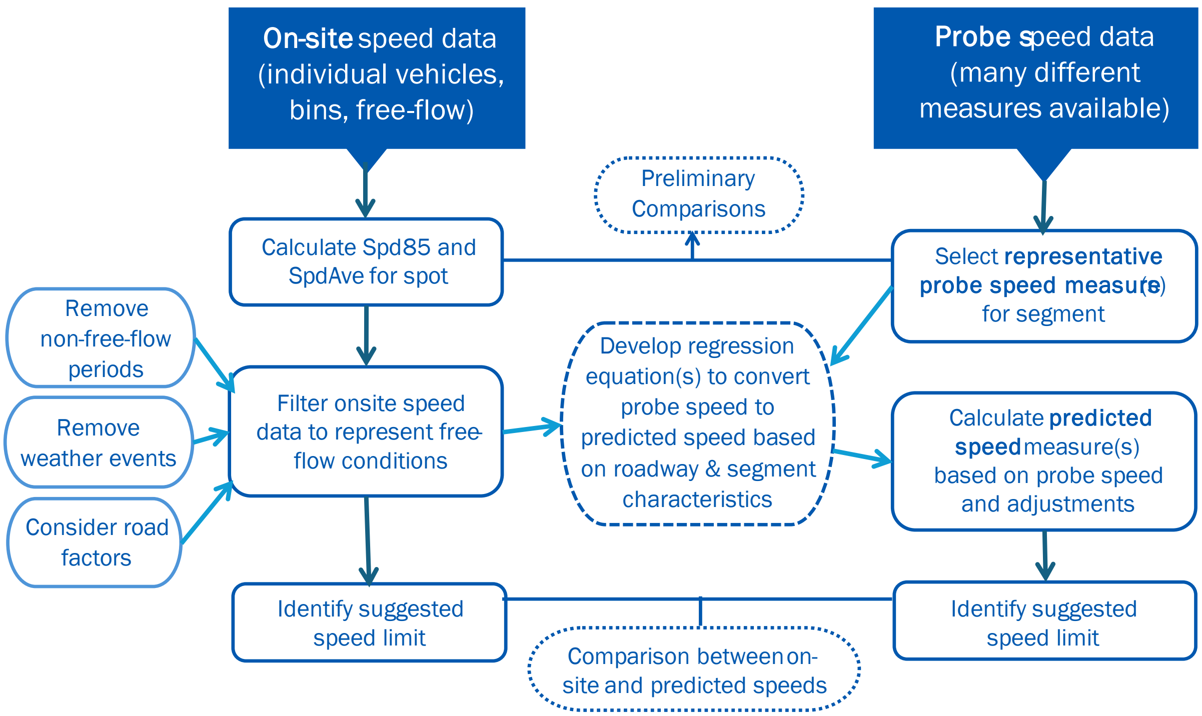


Figure 4. Process for Comparing On-Site and Probe Speed Data.

The research team considered sites and data available from previous projects, along with examples from several roadway types and roadway contexts. The following test cases were initially identified for consideration:

- Suburban arterials using sites identified as part of TxDOT Project 0-7049 (*8*) within the San Antonio District, initially called the *suburban test case*.
- Freeway locations using I-20 sites identified as part of TxDOT Project 0-7096, called the *freeway test case*.

- Urban and suburban arterials and collector sites identified as part of NCHRP 17-76 (*6*), called the *urban test case*.
- Highways identified from ATR locations, called the *highway test case*.

Based on preliminary feedback, the decision was made to obtain a larger sample of data from speed zone studies, and additional efforts were undertaken by the research team to contact districts.

The test cases were refined into the following two groups:

- Freeway test case.
    - Freeway sites using data along I-20 collected as part of TxDOT Project 0-7096.
    - ATR sites on freeways.
- Non-freeway test case.
    - Urban test case including suburban and urban arterials and collector sites from NCHRP 17-76 (sites within the city of Austin).
    - Suburban test case including sites from TxDOT Project 0-7049 within the San Antonio District.
    - Mix test case including a sample of speed studies conducted within the past 5 years in Houston, Fort Worth, or Dallas.
    - Highways test case including highways identified from ATR locations.

These two groups were created based on the types of roadway site characteristic data collected (e.g., ramp density for freeway sites as opposed to access density for non-freeway sites). Both test cases were subdivided into rural and urban/suburban classifications based on preliminary feedback.

This chapter describes the data sources used for on-site speed data, INRIX XD-based speed data, roadway characteristics, and weather. This chapter also describes the resulting databases developed for the test case evaluations.

DATA TYPES

The research team developed databases for two test cases that consisted of data from several sources.

For *site identification*, the research team considered sites with existing on-site speed data. Sources included the following:

- Previous Texas A&M Transportation Institute (TTI) projects that collected speed data.
- TxDOT ATR locations.
- Recent TxDOT speed study locations.

These sites were then compared to the INRIX network to determine if the on-site speed data occurred within an existing INRIX segment. Whether INRIX speed data were available for the date and time of the on-site speed data also had to be checked.

For *speed data*, the research team used the following sources:

- On-site speed zone studies.
- On-site temporary equipment including tube counters.
- On-site temporary equipment including side-fire radar.
- On-site permanent equipment including ATRs.
- INRIX XD via RITIS.

For *roadway characteristics*, researchers used the following sources:

- TxDOT's RHINO.
- FHWA's HPMS.
- U.S. Environmental Protection Agency's (EPA's) Smart Location Database (SLD).
- TxDOT's Crash Records Information System (CRIS).
- Texas Curves.
- Google Earth.

For *weather*, the following source applied:

- Southern Regional Climate Center (SRCC).

Each of these data sources used to build the test case databases are detailed in the remainder of this chapter.

SITE IDENTIFICATION DATA

Site selection began by identifying the availability of existing on-site speed data that had been collected within the past 5 years. The research team identified the latitude and longitude where the speed data were collected for each candidate site.

These latitude and longitude values were used to identify whether an INRIX segment was present. Using GIS applications, a buffer of 100 ft was created around each site. All INRIX segments within the buffer were spatial joined to the study site. Research team members then reviewed the extracted segments and eliminated any segment not of interest. For example, when reviewing freeway sites, the buffer could include segments on parallel frontage roads or cross streets. The frontage road or cross street segments were removed, and the INRIX segment for the freeway was retained.

Note that not all candidate sites had corresponding INRIX segments; some sites were located on minor streets that were not covered by the INRIX XD network. Furthermore, the available INRIX XD data was not collected until December 2017. Thus, the candidate site was dropped if an INRIX segment was not present or if the speed data collection occurred prior to the availability of the INRIX speed data.

Table 8 provides the list of variables obtained for each INRIX segment included in the database.

Table 8. Typical Variables Available per INRIX Segment.

Variable Name	Description
SegID_INRIX(Seg)	Identification number for the segment
PreviousSe_INRIX(Seg)	Identification number for the previous segment
NextSegID_INRIX(Seg)	Identification number for the next segment
FRC_INRIX(Seg)	Functional road class or group of roads to which the road belongs—the available list varies depending on the segment type that is being selected but generally 1 = National highway network, 2 = State highway network, 3 = Interconnecting network, 4 = Major connectors, 5 = Minor roads (additional information can be found in the INRIX data dictionary)
Miles_INRIX(Seg)	Length of the segment
Lanes_INRIX(Seg)	INRIX variable definition not found
StartLat_INRIX(Seg)	Latitude of the beginning of the segment
StartLong_INRIX(Seg)	Longitude of the beginning of the segment
EndLat_INRIX(Seg)	Latitude of the end of the segment
EndLong_INRIX(Seg)	Longitude of the end of the segment
RoadNumber_INRIX(Seg)	Road number
RoadName_INRIX(Seg)	Road name
LinearID_INRIX(Seg)	Reference to the linear TMC that includes the TMC segment (typically, several TMC segments form a linear TMC, which represents a road corridor through a single county), which is intended to assist in filtering and locating TMC segments and simplify the process of linking consecutive TMC segments
Country_INRIX(Seg)	Country name
State_INRIX(Seg)	State name
County_INRIX(Seg)	County name
PostalCode_INRIX(Seg)	Postal code
SlipRoad_INRIX(Seg)	Slip road (a road especially designed to enter or leave a line)
Bearing_INRIX(Seg)	Direction of the road segment
XDGroup_INRIX(Seg)	INRIX variable definition not found

Note: The (Seg) extension was provided for those variables associated with the INRIX segment.

SPEED DATA

On-Site Speed Zone Studies

The procedure for conducting a speed zone study is fully documented in the SZM (*2*). TxDOT policy calls for posted regulatory speed limits to be checked and updated periodically. The analyzed highway section is divided into speed zones, speed check locations are identified within the zones away from traffic signals or other roadway features that may alter vehicle speeds, and TxDOT practitioners measure vehicle speeds at the speed check locations. The SZM calls for the speeds of 125 free-flowing vehicles in each direction of travel at each location and allows the speed zone study to be discontinued after 2 hours if radar is used or 4 hours if traffic classifiers are used, even if the desired 125 vehicles have not been measured. Frequently, the speed data are collected using a portable radar or laser gun. The vehicle speeds are tallied, and the 85th percentile speed is determined and used to set the regulatory speed limit.

On-Site Temporary Equipment: Tubes

Road tube classification equipment is a common method for obtaining short-term vehicular speed and volume data. A pair of pneumatic road tubes are installed on the travel lanes, perpendicular to the traffic flow. When a vehicle travels over the tubes, a burst of air pressure is sent to the counter, which translates that information into vehicle count, speed, classification, and other data.

Typically, the count of vehicles is stored within 5-mph speed bins. A limitation with on-road tube speed binned data is that comparable free-flow speed cannot be determined for the site. The system collects speeds for all vehicles, rather than just the free-flow vehicles, and bins the data into 5-mph groups.

Many on-road data collection systems can be programmed to retain speed data for individual vehicles and include the headway or gap time between the subject vehicle and the previous vehicle. When so, this information can be used to identify vehicles assumed to be within a queue or whose speed is influenced by the previous vehicle. For example, a vehicle might be considered free flowing if its headway is more than 3 to 5 seconds from the previous vehicle. This assumption can still include vehicles whose speeds are influenced by other vehicles present in neighboring lanes.

On-Site Temporary Equipment: Side-Fire Radar

Side-fire radar units are another common tool used to collect short-term vehicular speed and volume data. These sensors offer the advantage of being able to measure vehicle speeds from the roadside without installing sensors on the pavement. The sensor is attached to the end of a portable pole, the portable pole is placed next to an existing sign pole and secured, and the sensor cable runs to a portable equipment box that contains a battery and a data recorder unit. Alternatively, the portable pole can be inserted into a portable pole base that is driven into the ground with a sledgehammer. The sensor is aimed perpendicular to the direction of travel.

These side-fire radar systems provide records for individual vehicles, including arrival time stamps, speeds, lengths, and lane numbers (where lane 1 is the lane closest to the sensor and lane *n* is the lane farthest from the sensor, with *n* equal to the number of lanes included in the view).

The sensors can be programmed to include only the lanes of interest (e.g., include the freeway mainline roadbeds but exclude any frontage roads within range of the unit). Vehicle headways are computed from the arrival timestamps of consecutive vehicles in each lane, and free-flowing vehicles are identified based on headway thresholds, as is done with road tube data records.

Side-fire radar was used to collect speed data along I-20 in 2021 as part of another TxDOT project. The I-20 project examined changes in operating speed on a four-lane freeway after the speed limit was lowered from 75 to 70 mph (effective June 22, 2021) for a section of I-20 in Harrison County in an effort to mitigate run-off-the-road crash severity. Data were collected at six treated sites and three control sites. Table 9 presents the characteristics of the study sites.

Table 10 lists the data collection dates and times for each site. The speed data were stored as a text file for further analysis. The variables collected include speed, lane ID, time, and vehicle length. The lane ID variable facilitated the identification of the travel direction, while the time variable enabled matching the radar data and INRIX XD data.

Table 11 lists the values for passenger car mean operating speeds by site for the I-20 corridor. This table includes the posted speed limits before and after any changes as well as the number of readings taken during each period.

Similarly, Table 12 lists the values for the 85th percentile speed (Spd85), the standard deviation of operating speed (SpdStd), and the percentages of drivers 5 and 10 mph over the posted speed limits (%Ov5 and %Ov10) for the before and after periods. Overall, the changes in Spd85 and SpdStd between the before and after periods were nominal, resulting in increased percentages of drivers operating 5 or 10 mph over the posted speed limit in the after period for those sites with a posted speed limit reduction.

The research team developed plots showing the mean operating speeds for each site in the before and after periods, along with each site's relative distance from the point where the speed limit changed, to provide a visual appreciation of the speeds within the corridor. Figure 5 and Figure 6 show the passenger car mean speeds for the eastbound and westbound directions of I-20, respectively. The eastern edge of the I-20 corridor—where the speed limit was 70 mph in both the before and after periods—is in Louisiana.

Table 9. Study Site Characteristics.

Site ID	Treated or Control	Before Posted Speed Limit (mph)	After Posted Speed Limit (mph)	Date Signs Changed	Before Distance (miles)	After Distance (miles)
I-20EB.01 & WB.61	Control Sites	75	75	No change	–55.31	–16.09
I-20EB.02 & WB.60	Control Sites	75	75	No change	–48.28	–9.06
I-20EB.03 & WB.59	Control Sites	75	75	No change	–45.28	–6.06
I-20EB.04 & WB.58	Treated Sites	75	70	6/22/2021	–38.02	1.2
I-20EB.05 & WB.57	Treated Sites	75	70	6/22/2021	–31.38	7.84
I-20EB.06 & WB.56	Treated Sites	75	70	6/22/2021	–26.12	13.1
I-20EB.07 & WB.55	Treated Sites	75	70	6/22/2021	–16.44	22.78
I-20EB.08 & WB.54	Treated Sites	75	70	6/22/2021	–8.78	30.44
I-20EB.09 & WB.53	Treated Sites	75	70	6/22/2021	–4.05	35.17

Note: Negative values indicate that the site is upstream of the reduced speed limit.

Table 10. Radar-Based Speed Data Collection Dates and Times.

Site ID	Before Data Collection Date	Before Data Collection Time	After Data Collection Date	After Data Collection Time
I-20EB.01 & WB.61	6/2/2021	1:15:00 PM	9/30/2021	10:15:00 AM
I-20EB.02 & WB.60	6/2/2021	12:30:00 PM	9/30/2021	9:00:00 AM
I-20EB.03 & WB.59	6/2/2021	11:45:00 AM	9/30/2021	8:45:00 AM
I-20EB.04 & WB.58	5/6/2021	10:00:00 AM	9/29/2021	10:00:00 AM
I-20EB.05 & WB.57	5/6/2021	9:45:00 AM	9/29/2021	9:45:00 AM
I-20EB.06 & WB.56	5/6/2021	9:30:00 AM	9/29/2021	9:30:00 AM
I-20EB.07 & WB.55	5/5/2021	3:00:00 PM	9/29/2021	9:00:00 AM
I-20EB.08 & WB.54	5/5/2021	2:00:00 PM	9/28/2021	1:15:00 PM
I-20EB.09 & WB.53	5/5/2021	12:00:00 PM	9/28/2021	12:45:00 PM
I-20EB.10 & WB.52	6/3/2021	9:45:00 AM	9/28/2021	12:30:00 PM
I-20EB.11 & WB.51	6/3/2021	9:00:00 AM	9/28/2021	12:00:00 PM

Table 11. Passenger Car Mean Speeds by Site for I-20 Corridor.

Site Name	Before Posted Speed Limit (mph)	After Posted Speed Limit (mph)	Before Number of Readings	After Number of Readings	Before Mean Operating Speed (mph)	After Mean Operating Speed (mph)
I-20EB.01	75	75	598	300	81.46	77.82
I-20EB.02	75	75	732	338	76.86	77.45
I-20EB.03	75	75	681	320	78.57	78.44
I-20EB.04*	75	70	433	451	78.70	78.15
I-20EB.05*	75	70	422	464	78.01	75.60
I-20EB.06*	75	70	459	475	78.68	78.80
I-20EB.07*	75	70	412	498	77.84	75.30
I-20EB.08*	75	70	649	587	78.36	77.86
I-20EB.09*	75	70	859	617	77.58	78.00
I-20EB.10	70	70	364	646	78.39	78.03
I-20EB.11	70	70	454	700	78.31	72.39
I-20WB.51	70	70	391	636	74.96	73.83
I-20WB.52	70	70	318	640	76.86	77.87
I-20WB.53*	75	70	841	592	76.09	76.11
I-20WB.54*	75	70	624	611	76.55	76.51
I-20WB.55*	75	70	583	394	81.34	77.65
I-20WB.56*	75	70	449	434	78.87	75.84
I-20WB.57*	75	70	372	302	75.76	73.36
I-20WB.58*	75	70	432	554	77.07	79.18
I-20WB.59	75	75	603	369	78.23	76.78
I-20WB.60	75	75	554	330	77.12	77.24
I-20WB.61	75	75	518	250	80.07	76.82

Note: *Shaded rows (or site names with an asterisk) are sites with a change in posted speed limit.

Table 12. Descriptive Statistics for Passenger Car Operating Speed by Site for I-20 Corridor.

Site	Group	Before Spd85 (mph)	After Spd85 (mph)	Before StdSpd (mph)	After StdSpd (mph)	Before %Ov5 (%)	After %Ov5 (%)	Before %Ov10 (%)	After %Ov10 (%)
I-20EB.01	75–75	87.00	83.00	6.11	6.53	56.35	30.00	22.91	9.33
I-20EB.02	75–75	82.00	82.00	5.52	5.22	20.08	23.37	5.05	3.55
I-20EB.03	75–75	83.00	83.00	5.32	5.15	29.66	29.69	7.93	5.31
I-20EB.04*	75–70	84.00	84.00	6.21	6.35	34.64	66.52	12.01	32.37
I-20EB.05*	75–70	83.00	80.00	5.64	5.41	29.86	51.94	8.29	13.79
I-20EB.06*	75–70	83.00	83.00	4.91	5.23	36.17	77.89	6.10	33.68
I-20EB.07*	75–70	83.00	80.00	5.59	5.91	28.16	52.81	7.04	14.46
I-20EB.08*	75–70	83.80	84.00	5.86	6.28	31.12	69.85	10.79	33.73
I-20EB.09*	75–70	82.00	83.00	5.39	5.67	26.43	72.93	6.17	30.47
I-20EB.10	70–70	84.00	82.00	6.15	5.10	73.90	73.68	35.44	28.17
I-20EB.11	70–70	84.00	78.00	5.54	5.79	71.59	32.71	32.38	6.14
I-20WB.51	70–70	80.00	79.00	5.06	5.67	42.46	37.17	12.53	8.98
I-20WB.52	70–70	83.00	83.00	6.35	5.92	61.64	69.38	28.30	32.34
I-20WB.53*	75–70	81.00	82.00	5.64	5.77	18.67	58.61	3.09	20.44
I-20WB.54*	75–70	82.00	81.00	6.12	5.73	25.32	61.05	6.41	20.13
I-20WB.55*	75–70	87.00	83.00	5.77	5.68	59.01	72.34	20.24	28.17
I-20WB.56*	75–70	84.80	81.00	5.97	5.93	38.98	59.45	12.92	18.89
I-20WB.57*	75–70	81.00	80.00	5.57	7.01	16.67	46.69	1.88	11.92
I-20WB.58*	75–70	82.00	85.00	5.72	5.83	24.54	75.63	5.09	41.52
I-20WB.59	75–75	84.00	82.80	6.18	6.35	35.16	26.56	9.62	4.88
I-20WB.60	75–75	82.00	81.00	5.84	5.32	23.47	20.00	4.69	5.45
I-20WB.61	75–75	86.00	84.00	6.49	8.07	49.03	28.00	17.57	11.60

Note: Spd85 = 85th percentile operating speed. StdSpd = standard deviation speed. %Ov5 = percent of readings 5 mph over PSL. %Ov10 = percent of readings 10 mph over PSL. *Shaded rows (or site names with an asterisk) are sites with a change in posted speed limit.

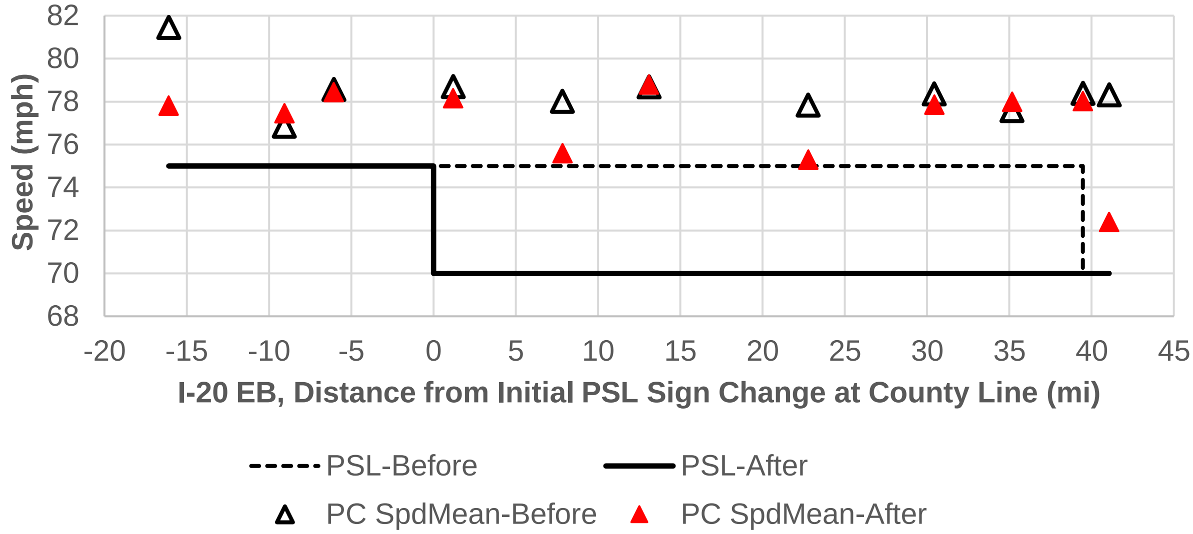


Figure 5. Passenger Car Mean Speeds Before and After Posted Speed Limit Changes at the I-20 Eastbound Sites.

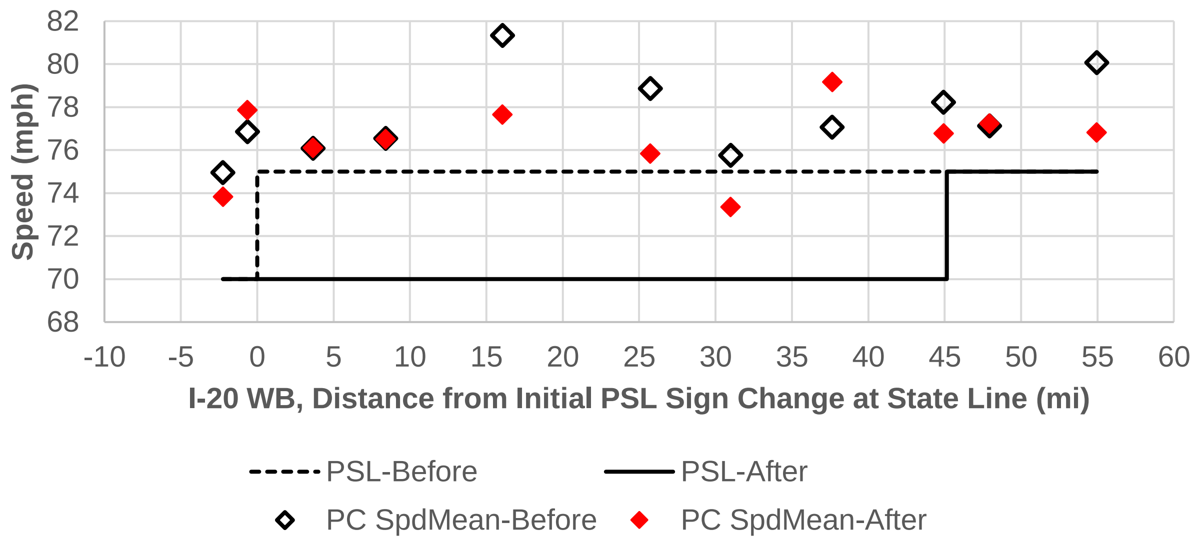


Figure 6. Passenger Car Mean Speeds Before and After Posted Speed Limit Changes at the I-20 Westbound Sites.

Permanent Equipment: ATRs

Because the ATRs collect data in each direction for 24 hours a day, 365 days a year, a subset of the full available dataset was considered for this project. The research team received speed data for 256 ATR sites from TxDOT, which covered the period between January 2019 and December 2021. However, the research team utilized only the second Wednesday of each month in the

2021 data. The ATR speed data is grouped into 15 categories. Class 1 includes speeds ranging from 0 to 30 mph; each subsequent 5 mph increment between 30 and 90 mph is categorized as a new speed class. The last two categories have different classification criteria. Class 14 includes speeds ranging from 90 to 120 mph, while Class 15 includes speeds over 120 mph speed. The dataset includes the number of vehicles per hour for each speed category.

The research team determined the average and 85th percentile speeds using a random number (speed) generator. For each speed class in a given hour of data collection, the lower and upper boundary speeds were established, and the number of vehicles was assigned. For instance, if 30 vehicles traveling between 40 and 45 mph were recorded at a segment between 1 and 2 PM, the lower and upper boundaries were 40 and 45 mph, and the number of vehicles was recorded as 30. The random number generator approach generated 30 speed data points between 40 and 45 mph. The same approach established the randomized speed for other classes for the same segment and hour of interest. The average and 85th percentile speeds were then computed using the generated random speed data. The process was repeated for all the segments and their respective hours of data collection.

INRIX XD via the RITIS Website

As noted previously, INRIX XD contains real-time, highly granular speed data from probe vehicles, crowdsourced devices, connected vehicles, and fixed sensors. INRIX provides real-time speed data coverage across the U.S. roadway network. INRIX compiles and aggregates crowdsourced, passively collected data from a variety of different sources and data resellers, including smartphones, connected cars, fleet telematics, and fixed-sensor networks. They blend these data sources using proprietary algorithms to produce several different traffic data products. Their most popular data product is segment-based traffic speeds. INRIX traffic speeds have been tested and evaluated on major highways, freeways, and arterial streets and found to be accurate for real-time and historical archived use (*30*). Recently, they added INRIX XD traffic service, which includes non-freeways in many locations across the country.

The research team downloaded the INRIX speed data using their Massive Data Downloader application available on the RITIS website (Figure 3).

Site Descriptor Data

In addition to the speed data, the INRIX XD data from the RITIS website provides a site descriptors file that includes segment IDs, road names, road numbers, bearings, miles, ZIP codes start and end longitudes and latitudes, and more.

Yearly Speed Data

After logging in to the website, researchers performed a query using the INRIX XD segment IDs, the start and end dates and times, and the averaging measures. The team utilized the INRIX

XD segment IDs for the previously identified sites of interest. The start and end dates were defined as January 1 and December 31, respectively, of the year corresponding to the on-site speed data collection. The downloaded speed data was aggregated by hour. Other aggregation options available included *no averaging*, *5 minutes*, *10 minutes*, and *15 minutes*. To avoid zero speed values in the dataset, the team chose not to include records with null values. After speed data were downloaded for all hours, a total of 8,760 records (365 days × 24 hours/day) per segment were available.

The downloaded speed data contained eight variables: segment ID, timestamp, speed, average speed, reference speed, travel time, confidence score, and c-value. The timestamp variable indicates the date and time of data collection. The speed variable represents the current estimated harmonic mean speed for a roadway segment for a specified period of time (1 hour for this case). The average and reference speed variables represent the typical speed and the free-flow speed, respectively, on a segment for a given day and time. The travel time variable (minutes/second) represents the travel time along a segment at a current speed. The confidence score is a simple confidence factor (30 = high confidence, 20 = medium confidence, and 10 = lower confidence). Lastly, the c-value indicates the probability that a current probe reading represents the actual roadway conditions based on recent and historical trends (0 = low probability, 100 = high probability). This value is only used when the confidence score is 30.

The INRIX XD speed data obtained by the research team were cleaned and checked for completeness prior to creating speed measures. The completeness check showed that the available date ranged between 99.7 and 100 percent of the required number of observations of 8,760 (365 days × 24 hours/day) per segment. In other words, a few observations were missing for some of the segments. When computing speed measures, the segment ID variable was used for the yearly aggregation of data.

Hourly Speed Data

When the on-site speed data were obtained using tubes or side-fire radar, the research team aggregated the speed data by hour. To obtain the comparable INRIX hourly speed data, the research team used the same dataset downloaded in the previous section for yearly data. However, to identify the data for the hour of interest, another variable containing the segment ID and the hour of data collection (ID_Hour) was created and used for matching. The resultant variable, which combined the segment ID and the hour of data collection, made it easier to determine speed measures for each segment for a given hour of on-site data collection.

Speed Data for a Specific Time Period

When the on-site speed data were from a TxDOT speed zone study, the length of time reflected in the time period could be more than 1 hour. The start and end times of the speed zone study were used to obtain the INRIX speed data.

Potential Speed Measures Based on Available Data

On-Site Data

Table 13 provides the speed measures being considered for the on-site speed data, including the typical 85th percentile and average speed measures. The number of vehicles represented in the speed measure was considered as well. For locations where on-site speed data represented individual vehicles, headway was considered in speed measure calculations. For the I-20 data, headways of 0, 3, and 5 seconds were used, with speed measures reflecting a 5-second headway.

Table 13. On-Site Speed Measures Considered.

Variable Name	Description
SpdAve	Average speed (mph) collected for a specific hour or speed zone study duration
SpdSdDev	Standard deviation of speed (mph) collected for a specific hour or speed zone study duration
Spd85	85th percentile speed (mph) collected for a specific time period, generally 1 hour
Date	Date of collection
SpdTimePeriod	Time period (hours) represented in the speed measures
N_Veh	Number of vehicles included in the speed measures for a specific time period (and for 5-second headways in the I-20 data)

INRIX Probe Data

The INRIX speed data were used to calculate the speed measures lists in Table 13. In addition to the typical average and 85th percentile speed measures, the research team also considered a Gaussian mixture model to calculate potential representative speed measures. In statistics, a mixture model is a probabilistic model for representing the presence of sub-populations within an overall population without requiring that the sub-population for the individual observations be preidentified. Mixture models make statistical inferences about the properties of the sub-populations given only observations on the pooled population, without sub-population identity information. The number of sub-populations can be specified. Within daily speed distributions, it is reasonable to assume that two scenarios exist: congested and free flow. When two sub-populations are assumed, the statistical package returns two values: Com1 and Com2. The value for Com2 is believed to be more representative of free-flow or non-congested operations as compared to Com1.

The research team considered various speed measures that can be calculated from probe speed datasets (Table 14 and Table 15). When matching the time periods, the research team focused on the average speeds. When examining the yearly data, the research team decided to start with the available average speeds for individual hours for an entire year for the segment. If no data are missing, 8,760 records (365 days × 24 hours/day) would be available. This group of 8,760 records would represent the overall speed behavior for a segment. Several other speed measures were considered (Table 15). After examining preliminary findings, the research team focused the two test cases on the Spd85InrixAllHrAllDay_INRIX(YrData) speed measure.

Table 14. Inital INRIX Speed Measures Considered when Matching Time Periods in On-Site Speed Measures.

Variable Name	Description
Ave.of.speed_INRIX-MatchTimePeriod	Average INRIX estimated harmonic mean speed (mph) for the segment representing the same time period as the on-site data collection (typically 1 hour but could be more or less for speed zone studies)
SpdHistAve_ INRIX(HrData)	Historical average speed (mph) for the segment for a specific hour of the day and day of the week
SpdRef_ INRIX(HrData)	Free-flow mean speed (mph) for the segment, calculated using the 66th percentile of observed speeds on the segment for all time periods, which establishes a reliable proxy for free-flow traffic speed for the segment

Table 15. Inital INRIX Speed Measures Considered when Using Yearly INRIX Data.

Variable Name	Description
SpdCom1_ INRIX(YrData)	Average speed (mph) for Com1 based on a Gaussian mixture model that considered non-zero INRIX XD hourly speed data for up to 8,760 hourly speed readings for the segment's year of interest, including both daytime and nighttime speed data
SpdStdCom1_ INRIX(YrData)	Standard deviation of speed (mph) for Com1 based on a Gaussian mixture model that considered non-zero INRIX XD hourly speed data for up to 8,760 hourly speed readings for the segment's year of interest, including both daytime and nighttime speed data
SpdCom2_ INRIX(YrData)	Average speed (mph) for Com2 based on a Gaussian mixture model that considered non-zero INRIX XD hourly speed data for up to 8,760 hourly speed readings for the segment's year of interest, including both daytime and nighttime speed data
SpdStdCom2_ INRIX(YrData)	Standard deviation of speed (mph) for Com2 based on a Gaussian mixture model that considered non-zero INRIX XD hourly speed data for up to 8,760 hourly speed readings for the segment's year of interest, including both daytime and nighttime speed data
SpdAve_InrixAll_ INRIX(YrData)	Average INRIX speed (mph) using non-zero INRIX XD hourly speed data for up to 8,760 hourly speed readings for the segment's year of interest, including both daytime and nighttime speed data
Spd85InrixAllHr AllDay_INRIX(YrData)	85^{th} percentile INRIX speed (mph) using non-zero INRIX XD hourly speed data for up to 8,760 hourly speed readings for the segment's year of interest, including both daytime and nighttime speed data
SpdAve_Inrix2345 WkDay_INRIX(YrData)	Average INRIX speed (mph) for 2, 3, 4, and 5 AM hours on weekdays using non-zero INRIX XD hourly speed data for up to 8,760 hourly speed readings for the segment's year of interest
SpdAve_Inrix91011 WkDay_INRIX(YrData)	Average INRIX speed (mph) for 9, 10, and 11 AM hours on weekdays using non-zero INRIX XD hourly speed data for up to 8,760 hourly speed readings for the segment's year of interest
SpdAve_Inrix91011 WkEnd_INRIX(YrData)	Average INRIX speed (mph) for 9, 10, and 11 AM hours on weekends using non-zero INRIX XD hourly speed data for up to 8,760 hourly speed readings for the segment's year of interest
ffspd_Inrix_ INRIX(YrData)	INRIX free-flow speed (mph) taken as the 67^{th} percentile speed

ROADWAY CHARACTERISTICS DATA

TxDOT's RHiNO

TxDOT's RHiNO includes a variety of roadway characteristics. This database primarily provides road characteristic information, including estimated traffic volumes and corridor lengths, for every known road in Texas. This database can supplement the information available in TxDOT's CRIS database related to crashes.

FHWA's HPMS

FHWA's HPMS is a national level highway information system that includes data on the extent, condition, performance, use, and operating characteristics of the nation's highways (*31*). The HPMS contains information on all public roads. Limited information on travel and paved miles is included in summary form for the lowest functional systems.

U.S. EPA's SLD

U.S. EPA's SLD (*32*) summarizes more than 90 different indicators (variables) associated with the built environment or location. Indicators include density of development, diversity of land use, street network design, and accessibility to destinations, as well as various demographic and employment statistics. The SLD uses multiple sources to generate their data. The research team utilized GIS applications to associate the SLD data to the study sites. The study sites were mapped on the GIS application. Using spatial join functions in the GIS application, the census block group characteristics of the SLD were joined to the corresponding study sites.

TxDOT's CRIS

TxDOT's CRIS database includes crash data from the Texas Peace Officer's crash reports (form CR-3). The research team used this database to generate the following variables:

- Num_TotalCrashesMile(2019_2022)_CRIS reflects the number of total (KABCO) crashes per mile for 4 years (2019–2022).
- Num_KABCCrashesMile(2019_2022)_CRIS reflects the number of fatal and injury (KABC) crashes per mile for 4 years (2019–2022).

Texas Curves

The research team assembled a database of horizontal curves on Texas highways using GIS data. Researchers linked a curve to a speed data record if the curve midpoint was within 1 mile of the speed data collection point on the same roadway. To do so, a half-mile radius buffer was created for each site using the coordinates (latitudes and longitudes) of the study sites. The Texas highway curve data was overlayed on the buffered sites. All curves within the buffer were spatial joined to the study site. Researchers then reviewed the extracted curves and eliminated any curves that were not of interest, such as curves on parallel or intersecting roadways. Researchers further identified two special categories of curves based on radius threshold values of less than 750 or 1500 ft. The threshold radius of 750 ft is based on research conducted by Bonneson et. al (*33*), which showed that on rural highways with approach tangent speeds of 50–60 mph, curve geometry notably affects curve speeds if the radius is approximately 750 ft or less. The threshold radius of 1500 ft is based on research conducted by Pratt et. al (*34*), which showed that on rural freeways with approach tangent speeds of 70–80 mph, curve geometry notably affects curve speeds if the radius is approximately 1500 ft or less.

The research team used this database to generate the following variables:

- NumCurvesMile_TX_Curves reflects the number of horizontal curves within 1 mile of on-site data collection (1/2 mile upstream and downstream of the data collection point).
- TotalLengthCurvesMile_TX_Curves reflects the total length of the curved segment within a 1-mile section.
- NumCurvesMileR<750_TX_Curves reflects the number of curves per mile with a radius less than 750 ft.
- Prp_SegmentWithR<750 reflects the proportion of curves per mile with a radius less than 750 ft.
- NumCurvesMileR<1500_TX_Curves reflects the number of curves per mile with a radius less than 1500 ft.
- Prp_SegmentWithR<1500 reflects the proportion of curves per mile with a radius less than 1500 ft.

Google Earth

While the previous databases provide extensive details about the roadway conditions, the research team believed that there were additional roadway characteristics that could help explain typical operating speeds for a site. After those characteristics were identified, researchers collected the data using Google Earth aerial or street views. Table 16 and Table 17 list the site characteristics collected using Google Earth for non-freeway and freeway sites, respectively.

Table 16. Site Characteristics Obtained Using Google Earth for Non-freeway Sites.

Variable Name	Description
Site	Site description including highway number or name and location (expressed using 2 or 3 digits with 01 as the first location)
Site-Period	Site description including highway number or name and location and period reflected in hourly speed data (test case abbreviation followed by road number, site number, direction of traffic, date of study, and study start time)
Bike-1yes	Presence of marked bike lane present (1 = Yes, 0 = No)
NumThruLanes	Number of through lanes for direction of travel
Median	Median type (none, two-way left-turn lane, raised)
Curb-1yes	Presence of curb and gutter (1 = Yes, 0 = Shoulder present)
RoadType or CrossSection	Road type based on number of lanes and median type (e.g., 3T, 4D, etc.)
Sidwlk-1yes	Presence of sidewalk (1 = Yes, 0 = No)
PSL	Posted speed limit (mph)
DrvUsigPerMileBoth or AccessDensity	Driveways/unsignalized intersections per mile in both directions or access density (accesses/mile for the segment length [previous study segment lengths ranged from 0.25 to 2.0 miles])
SigDen	Signal density (signals/mile)

Table 17. Site Characteristics Obtained Using Google Earth for Freeway Sites.

Variable Name	Description
AvgLaneWidth	Average lane width (ft)
LeftShoulderWidth	Left shoulder width (ft)
NumDR_1mi	Number of downstream ramps within 1 mile
DR_Dist	Distance to nearest downstream ramp (miles)
DR_Side	Downstream ramp location/side for the nearest downstream ramp (left or right)
DR_Type	Downstream ramp type for the nearest downstream ramp (entrance or exit)
NumAuxLanes	Number of auxiliary lanes
NumThruLanes	Number of through lanes
NumUR_1mi	Number of upstream ramps within 1 mile
UR_Dist	Distance to the nearest upstream ramp (miles)
UR_Side	Upstream ramp location/side for the nearest upstream ramp (left or right)
UR_Type	Upstream ramp type for the nearest upstream ramp (entrance or exit)
PSL	Posted speed limit at the data collection site (mph)
RampDensity	Ramp density, computed as the number of ramps per mile covering a 2-mile distance (1 mile downstream and 1 mile upstream)
RightShoulderWidth	Right shoulder width (ft)

WEATHER DATA

The SRCC is a cooperative National Oceanic and Atmospheric Administration project involving TTI, Texas A&M University Atmospheric Sciences, and Trabus Technologies to deliver climate data and analysis and provide user support. Additional details are available at Southern Regional Climate Center | Dashboard (tamu.edu). The research team supplied the following information to the SRCC for each speed reading: location (latitude and longitude), date, and hour. The SRCC provided the following data for each speed reading:

- PCPN reflects the precipitation (inches) for the hour. Precipitation generally includes rainfall; however, it can include other types of *water falling from the sky* such as slush, sleet, etc. In some cases, the data was missing either because the airport station did not report for that hour (unfortunately quite common in hourly data), or a nearby airport station could not be located for that site.
- Temp reflects the temperature (degree Fahrenheit) for the hour.
- AP_ID reflects the nearest airport station code. Blanks fields occur when a sufficiently close airport station could not be identified.
- Distance reflects the distance (kilometers) between the nearest airport station and the spot location for the on-site speed sensor.

DEVELOPED DATABASES FOR TEST CASES

Test case data used in this research were grouped into either freeways (access controlled) or non-freeways (non-access controlled). These databases were then separately filtered to remove data as appropriate.

Freeways

Table 18 provides an overview of the speed measures considered at the freeway sites. The filters used in refining the freeway database included the following:

- Remove nighttime hours (used local sunrise and sunset data).
- Remove site-period when on-site volume is more than 1,000 vehicles per lane per hour. The *Highway Capacity Manual* (HCM) identifies volumes less than 1,000 passenger cars per hour per lane as being representative of free-flow conditions for freeways and uninterrupted-flow multilane highways (*35*, Chapter 12, pages 12–27).
- Remove site-period when on-site average speed is less than 53 mph. Intended to identify potential congestion, the 53-mph value was selected based on work done in a previous TxDOT project (*8*).
- Remove site-period when on-site volume is less than 100 vehicles for the hour based on ATR or tube data.
- Remove site-period when either on-site average or 85th percentile speed is more than or less than 25 mph from the posted speed limit. This filter helped identify potential outliers, equipment concerns, and congestion.
- Remove site-period when temperature is less than 32 degrees. This filter removed site-periods with a potential for slick surface conditions due to precipitation occurring in a previous hour.
- Remove site-period when precipitation for the hour was more than 0. Site-periods with missing data (about 34 percent of the database) were retained.

Finally, the research team used the RHiNO RU-F-SYSTE variable to identify whether a site was in a rural or urban area using the codes provided in Table 19.

Table 18. Spot and Segment Speed Characteristics for Freeways.

Data Type	Segment Speed Data, INRIX Probe	Spot Speed Data, Side-Fire Radar	Spot Speed Data, ATR
Key data collection characteristics	• Sample of vehicles present during time period • If sufficient sample is not available, could be estimated from historical data	• Speeds for all vehicles (cars, trucks, buses, etc.) • Binned data • Locations selected by research team	• Speeds for all vehicles (cars, trucks, buses, etc.) • Binned data • In-road sensors maintained by TxDOT • Locations selected by TxDOT to represent geographical diversity
Key speed data characteristics	Average segment speed (segments typically range from 0.5 to 1.0 miles)	Spot speed of all vehicles passing the side-fire radar	Spot speed of all vehicles passing the ATR sensor
Potential factors influencing measured speed	• Segment length • Number of ramps within segment • Type of ramps (entrance or exit) within segment • Vehicle volume • Peak vehicle volume • Truck volume • Month of year and hour of day	• Upstream and downstream distance to ramp nearest to measurement location • Type of ramp (entrance or exit) nearest to measurement location • Other site characteristics • Month of year and hour of day	• Upstream and downstream distance to ramp nearest to measurement location • Type of ramp (entrance or exit) nearest to measurement location • Other site characteristics • Month of year and hour of day

Table 19. Rural and Urban Codes.

Rural or Urban Assignment	RU-F-SYSTE Codes	RU-F-SYSTE Description
Rural	R3	Other principal arterial
Rural	R4	Minor arterial
Rural	R5	Major collector
Rural	R6	Minor collector
Rural	R7	Local
Urban	U3	Other principal arterial
Urban	U4	Minor arterial
Urban	U5	Major collector
Urban	U7	Local

The above filters resulted in a database that contained 11,436 records. Figure 7 illustrates the speed distribution curves for the on-site and INRIX speed distributions for urban and rural environments. Table 20 provides summary statistics for the freeway speeds, including minimums, maximums, and ranges.

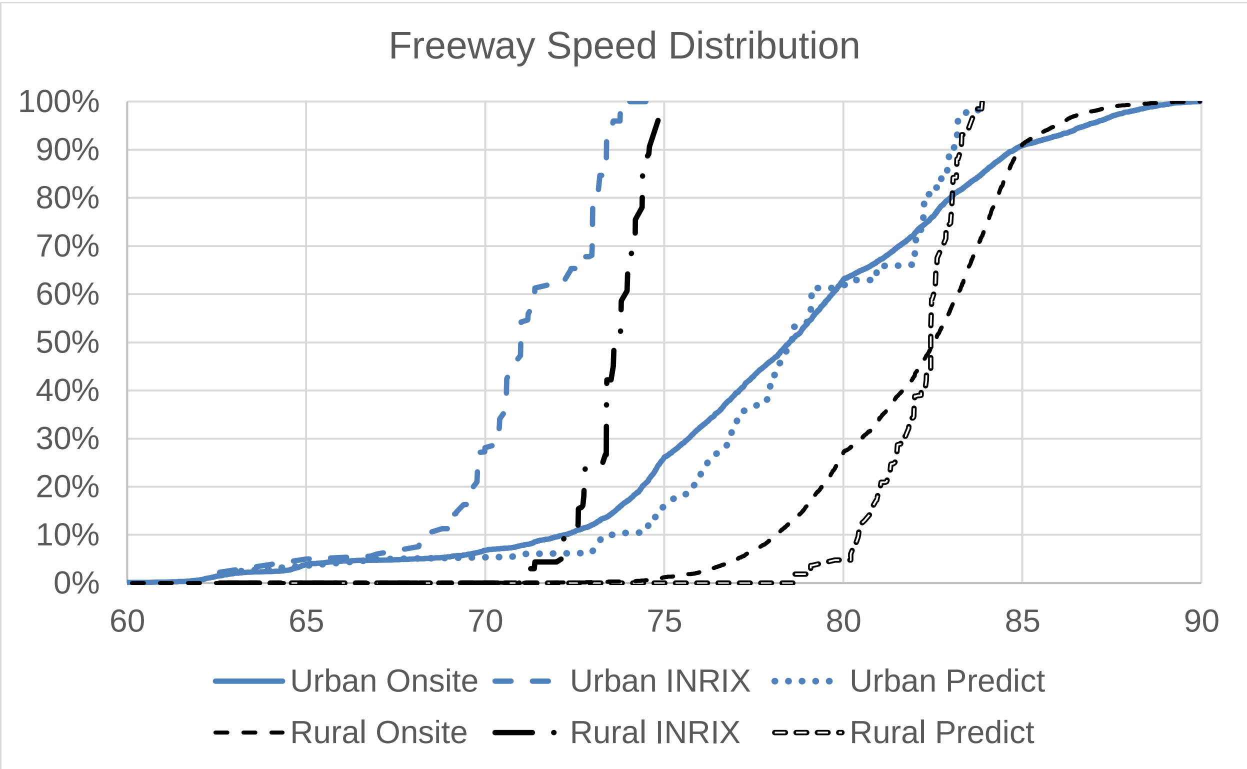


Figure 7. Speed Distributions Using On-Site and INRIX Speed Data for Freeways.

Table 20. Summary Statistics for On-Site and INRIX Speed Data for Freeways.

Measure	Rural	Urban
Count	6,119	5,317
Minimum Spd85_Onsite-R (mph)	69.37	59.35
Minimum Spd85_AllHrAllDay_INRIX-YrData	71.18	62.58
Maximum Spd85_Onsite-R	89.65	89.96
Maximum Spd85_AllHrAllDay_INRIX-YrData	75.00	73.78
Range Spd85_Onsite-R	20.28	30.61
Range Spd85_AllHrAllDay_INRIX-YrData	3.82	11.20

Non-freeways

Table 21 provides an overview of the speed measures considered at the non-freeway sites. The filters used in refining the freeway database included the following:

- Remove nighttime hours (used local sunrise and sunset data).
- Remove site-period when on-site volume is more than 250 vehicles per lane per hour. The HCM identifies volumes less than 250 vehicles per hour per lane as being representative of free-flow conditions for interrupted-flow streets (*35*, Chapter 12, pages 12–27; Chapter 15, Equation 15-7; and Chapter 18, Exhibit 18-12).
- Remove site-period when temperature is less than 32 degrees. This filter removed site-periods with a potential for slick surface conditions due to precipitation occurring in a previous hour.
- Remove site-period when precipitation for the hour was more than 0. Site-periods with missing data (about 33 percent of the database) were retained.
- Remove site-period when less than 100 vehicles for the hour for ATR or tube data.
- Remove site-period when either on-site average or 85th percentile speed is more than or less than 25 mph from the posted speed limit. This filter helped identify potential outliers, equipment concerns, and congestion.
- Remove site-period when on-site average speed is less than the posted speed limit minus 2 mph. The 2-mph value was added in consideration of equipment accuracy. This filter, while imprecise, helped remove site-periods where non-free-flow conditions or congestion may be present.

As a final step, the research team again used the RHINO RU-F-SYSTE variable to identify whether a site is in a rural or urban area using the codes provided in Table 19.

The above filters resulted in a database that contained 12,814 records. Figure 8 illustrates the speed distribution curves for the on-site and INRIX speed distributions for urban and rural environments. Table 22 provides summary statistics for non-freeway speeds including minimums, maximums, and ranges.

The rural speeds represented a range of 46.0 mph for on-site speed data, compared to 36.0 mph for INRIX speed data. The minimum rural speeds based on the INRIX and on-site speed data were similar (within 3 mph); however, the difference in the maximum rural speeds was higher (13.0 mph).

For urban speeds, a greater range existed in the data. The minimum speed based on the INRIX data was 20.0 mph, while the minimum speed based on the on-site data was 29.0 mph. The difference in maximum speed was 12.3 mph.

Table 21. Spot and Segment Speed Characteristics for Non-freeways.

Type of Data	Segment Speed Data, INRIX Probe	Spot Speed Data, Speed Zone Study	Spot Speed Data, Tube	Spot Speed Data, ATR
Key data collection characteristics	• Sample of vehicles present during time period • If sufficient sample is not available, could be estimated from historical data	• Sample of vehicles selected by trained technicians to represent free-flow passenger cars	• Speeds for all vehicles (cars, trucks, buses, etc.) • Binned data • Tubes installed by research team at selected sites	• Speeds for all vehicles (cars, trucks, buses, etc.) • Binned data • In-road sensors maintained by TxDOT • Locations selected by TxDOT to represent geographical diversity
Key speed data characteristics	Average segment speed (segments typically range from 0.5 to 1.0 miles)	Spot speed of free-flow vehicles	Spot speed of all vehicles crossing the road tubes	Spot speed of all vehicles passing the ATR sensor
Potential factors influencing measured speed	• Segment length • Number of signals • Number of access points (driveways and unsignalized intersections) • Activity level for the access points (not currently available) • Vehicle volume • Peak vehicle volume • Truck volume • Road type (functional classification)	• Skill of technician selecting free-flow vehicles • Distance to speed influencing feature (e.g., signal, high-volume driveway, unsignalized intersection) • Month of year and hour of day	• Month of year and hour of day • Removal of non-free-flowing vehicles or non-passenger cars from dataset • Site characteristics (e.g., distance to nearby driveway, etc.)	• Month of year and hour of day • Inclusion of all vehicles versus only free-flowing passenger cars • Site characteristics (e.g., distance to nearby driveway, etc.)

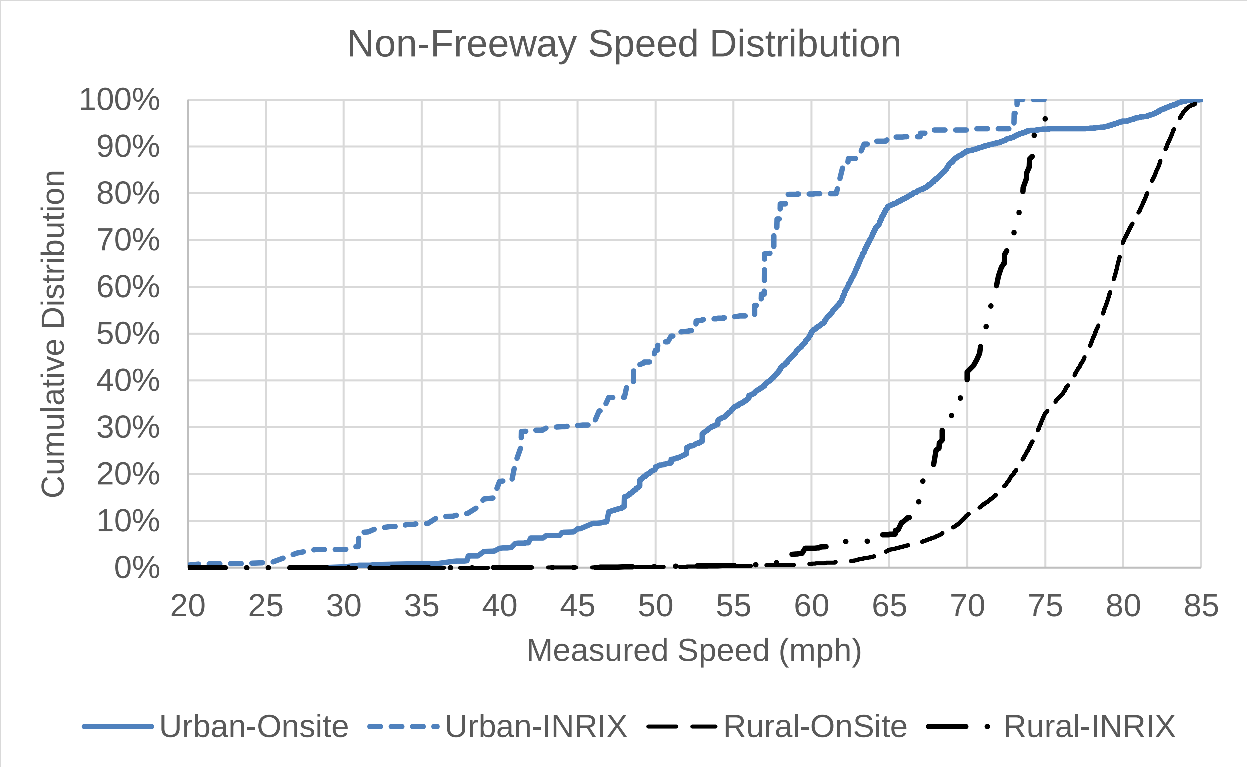


Figure 8. Speed Distributions Using On-Site and INRIX Speed Data for Non-freeways.

Table 22. Summary Statistics for On-Site and INRIX Speed Data for Non-freeways.

Measure	Rural	Urban
Count	9,325	3,489
Minimum Spd85_Onsite-R (mph)	42.0	29.0
Minimum Spd85_AllHrAllDay_INRIX-YrData	39.0	20.0
Maximum Spd85_Onsite-R	88.0	85.5
Maximum Spd85_AllHrAllDay_INRIX-YrData	75.0	73.2
Range Spd85_Onsite-R	46.0	56.5
Range Spd85_AllHrAllDay_INRIX-YrData	36.0	53.2

CHAPTER 6: FREEWAY TEST CASE

INRIX XD DATA/LOCATIONS AVAILABLE FOR TEST CASE EVALUATION

Two sources for freeway speed data were identified by the research team: side-fire radar data collected in a previous TxDOT project on I-20 and ATR data.

To obtain the specific segments associated with the study sites, the research team first obtained coordinates for the nine I-20 sites and relevant ATR sites. These coordinates were used to generate a shapefile. Using the study site shapefile, a 250-ft buffer was created around each site, the INRIX XD shapefile was then overlayed, and the segments that fell within the buffer were extracted. An additional check was performed to make sure that only the segments of interest were considered for further analysis (i.e., all frontage road segments were removed). INRIX XD speed data for the same the dates and times of the on-site data collection were obtained to support the matched time period analysis. Speed data during the same year were also obtained.

The database was then filtered as previously discussed to remove speed readings that occurred at night or suggested equipment concerns (i.e., a small number of speed readings for the hour). Filters were also applied to remove speed readings potentially affected by weather (rain or temperature) and congestion. Table 23 provides the number and characteristics of readings at freeway sites, including the total number of unique speed readings used in the modeling efforts.

Table 23. Number and Characteristics of Readings at Freeway Sites.

Rural or Urban	Posted Speed Limit (mph)	Data Equipment	Number of Unique INRIX Segments	Average Spd85_Onsite-R (mph)	Number of Unique Speed Readings
Rural	60	ATR	2	79.6	224
Rural	65	ATR	4	79.6	286
Rural	70	ATR	7	80.6	709
Rural	70	Side-fire	10	79.7	49
Rural	75	ATR	45	82.6	4,540
Rural	75	Side-fire	14	81.5	101
Rural	80	ATR	4	85.3	210
Rural Total	**All**	**All**	**86**	**81.8**	**6,119**
Urban	55	ATR	3	75.8	310
Urban	60	ATR	18	73.7	570
Urban	65	ATR	29	76.5	2,057
Urban	70	ATR	17	79.1	857
Urban	70	Side-fire	2	82.0	8
Urban	75	ATR	11	81.4	942
Urban	75	Side-fire	2	81.1	8
Urban	80	ATR	6	86.3	565
Urban Total	**All**	**All**	**88**	**77.9**	**5,317**
Rural and Urban Total	**All**	**All**	**174**	**79.9**	**11,436**

ON-SITE SPEED DATA

ATR Speed Data

The research team utilized ATR speed data as one of the sources for on-site speed data. The ATR stations are scattered across the State of Texas, providing better geographical coverage as compared to other speed data that were available to the research team. Further, ATR stations record speed data for each travel lane for 24 hours a day and 365 days a year, providing a more temporally robust dataset. For the ATR sites, the speed binned data were obtained for all hours for the second Wednesday of each month for 2021. As indicated previously, the research team determined the average and 85th percentile speeds using a random number (speed) generator. The database was filtered as detailed in Chapter 5. Figure 9 shows the resulting average 85th percentile speeds for the urban ATR sites by posted speed limit and month. Figure 10 shows similar findings for the rural ATR sites.

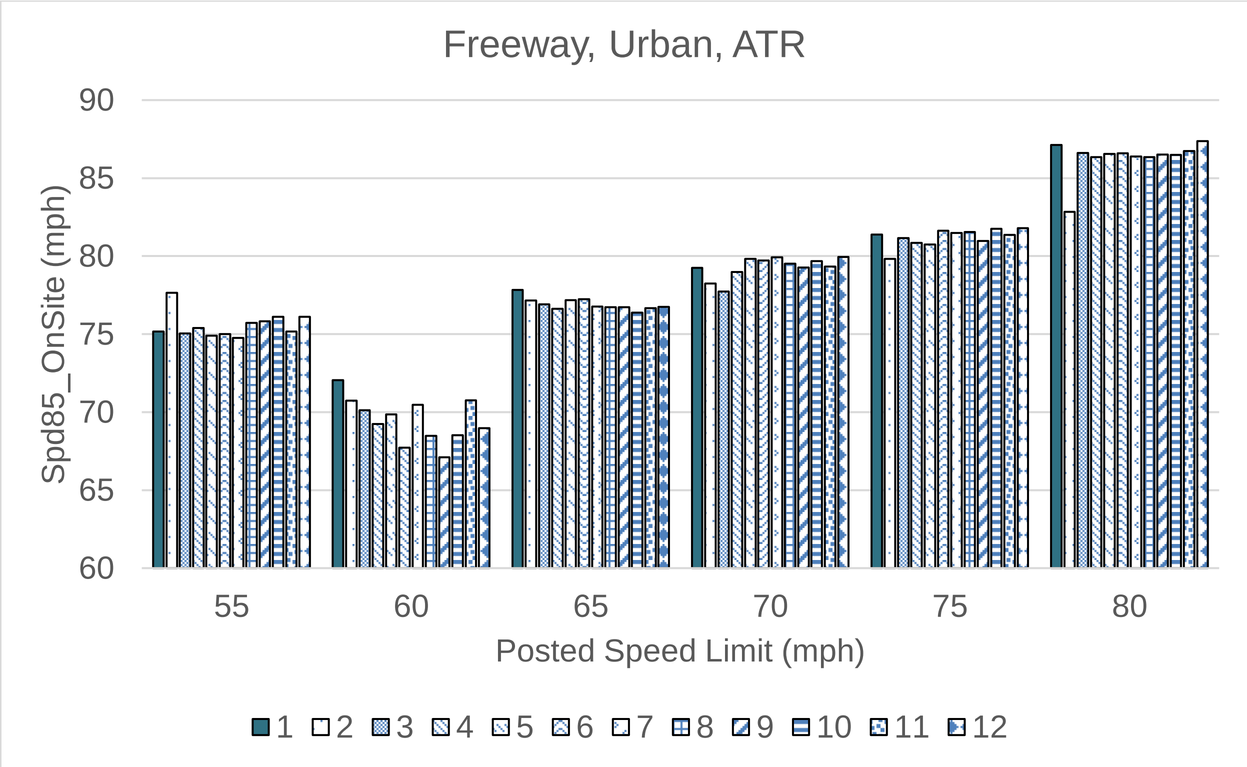


Figure 9. Average 85th Percentile Speeds (Spd85_Onsite-R) at Urban Freeway ATR Sites by Posted Speed Limit and Month.

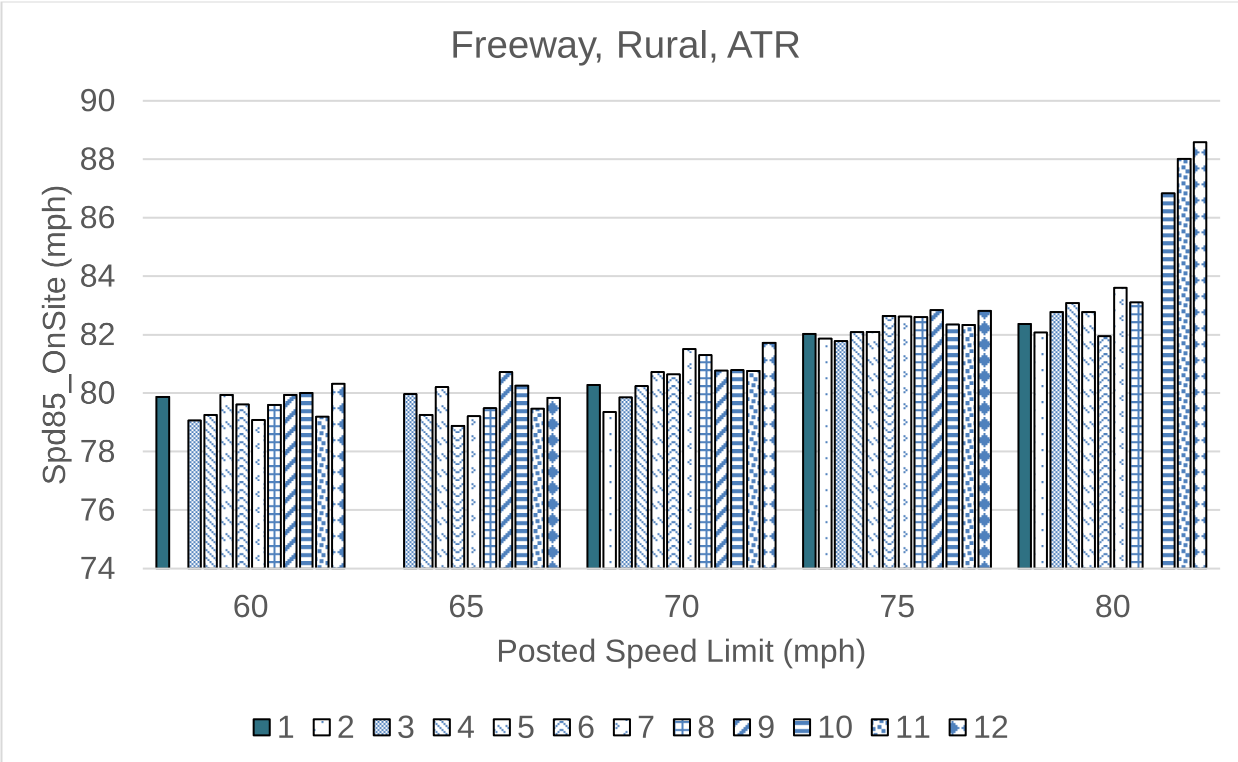


Figure 10. Average 85th Percentile Speeds (Spd85_Onsite-R) at Rural Freeway ATR Sites by Posted Speed Limit and Month.

For most of the posted speed limit groups, the monthly 85th percentile speed was relatively consistent. For urban ATR sites, the freeway segments with 60 mph posted speed limits showed the most variation across the different months, with a range of 3.7 mph (67.1 to 70.8 mph). The urban ATR sites with 80 mph posted speed limits showed a consistent speed except for February, which was 82.8 mph as compared to the typical 86 to 87 mph average 85th percentile speed. The rural ATR sites with 80 mph posted speed limits also had unexpectedly higher speeds from October to December. In 2021, the 85th percentile speed at urban sites with 80 mph posted speed limits was typically 86.4 mph. The 85th percentile speed at rural sites with 80 mph posted speed limits was typically 82.7 mph from January to August but higher (typically 87.8 mph) from October to December. The reason for this 5-mph increase could not be identified.

Side-Fire Radar Speed Data

The research team utilized nine sites along the I-20 freeway that were previously used in TxDOT Project 0-7096. Side-fire radar was used to collect the data on I-20. Multiple speed readings were available because data were collected for several hours during the 1–2 days when the equipment was installed. Table 24 provides the average 85th percentile speed for each month, along with the number of readings included in the average.

Table 24. Number of Readings per Month at Freeway Sites.

Posted Speed Limit (mph)	Month	Rural Average Spd85_Onsite-R (mph)	Rural Number of Readings	Urban Average Spd85_Onsite-R (mph)	Urban Number of Readings
70	9	79.9	49	82.0	8
75	5	81.5	40	81.1	8
75	6	81.8	41	ND	ND
75	9	80.4	20	ND	ND

Note: ND = no data. The database did not include any sites with this posted speed limit, urban, and month combination.

VARIABLES AND DESCRIPTIVE STATISTICS

The assembled freeway database included several variables that could affect speed. Based on preliminary model development efforts, a subset of these variables was identified for later evaluations (Table 25). Table 26 and Table 27 provide summary statistics for the variables considered in the final models for rural and urban freeway sites, respectively.

Table 25. Variable Descriptions for Freeway Models.

Variable	Description
Miles_INRIXSeg	Length of INRIX segment
RampDen_SiteChar	Ramp density (signals/mile)
Spd85_AllHrAllDay_INRIX-YrData	85^{th} percentile speed (mph) based on INRIX NAS168 file data (speed data for 168 hours per week, by hour of day and day of week)
Spd85_Onsite-Spd-R	85^{th} percentile speed (mph) based on on-site data
SpdAve_All_INRIX-YrData	Average speed (mph) based on INRIX NAS168 file data (speed data for 168 hours per week, by hour of day and day of week)
SpdAve_Onsite-Spd-R	Average speed (mph) based on on-site data

Table 26. Summary Statistics for On-Site Speeds and Predictors at Rural Freeway Sites.

Variable	Variable Type	N	Minimum	Maximum	Mean	Standard Deviation
Spd85_Onsite-Spd-R	Numerical	6,119	69.37	89.65	82.54	2.79
SpdAve_Onsite-Spd-R	Numerical	6,119	53.36	84.30	75.14	3.14
Miles_INRIXSeg	Numerical	6,119	0.40	0.99	0.54	0.14
RampDen_SiteChar	Numerical	6,119	0.00	3.50	0.50	0.74
Spd85_AllHrAllDay_INRIX-YrData	Numerical	6,119	71.18	75.00	73.60	0.90
SpdAve_All_INRIX-YrData	Numerical	6,119	68.49	72.01	70.88	0.82

Notes: N denotes the number of non-missing values. See Table 25 for description of variables.

Table 27. Summary Statistics for On-Site Speeds and Predictors at Urban Freeway Sites.

Variable	Variable Type	N	Minimum	Maximum	Mean	Standard Deviation
Spd85_Onsite-Spd-R	Numerical	5,317	59.35	89.96	78.50	5.50
SpdAve_Onsite-Spd-R	Numerical	5,317	53.29	84.93	71.00	5.45
Miles_INRIXSeg	Numerical	5,317	0.15	0.99	0.58	0.18
RampDen_SiteChar	Numerical	5,317	0.00	4.00	2.00	0.87
Spd85_AllHrAllDay_INRIX-YrData	Numerical	5,317	62.58	73.78	70.99	2.31
SpdAve_All_INRIX-YrData	Numerical	5,317	59.35	89.96	78.50	5.50

Notes: N denotes the number of non-missing values. See Table 25 for description of variables.

FINDINGS

Match of Time Periods

Initial efforts were made to compare the on-site spot speeds to available INRIX segment speeds for the same time period reflected in the spot speeds. Average INRIX segment speeds were compared to average spot speeds collected using side-fire radar with data limited to vehicles with at least 5-second headways and tailways and side-fire radar and ATRs for all freeway sites.

By matching the same time period (specific hour and day) for the INRIX and on-site data, confounding factors such as enforcement levels could be better controlled. Several combinations of variables were explored during model development. Variables were discarded if they had counterintuitive signs (positive or negative) or had low statistical t-values. The research team decided to focus on those variables that, in theory, would help convert a freeway segment speed to a spot speed. After removing all insignificant variables, only the ramp density variable remained in the model intended to help modify/convert the INRIX segment speed to a spot speed. Table 28 details the summary of fit measures for the final urban and rural models. Table 29 provides the parameter estimates for these models.

Table 28. Summary of Fit for Freeway Models Using Average Speed and Matched Time Periods (M-5-Average).

Measure	Urban	Rural
RSquare FE	0.6735	0.1719
Adj_Rsq FE	0.6734	0.1716
RSquare ME	0.8799	0.7530
Adj_Rsq ME	0.8799	0.7528
Root Mean Square Error FE	3.1138	2.8556
Root Mean Square Error ME	1.4930	1.4930
Mean of Response	71.0210	71.0210
Mean of Predicted	71.0210	71.0210
AIC	19,881.46	23,331.63
BIC	19,914.35	23,365.23
Observations	5,317	6,119

Table 29. Parameter Estimates for Freeway Models Using Average Speed and Matched Time Periods (M-5-Average).

Fixed Effects	Urban Estimate	Urban Standard Error	Urban t-statistic	Rural Estimate	Rural Standard Error	Rural t-statistic
Intercept	29.22680	1.28191	22.799	21.88908	1.30216	16.810
Ave.of.speed_INRIX-MatchTimePeriod	0.65201	0.01394	46.789	0.75277	0.01702	44.238
RampDensity_SiteChar	–1.52186	0.35613	–4.273	–1.07482	0.37863	–2.839

Conversion of Yearly Data to 85th Percentile Speed

Initial efforts were made to compare the on-site spot speeds to available INRIX segment speeds for the same time period reflected in the spot speeds. Next, a speed measure representing the yearly INRIX segment speeds was compared to the average spot speed collected using ATR or side-fire radar equipment. Based on the findings from the matched comparisons, the research team decided to focus on the variable that, in theory, would best help convert a freeway segment speed to a spot speed—ramp density. Table 30 shows the resultant model. Table 31 details the summary of fit measures for the model. When comparing average speeds for the same time period, ramp density was statistically significant for both rural and urban conditions. Furthermore, the research team computed the Root Mean Square Error with and without segment ID (SegID) included. The Root Mean Square Error without SegID included was computed by first predicting the 85th speed using the prediction equation and then computing the square root of the square of the difference between predicted values and observed values. On the other hand, the Root Mean Square Error with SegID included was computed directly from statistical software.

Figure 11 provides the scatter plot of the 85th percentile speeds based on the on-site and INRIX speed data calculated using all hours of the year for the urban sites. Figure 12 provides a similar scatter plot for the rural data. Figure 13 and Figure 14 show the scatter plot for on-site and predicted speed values for urban and rural conditions, respectively. These plots illustrate a range of on-site speeds for a specific INRIX speed. For example, for an average INRIX speed was 60 mph, on-site speeds ranged from 54 to 70 mph.

Table 30. Parameter Estimates for Freeway Models Using 85th Percentile Speed (Yr-5-85).

Fixed Effects	Urban Estimate	Urban Standard Error	Urban t-statistic	Rural Estimate	Rural Standard Error	Rural t-statistic
Intercept	–48.6515	9.5427	–5.098	29.1680	21.4704	1.359
Spd85_AllHrAllDay_INRIX(YrData)	1.8024	0.1305	13.807	0.7335	0.2918	2.513
RampDensity_SiteChar	–0.4476	0.3122	–1.433	–1.1163	0.3598	–3.102

Table 31. Summary of Fit for Freeway Models Using 85th Percentile Speed (Yr-5-85).

Measure	**Urban**	**Rural**
RSquare FE	0.7178	0.1198
Adj_Rsq FE	0.7214	0.1195
RSquare ME	0.9188	0.7653
Adj_Rsq ME	0.9187	0.7652
Root Mean Square Error FE	2.9034	2.6134
Root Mean Square Error without SegID included	2.9263	2.6228
Root Mean Square Error with SegID included	1.4520	1.3721
Mean of Response	78.2616	81.9759
Mean of Predicted	78.2616	81.9759
AIC	19,543.65	21,711.81
BIC	19,576.54	21,745.41
Observations	5,317	6,119

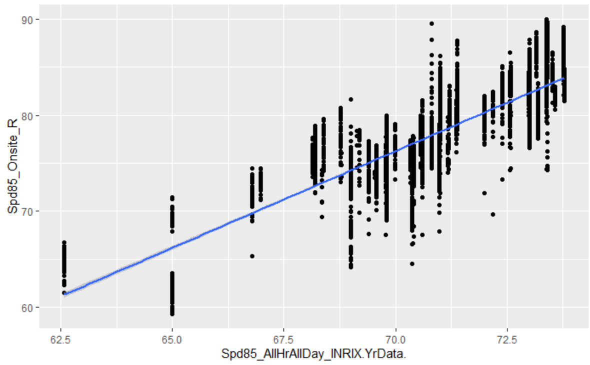


Figure 11. On-Site vs. INRIX 85th Percentile Speeds for Urban Sites.

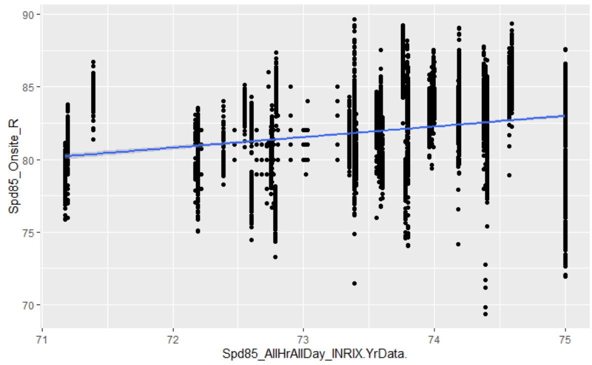


Figure 12. On-Site vs. INRIX 85th Percentile Speeds for Rural Sites.

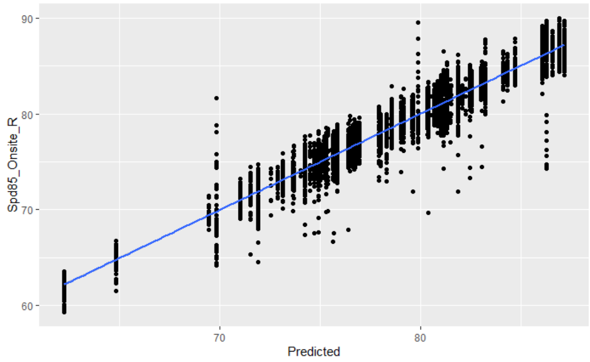


Figure 13. On-Site vs. Predicted 85th Percentile Speeds for Urban Sites.

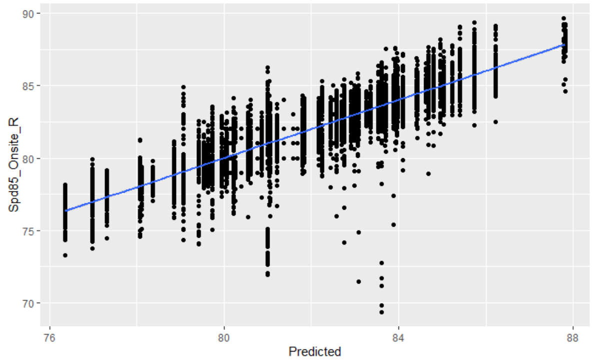


Figure 14. On-Site vs. Predicted 85th Percentile Speeds for Rural Sites.

Conversion of Yearly Data to Average Value

To use the NCHRP 17-76 SSL-Tool, average speed values were required. Table 32 shows the resultant model using average speed instead of 85th percentile speed. Table 33 details the summary of fit measures for this model.

Table 32. Parameter Estimates for Freeway Models Using Average Speed (Yr-5-Average).

Fixed Effects	Urban Estimate	Urban Standard Error	Urban t-statistic	Rural Estimate	Rural Standard Error	Rural t-statistic
Intercept	-51.9589	9.6027	-5.411	-48.6515	9.5427	-5.098
Spd85_AllHrAllDay_ INRIX.YrData.	1.7497	0.1314	13.319	1.8024	0.1305	13.807
RampDensity_SiteChar	-0.5943	0.315	-1.887	-0.4476	0.3122	-1.433

Table 33. Summary of Fit for Freeway Models Using Average Speed (Yr-5-Average).

Measure	Urban	Rural
RSquare FE	0.6842	0.0979
Adj_Rsq FE	0.6841	0.0976
RSquare ME	0.8821	0.6744
Adj_Rsq ME	0.8820	0.6742
Root Mean Square Error FE	3.0465	2.9805
Root Mean Square Error without SegID included	3.0556	2.9944
Root Mean Square Error with SegID included	1.7690	1.8024
Mean of Response	71.0210	74.8460
Mean of Predicted	71.0210	74.8460
AIC	21610.13	25016.26
BIC	21643.02	25049.85
Observations	5,317	6,119

Conversion Equations

The modeling efforts produced a series of equations that can be used to convert INRIX segment speed data to 85th percentile and average spot speeds along rural and urban freeways. These conversion equations are described next.

Equation to Predict 85th Percentile Speed on Rural Freeways

The equation to predict the 85th percentile spot speed for a rural corridor using INRIX yearly speed is as follows:

$$Spd85(RuralPredicted) = 29.1680 + 0.7335\ X\ \mathrm{Spd85(YrDataINRIX)} - 1.1163\ X\ \mathrm{RampDen} \quad \text{Equation 1}$$

where:

Spd85(RuralPredicted)	=	Predicted 85th percentile speed (mph) for rural freeways
Spd85(YrDataINRIX)	=	85th percentile speed (mph) using non-zero INRIX XD hourly (daytime and nighttime) speed data for up to 8,760 hourly speed readings for the segment's year of interest
RampDen	=	Ramps per mile for the corridor

Equation to Predict Average Speed on Rural Freeways

The equation to predict the average spot speed for a rural corridor using INRIX yearly speed is as follows:

$$SpdAve(RuralPredicted) = 19.2780 + 0.7719X\ Spd85(YrDataINRIX) - 1.0883\ X\ RampDen \qquad \text{Equation 2}$$

where:

SpdAve(RuralPredicted)	=	Predicted average speed (mph) for rural freeways
Spd85(YrDataINRIX)	=	85th percentile INRIX speed (mph) using non-zero INRIX XD hourly (daytime and nighttime) speed data for up to 8,760 hourly speed readings for the segment's year of interest
RampDen	=	Ramps per mile for the corridor

Equation to Predict 85th Percentile Speed on Urban Freeways

The equation to predict the 85th percentile spot speed for an urban corridor using INRIX yearly speed is as follows:

$$\text{Spd85(UrbanPredicted)} = -48.6515 + 1.8024\ \text{X}\ \text{Spd85(YrDataINRIX)} - 0.4476\ \text{X}\ \text{RampDen} \qquad \text{Equation 3}$$

where:

Spd85(UrbanPredicted)	=	Predicted 85th percentile speed (mph) for urban freeways
Spd85(YrDataINRIX)	=	85th percentile INRIX speed (mph) using non-zero INRIX XD hourly (daytime and nighttime) speed data for up to 8,760 hourly speed readings for the segment's year of interest
RampDen	=	Ramps per mile for the corridor

Equation to Predict Average Speed on Urban Freeways

Finally, the equation to predict the average spot speed for an urban corridor using INRIX yearly speed is as follows:

$$SpdAve(UrbanPredicted) = -51.9589 + 1.7497\ X\ Spd85(YrDataINRIX) - 0.5943\ X\ RampDen \qquad \text{Equation 4}$$

where:

SpdAve(UrbanPredicted)	=	Predicted average speed (mph) for urban freeways

Spd85(YrDataINRIX)	=	85th percentile INRIX speed (mph) using non-zero INRIX XD hourly (daytime and nighttime) speed data for up to 8,760 hourly speed readings for the segment's year of interest
RampDen	=	Ramps per mile for the corridor

Suggested Default Values for Equations to Predict Speed on Freeways

The research team developed suggested default values by considering the variable averages in the databases when developing the regression equations and applying engineering judgement. Table 34 lists these suggested default values for select variables.

Table 34. Suggested Default Values when Actual Values are Not Available or Difficult to Obtain for Freeway Corridors.

Variable	Urban	Rural
Spd85_AllHrAllDay_INRIX(YrData)	70.99	73.60
RampDensity_SiteChar	1.95	0.94

Assessment of Equations to Predict Speed on Freeways

Table 35 presents a summary of statistical measures for assessing the prediction accuracy of the freeway equations. The two statistical measures that are used include the adjusted R-squared and the root mean square error. Because the research team utilized mixed-effect models, the measures are divided into fixed-effects (FE) and mixed- or random-effects (ME) models. Hypothetically, the adjusted R-squared values range from 0 to 1; a value of 0 means that the independent, explanatory variables have no explanatory power, while a value of 1 means the explanatory variables perfectly explain the variability in the dependent variable. The root mean square error provides an appreciation of the potential magnitude of the difference between the observed and predicted speeds. The minimum value for the root mean square error is 0, which implies that the independent variables perfectly explain the variabilities in the dependent variable.

According to the summary in Table 35, the mixed-effects models performed relatively better than the fixed-effect models. The mixed-effects models had higher adjusted R-squared values (Adj_Rsq ME) than the fixed-effects models (Adj_Rsq FE) and lower root mean square errors than the fixed-effects models. The mixed-effect parameters in the mixed-effects models control additional variations. Thus, any subsequent interpretation is based on the summary statistics of the mixed-effects model measures.

The adjusted R-squared values for the regression equations (Adj_Rsq ME) range from 0.67 to 0.92. These values indicate that the independent variables used in the models explain between 67 and 92 percent of the variability in the observed speeds. The implication is that the developed models will generate a reasonably predicted speed. Further, the values for the root mean square error range from 1.3 to 1.8 mph. These values imply that, on average, the predicted speeds are off by 1.3 to 1.8 mph, which are lower than the suggested incremental speed limits (5 mph).

Table 35. Summary of Statistical Measures for Freeway Equations.

Context	Measure	Adjusted R-squared – Fixed Effects	Adjusted R-squared –Mixed Effects	Root Mean Square Error with SegID included	Root Mean Square Error without SegID included
Rural	85th Percentile	0.1195	0.7652	1.37	2.62
Rural	Average	0.0976	0.6742	1.80	2.99
Urban	85th Percentile	0.7214	0.9187	1.45	2.93
Urban	Average	0.6841	0.8820	1.77	3.06

Suggested Speed Limits

Inputs

The research team used the following methodologies to identify a suggested speed limit for each hour and for each site:

- TxDOT's SZM for upper and lower levels.
- NCHRP's SLS-Tool developed in Project 17-76 and described in Report 966 (*7*).

The suggested speed limit methodologies produced three suggested speed limits:

- SSL_SZM_Lower represents the suggested speed limit using TxDOT's SZM when speed limits are lower because one or more of the SZM criteria are met.
- SSL_SZM_Upper represents the suggested speed limit using TxDOT's SZM when assuming none of the SZM criteria are met.
- SSL_17-76 represents the suggested speed limit using NCHRP's SLS-Tool.

Rounding the 85th percentile speed to the nearest 5-mph increment generated the SSL_SZM_Upper value. For the freeway sites, the research team used the following thresholds to determine when the 85th percentile speed should be reduced by 10 mph (or 12 mph based on crash history) to generate the SSL_SZM_Lower value:

- Narrow roadway pavement widths (i.e., average lane widths of less than 11 ft).
- Excessive horizontal curves (i.e., proportion of speed zone length that contains curves with radii less than 1500 ft exceeds 0.2).
- Lack of striped, improved shoulders (i.e., no paved shoulders or shoulder widths of less than 6 ft).
- High crash history (i.e., rate of KABCO or KABC crashes in the speed zone of interest exceeds relevant statewide average rate computed by Fitzpatrick et al. (*6*) using 2019 CRIS and RHiNO data).

The selected thresholds reflected the research team's judgment based on experience and reviews of previous research, especially NCHRP Report 966 (*7*).

The methodology documented in NCHRP Report 966 (*7*) was used to generate the SSL_17-76 values. To apply the this methodology, the research team used the calculation methods built into the analysis worksheets of NCHRP's SLS-Tool spreadsheet. This methodology yields a single suggested speed limit value for the speed zone of interest, unlike the SZM methodology developed by the research team, which yields a range of possible values.

The suggested speed limit methodologies were applied to each site-period using the following speed measures:

- Spd85_Onsite-Spd-R.
- Predicted 85th percentile speed based on Model Yr-3-1 using Spd85_AllHrAllDay_INRIX(YrData)

A prediction model was also used to calculate the average speed for use in NCHRP's SSL-Tool.

Results

Statutory speed limits of 75 or 80 mph were considered. Table 36 shows the percentage of freeway site-periods with a suggested speed limit based on the Spd85_Onsite-R speed measurement that was equivalent to the existing posted speed limit. The suggested speed limit was generally higher than the current existing posted speed limit except for those sites with a posted speed limit of 75 or 80 mph. Table 37 shows the results when a predicted speed based on the INRIX data, Spd85_AllHrAllDay_INRIX(YrData), was used. Table 38 compares the suggested speed limits generated based on the on-site data (Spd85_Onsite-R) versus the INRIX data (Spd85_AllHrAllDay_INRIX(YrData)). For 85 percent of the site-periods, the two speed measures generated the same suggested speed limit.

Table 36. Percentage of Freeway Site-Periods with Suggested Speed Limit Based on Spd85_Onsite-R Equivalent to Existing Posted Speed Limit.

R or U SSL	PSL=55	PSL=60	PSL=65	PSL=70	PSL=75	PSL=80
R: 55	**0%**	0%	0%	0%	0%	0%
R: 60	0%	**0%**	0%	0%	0%	0%
R: 65	0%	0%	**0%**	3%	3%	0%
R: 70	0%	0%	0%	**4%**	5%	0%
R: 75	0%	100%	100%	94%	**92%**	2%
R: 80	0%	0%	0%	0%	0%	**98%**
R Site-Periods (Total = 6119)	*0*	*224*	*286*	*758*	*4641*	*210*
U: 55	**0%**	3%	1%	0%	0%	0%
U: 60	1%	**20%**	5%	8%	0%	0%
U: 65	25%	30%	**1%**	26%	0%	0%
U: 70	40%	7%	2%	**11%**	12%	0%
U: 75	35%	40%	91%	56%	**88%**	1%
U: 80	0%	0%	0%	0%	0%	**99%**
U Site-Periods (Total = 5317)	*310*	*570*	*2057*	*865*	*950*	*565*

Note: R=rural. U=urban. SSL=suggested speed limit. PSL=posted speed limit. Values based on Spd85_Onsite-R. Highlighted and bolded cells indicate the same suggested and existing posted speed limits.

Table 37. Percentage of Freeway Site-Periods with Suggested Speed Limit Based on Pred-Spd85_AllHrAllDay_INRIX(YrData) Equivalent to Existing Posted Speed Limit.

R or U SSL	PSL=55	PSL=60	PSL=65	PSL=70	PSL=75	PSL=80
R: 55	**0%**	0%	0%	0%	0%	0%
R: 60	0%	**0%**	0%	0%	0%	0%
R: 65	0%	0%	**0%**	0%	0%	0%
R: 70	0%	0%	0%	**6%**	8%	0%
R: 75	0%	100%	100%	94%	**92%**	0%
R: 80	0%	0%	0%	0%	0%	**100%**
R Site-Periods (Total = 6119)	*0*	*224*	*286*	*758*	*4641*	*210*
U: 55	**0%**	5%	0%	0%	0%	0%
U: 60	0%	**5%**	0%	0%	0%	0%
U: 65	31%	42%	**6%**	45%	0%	0%
U: 70	0%	6%	0%	**1%**	13%	0%
U: 75	69%	42%	94%	54%	**87%**	0%
U: 80	0%	0%	0%	0%	0%	**100%**
U Site-Periods (Total = 5317)	*310*	*570*	*2057*	*865*	*950*	*565*

Note: R=rural. U=urban. SSL=suggested speed limit. PSL=posted speed limit. Values based on Spd85_Onsite-R. Highlighted and bolded cells indicate the same suggested and existing posted speed limits.

Table 38. Percentage of Freeway Site-Periods with Suggested Speed Limit Difference Based on Spd85_Onsite-R and Pred-Spd85_AllHrAllDay_INRIX(YrData) Equivalent to Existing Posted Speed Limit.

SSL Difference	PSL=55	PSL=60	PSL=65	PSL=70	PSL=75	PSL=80	Grand Total
R: 10	0%	0%	0%	0%	0%	0%	0%
R: 5	0%	0%	0%	0%	0%	0%	0%
R: 0	**0%**	**100%**	**100%**	**97%**	**97%**	**98%**	**97%**
R: 5	0%	0%	0%	3%	3%	2%	3%
R: 10	0%	0%	0%	0%	0%	0%	0%
R Site-Periods	*0*	*224*	*286*	*758*	*4641*	*210*	*6119*
U: 10	0%	0%	0%	2%	0%	0%	0%
U: 5	6%	5%	0%	10%	0%	0%	2%
U: 0	**59%**	**78%**	**91%**	**80%**	**100%**	**99%**	**88%**
U: 5	35%	17%	8%	8%	0%	1%	8%
U: 10	0%	0%	1%	0%	0%	0%	1%
U Site-Periods	*310*	*570*	*2057*	*865*	*950*	*565*	*5317*

Note: Difference in suggested speed limit between suggested speed limit based on Spd85_Onsite-R and suggested speed limit based on Pred-Spd85_AllHrAllDay_INRIX. Highlighted and bolded cells indicate the same suggested and existing posted speed limits.

TxDOT Speed Zone Factors Contributing to Lower Suggested Speed Limits

Table 39 provides an overview of how often a specific TxDOT speed zone factor caused a reduction in the suggested speed limit. Among the four factors evaluated, crash rate was most influential. The 85th percentile speed considered in the suggested speed limit was reduced by 12 mph for 14 percent of the site-periods reviewed.

Table 39. Number and Percentage of Freeway Site-Periods Influenced by TxDOT Speed Zone Factors.

Rural or Urban	Factor	No, Site-periods	Yes, Site-periods	Total, Site-periods	No, %	Yes, %	Total, %
Rural	Crash history	5,717	402	6,119	93%	7%	100%
Urban	Crash history	4,515	802	5,317	85%	15%	100%
Rural	Horizontal curves	6,071	48	6,119	99%	1%	100%
Urban	Horizontal curves	5,301	16	5,317	100%	0%	100%
Rural	Lack of striped, improved shoulders	6,119	0	6,119	100%	0%	100%
Urban	Lack of striped, improved shoulders	5,163	154	5,317	97%	3%	100%
Rural	Narrow roadway pavement widths	6,119	0	6,119	100%	0%	100%
Urban	Narrow roadway pavement widths	5,242	75	5,317	99%	1%	100%

Note: Sites were identified as Yes when the site's speed zone factor value indicated that the 85th percentile being considered should be reduced by 10 mph (or 12 mph for crash history), No otherwise.

CHAPTER 7: NON-FREEWAY TEST CASE

INRIX XD DATA/LOCATIONS AVAILABLE FOR TEST CASE EVALUATION

The non-freeway test case consisted of on-site speed data from the following three sources:

- Free-flow spot speed data collected as part of previous speed studies conducted by TxDOT districts.
- Tube speed binned data representing spot speeds collected during previous research studies.
- ATR speed data representing spot speeds collected at TxDOT ATR sites.

The research team aimed to match the spot speed data (measured at a point) to the INRIX speed data measured along a segment to assess the suitability of INRIX data for use in TxDOT speed zone studies. For each location with available on-site speed data (from ATRs, tubes, etc.), the site's geolocation (coordinates) was used as an important variable for matching the INRIX segment data. A site was removed from consideration if the speed data for the INRIX XD segment was not available.

More specifically, corresponding geo-coordinates (latitudes and longitudes) for sites with existing on-site speed data were used to determine if INRIX speed data were available. To extract the INRIX XD segment that corresponds to the study site, an INRIX XD segment shapefile was overlayed on the study site points. A 150-ft buffer was created, and all segments that intersected with the buffer were extracted. An additional check was performed to make sure that only the segments of interest were captured.

ON-SITE SPEED DATA

Free-Flow Spot Speed Data

The free-flow spot speed data were obtained from two sources: TxDOT Project 0-7049 the TxDOT Project 0-7156. Both of these projects collected speed data at various sites that spanned several districts. The spot speed studies obtained from TxDOT Project 0-7049 were performed in 2018 or 2019; earlier spot speed studies from this project were removed from consideration. The spot speed studies obtained from TxDOT Project 0-7156 were performed between 2019 and 2023. For a few of the spot speed studies, only the strip map rather than the tally sheet was available. This omission prevented researchers from being able to determine the exact day and time of speed data collection and subsequently match the INRIX speed data. These sites were not included in the time period matching analysis that matched the on-site speed data to the INRIX speed data. Table 40 lists the number of speed study sites with available spot speed data.

Table 40. Number of Sites with Spot Speed Data from TxDOT Speed Studies.

Raw Data Source	Project Source	Year	Sites for Matched Evaluation	Sites for Year Evaluation
Tally sheet	TxDOT 0-7156	2019	11	14
Tally sheet	TxDOT 0-7156	2021	22	30
Tally sheet	TxDOT 0-7156	2022	127	132
Tally sheet	TxDOT 0-7156	2023	46	48
Tally sheet	TxDOT 0-7156	**Subtotal**	**206**	**224**
Tally sheet	TxDOT 0-7049	2018	35	35
Tally sheet	TxDOT 0-7049	2019	18	18
Tally sheet	TxDOT 0-7049	**Subtotal**	**53**	**53**
Strip map	TxDOT 0-7156	2021	0	31
Strip map	TxDOT 0-7156	2022	0	21
Strip map	TxDOT 0-7156	2023	0	2
Strip map	TxDOT 0-7156	**Subtotal**	**0**	**54**
All speed studies	All	All	**259**	**331**

Tube Speed Data

The research team had access to tube speed data from two previous projects: NCHRP Project 17-76 (*7*) and TxDOT Project 0-7049 (*8*). The NCHRP study sites were along several Austin urban/suburban arterial and collector streets with posted speed limits between 30 and 40 mph. The TxDOT study sites had posted speed limits between 35 and 60 mph. In both cases, most of the speed data reflected the number of vehicles recorded within a given speed bin for a given hour. Each vehicle within a bin was randomly assigned a value according to a uniform distribution so that the resulting speed measure would represent a typical value. For example, if 50 vehicles existed within the speed bin of 25 to 29 mph, these vehicles would be randomly assigned a value of 25, 26, 27, 28, or 29 mph. Some sites had individual vehicle data; the data for these sites were converted to hourly speed measures and traffic volumes for consistency. For the TxDOT sites, the tube-based data were collected between March and April 2021, while the NCHRP data were collected in 2018.

ATR Speed Data

The research team used the ATR speed data as one of the on-site speed data sources because the data were collected using permanent sensors at a given spot on the road for an entire year. The research team processed the data to obtain the average and 85th percentile speeds. As indicated earlier, the research team determined the average and 85th percentile speeds using a random number (speed) generator. Following the procedure described in Chapter 5 under the Permanent Equipment: ATR section, the research team extracted only the ATR stations located along the non-freeways for this test case. The average and 85th percentile speeds from these ATR stations were matched to the extracted INRIX data.

VARIABLES AND DESCRIPTIVE STATISTICS

The assembled non-freeway database included several variables that could affect speed. Based on preliminary model development efforts, a subset of these variables was identified for later evaluations (Table 41). Table 42 and Table 43 provide summary statistics for the variables considered in the final models for rural and urban non-freeway sites, respectively.

Table 41. Variable Descriptions for Non-freeway Models.

Variable	**Description**
AADT/Lane_SiteCharRhino	Average annual daily traffic per lane
AvgLaneWidth_SiteChar	Average lane width (measured width of through lanes divided by number of through lanes)
Curb-1yes_SiteChar	Presence of curb and gutter (1 = Yes, 0 = Shoulder present)
DrvUsigPerMileBoth_Site Char	Driveways/unsignalized intersections per mile in both directions
K_FAC_RHINO	Peak factor (%)
Miles_INRIXSeg	Length of INRIX segment
RU_F_SYSTE_RHINO	Roadway functional class (R1 = Rural interstate, R2 = Rural other freeway and expressway, R3 = Rural other principal arterial, R4 = Rural minor arterial, R5 = Rural major collector, R6 = Rural minor collector, R7 = Rural local, U1 = Urban interstate, U2 = Urban other freeway and expressway, U3 = Urban other principal arterial, U4 = Urban minor arterial, U5 = Urban major collector, U6 = Urban minor collector, U7 = Urban local)
SigDen_SiteChar	Signal density (signals/mile)
Spd85_AllHrAllDay_INRIX-YrData	85^{th} percentile speed (mph) based on INRIX NAS168 file data (speed data 168 hours per week, by hour of day and day of week)
Spd85_Onsite-Spd-R	85^{th} percentile speed (mph) based on on-site data
SpdAve_All_INRIX-YrData	Average speed (mph) based on INRIX NAS168 file data (speed data for 168 hours per week, by hour of day and day of week)
SpdAve_Onsite-Spd-R	Average speed (mph) based on on-site data

Table 42. Summary Statistics for On-Site Speeds and Predictors at Rural Non-freeway Sites.

Variable	Variable Type	N	Minimum	Maximum	Mean	Standard Deviation
Spd85_Onsite-R	Numerical	9,325	42	88.0	76.9	5.4
Spd85_AllHrAllDay_INRIX -YrData	Numerical	9,325	39	75	70.3	4.0
SpdAve_Onsite-R	Numerical	9,325	37.9	82.3	70.3	5.4
SpdAve_All_INRIX-YrData	Numerical	9,325	35.1	72.4	66.6	4.2
SigDen_SiteChar	Numerical	9,325	0	2	0.05	0.18
DrvUsigPerMileBoth_Site Char	Numerical	9,325	0	30	3.9	5.1
AADT/Lane_SiteCharRhino	Numerical	9,325	5	6,406	1,982.9	834.5
AvgLaneWidth_SiteChar	Numerical	9,325	10	16	11.8	0.5
Curb-1yes_SiteChar	Dichotomous	9,325	0 (9,097), 1 (228)			
Miles_INRIXSeg	Numerical	9,325	0.24	0.98	0.64	0.14
K_FAC_RHINO	Numerical	9,325	6.8	23.5	10.1	2.1
RU_F_SYSTE_RHINO	Categorical	9,325	R3 (6,346), R4 (2,740), R5 (210), R6 (9), R7 (20)			

Notes: N denotes the number of non-missing values. For dichotomous variables, *1* indicates the presence of the feature and *0* indicates its absence. See Table 41 for description of variables.

Table 43. Summary Statistics for On-Site Speeds and Predictors at Urban Non-freeway Sites.

Variable	Variable Type	N	Minimum	Maximum	Mean	Standard Deviation
Spd85_Onsite-R	Numerical	3,489	29	85.5	59.1	10.3
Spd85_AllHrAllDay_INRIX -YrData	Numerical	3,489	20	73.2	51.0	11.6
SpdAve_Onsite-R	Numerical	3,489	22.7	78.6	52.8	9.9
SpdAve_All_INRIX-YrData	Numerical	3,489	16.6	70.3	46.8	11.9
SigDen_SiteChar	Numerical	3,489	0	13.7	1.3	2.2
DrvUsigPerMileBoth_Site Char	Numerical	3,489	0	151.7	17.3	20.5
AADT/Lane_SiteCharRhino	Numerical	3,489	31	10,134	2,629.6	1,050.5
AvgLaneWidth_SiteChar	Numerical	3,489	9.5	16.5	11.5	0.8
Curb-1yes_SiteChar	Dichotomous	3,489	0 (2,012), 1 (1,477)			
Miles_INRIXSeg	Numerical	3,489	0.15	0.99	0.61	0.18
K_FAC_RHINO	Numerical	3,489	5.4	24.3	10.1	2.4
RU_F_SYSTE_RHINO	Categorical	3,489	U3 (2,042), U4 (1,270), U5 (145), U7 (32)			

Notes: N denotes the number of non-missing values. For dichotomous variables, *1* indicates the presence of the feature and *0* indicates its absence. See Table 41 for description of variables.

FINDINGS

Match of Time Periods

Initial efforts were made to compare the available INRIX segment speeds to on-site spot speeds obtained from previous speed zone studies or research projects that collected tube or ATR data for the same time period. The speeds obtained from tubes or ATRs were filtered to represent free-flow conditions. The average INRIX speed was compared to the average free-flow speed. By matching the same time period for the INRIX and on-site data, confounding factors such as enforcement levels or pedestrian activity could be better controlled.

Several combinations of variables were explored during model development. The research team decided to focus on those variables that, in theory, would help convert a segment speed into a spot speed. Variables were discarded if they had counterintuitive signs (positive or negative) For example, higher numbers of signals should be associated with lower speeds.

The research team decided not to include posted speed limit in the model. Previous research has shown that including posted speed limit in a model to predict operating speed improves the model performance. However, operating speed also influences the selection of the posted speed limit for a roadway. To consider the overall characteristics of the roadway, the research team included a functional classification variable (RU_F_SYSTE_RHINO). This variable helped differentiate roadways with a more rural appearance (e.g., no shoulders, minimal development) from those roadways with a more urban appearance.

For the rural sites, Table 44 describes the overall fit of the model, and Table 45 details the parameter estimates for the selected model. For the urban sites, Table 46 describes the overall fit of the model, and Table 47 details the parameter estimates for the selected model.

Table 44. Summary of Fit for Rural Non-freeway Model Using Average Speed and Matched Time Periods (Model M-7-3).

Measure	Value
RSquare	0.715028
RSquare Adj	0.714721
Root Mean Square Error	2.877339
Mean of Response	70.29155
Observations (or Sum Wgts)	9,280
AIC	45,963.96
BIC	46,049.55

Table 45. Parameter Estimates for Rural Non-freeway Model Using Average Speed and Matched Time Periods (Model M-7-3).

Fixed Effects	Estimate	Standard Error	t-statistic	Prob>|t|
Intercept	16.027265	0.634208	25.27	<0.0001*
Ave.of.speed_INRIX-MatchTimePeriod	0.822949	0.007413	111.02	<0.0001*
SigDen_SiteChar	–2.78265	0.172667	–16.12	<0.0001*
DrvUsigPerMileBoth_Site Char	–0.248331	0.006466	–38.41	<0.0001*
AADT/Lane_SiteCharRhino	5.6252e-5	4.02e-5	1.40	0.1617
Curb-1yes_SiteChar	0.0679583	0.224128	0.30	0.7617
Miles_INRIXSeg	–1.290315	0.240085	–5.37	<0.0001*
K_FAC_RHINO	–0.07576	0.015532	–4.88	<0.0001*
RU_F_SYSTE_RHINO[R3]	1.3022184	0.241205	5.40	<0.0001*
RU_F_SYSTE_RHINO[R4]	0.2063205	0.239296	0.86	0.3886
RU_F_SYSTE_RHINO[R5]	–0.911869	0.274729	–3.32	0.0009*

Note: An asterisk (*) denotes statistical significance.

Table 46. Summary of Fit for Urban Non-freeway Model Using Average Speed and Matched Time Periods (Model M-7-3).

Measure	Value
RSquare	0.866281
RSquare Adj	0.865889
Root Mean Square Error	3.615218
Mean of Response	52.96131
Observations (or Sum Wgts)	3,415
AIC	18,482.01
BIC	18,555.55

Table 47. Parameter Estimates for Urban Non-freeway Model Using Average Speed and Matched Time Periods (Model M-7-3).

Fixed Effects	Estimate	Standard Error	t-statistic	Prob>|t|
Intercept	29.986434	0.635808	47.16	<0.0001*
Ave.of.speed_INRIX-MatchTimePeriod	0.6017244	0.009298	64.71	<0.0001*
SigDen_SiteChar	–0.649743	0.045327	–14.33	<0.0001*
DrvUsigPerMileBoth_Site Char	–0.018304	0.003354	–5.46	<0.0001*
AADT/Lane_SiteCharRhino	–0.00011	0.000069	–1.60	0.1096
Curb-1yes_SiteChar	–1.364247	0.214963	–6.35	<0.0001*
Miles_INRIXSeg	1.2121079	0.452223	2.68	0.0074*
K_FAC_RHINO	–0.452337	0.038929	–11.62	<0.0001*
RU_F_SYSTE_RHINO[U3]	–0.600726	0.235811	–2.55	0.0109*
RU_F_SYSTE_RHINO[U4]	1.8269059	0.231181	7.90	<0.0001*
RU_F_SYSTE_RHINO[U5]	0.6221568	0.371998	1.67	0.0945

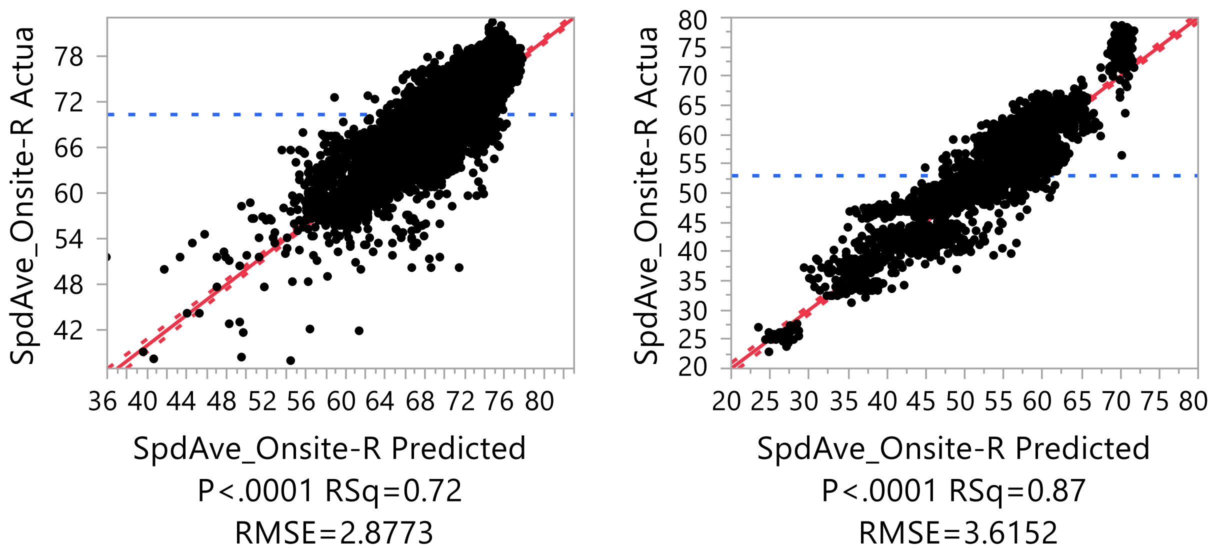
Note: An asterisk (*) denotes statistical significance.

For both urban and rural conditions, two of the three key variables anticipated to help convert a probe segment speed into a spot speed had the expected coefficient signs (positive or negative). For both urban and rural sites, SigDen_SiteChar and DrvUsigPerMileBoth_Site Char had logical coefficient signs. In each case, higher values for those variables were predicted to result in lower speeds.

In theory, as segment length increases, the likelihood that the segment speed is less than the spot speed increases. This phenomenon results from spot speed data collection locations being chosen to exclude roadway factors such as traffic control or access points that influence driver speed choice. The length of the segment (Miles_INRIXSeg) had different coefficient signs for rural (negative) and urban (positive). Reasons for this difference are not clear.

The K-factor may help convert a segment speed into a spot speed by accounting for vehicle volume peaking characteristics at a specific site. In both the urban and rural models, the K-factor had the expected coefficient sign. The AADT/Lane_SiteCharRhino variable may also help convert a probe speed to an on-site speed; however, the filtering (removal) of any on-site speed values with more than 250 vehicles per lane per hour likely blunted the value of this variable. In both the rural and urban models, this variable was not significant. The RU_F_Syste_Rhino variable helped account for differences in overall conditions for these different functional classifications.

Figure 15 illustrates the predicted speeds from the rural and urban models compared to the measured average speed. In both cases, the match appears to be good.



Rural **Urban**

Figure 15. Predicted Versus Actual SpedAve_Onsite-R for Rural and Urban Non-freeway Models Using Average Speed and Matched Time Periods (Model M-7-3).

Conversion of Yearly Data to 85th Percentile Value

As discussed in the previous section, several variables that were anticipated to help convert a segment speed to a spot speed had intuitive coefficients. These variables same were included in new models intended to help convert a segment speed measure from probe data that reflects an entire year to a spot speed measure that reflects about 1 hour of speed data.

For the rural sites, Table 48 describes the overall fit of the model, and Table 49 details the parameter estimates for the selected model.

Table 48. Summary of Fit for Rural Non-freeway Model Using 85th Percentile Speed (Model Yr-R-7-3).

Measure	Value
RSquare	0.727684
RSquare Adj	0.727333
Root Mean Square Error	2.815925
Mean of Response	76.89506
Observations (or Sum Wgts)	9,325
AIC	45,786.41
BIC	45,886.34

Table 49. Parameter Estimates for Rural Non-freeway Model Using 85th Percentile Speed (Model Yr-R-7-3).

Fixed Effects	Estimate	Standard Error	t-statistic	Prob>|t|
Intercept	9.6910152	0.948019	10.22	<0.0001*
Spd85_AllHrAllDay_INRIX-YrData	1.0212745	0.00918	111.24	<0.0001*
SigDen_SiteChar	–2.424099	0.166914	–14.52	<0.0001*
DrvUsigPerMileBoth_Site Char	–0.192001	0.00663	–28.96	<0.0001*
AADT/Lane_SiteCharRhino	0.0001054	3.922e-5	2.69	0.0072*
AvgLaneWidth_SiteChar	–0.34919	0.068522	–5.10	<0.0001*
Curb-1yes_SiteChar	–0.668602	0.219973	–3.04	0.0024*
Miles_INRIXSeg	–0.491492	0.238069	–2.06	0.0390*
K_FAC_RHINO	–0.076218	0.015519	–4.91	<0.0001*
RU_F_SYSTE_RHINO[R3]	1.4641188	0.244857	5.98	<0.0001*
RU_F_SYSTE_RHINO[R4]	1.1701795	0.239927	4.88	<0.0001*
RU_F_SYSTE_RHINO[R5]	–0.528482	0.278727	–1.90	0.0580

Note: An asterisk (*) denotes statistical significance.

For the urban sites, Table 50 describes the overall fit of the model, and Table 51 details the parameter estimates for the selected model.

Table 50. Summary of Fit for Urban Non-freeway Model Using 85th Percentile Speed (Model Yr-U-7-3).

Measure	Value
RSquare	0.881542
RSquare Adj	0.881201
Root Mean Square Error	3.55671
Mean of Response	59.11448
Observations (or Sum Wgts)	3,489
AIC	18,768.36
BIC	18,842.16

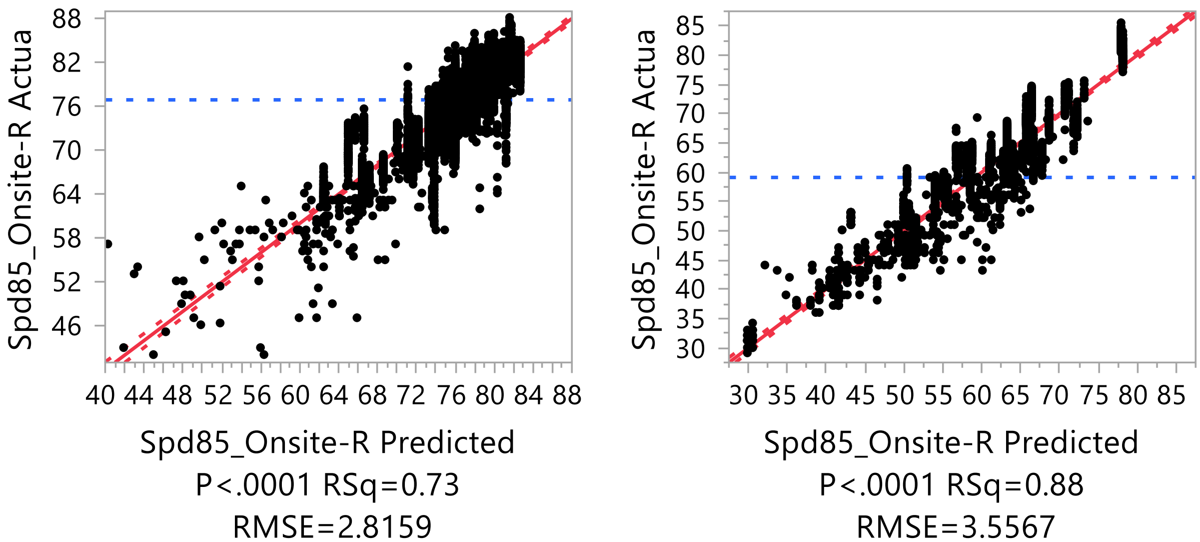
Table 51. Parameter Estimates for Urban Non-freeway Model Using for 85th Percentile Speed (Model Yr-U-7-3).

Fixed Effects	Estimate	Standard Error	t-statistic	Prob>|t|
Intercept	27.746304	1.212766	22.88	<0.0001*
Spd85_AllHrAllDay_INRIX-YrData	0.7737818	0.00925	83.65	<0.0001*
SigDen_SiteChar	–0.461219	0.049158	–9.38	<0.0001*
DrvUsigPerMileBoth_Site Char	–0.009492	0.003334	–2.85	0.0044*
AADT/Lane_SiteCharRhino	–0.000272	6.657e-5	–4.09	<0.0001*
AvgLaneWidth_SiteChar	–0.274323	0.0907	–3.02	0.0025*
Miles_INRIXSeg	–0.575033	0.441097	–1.30	0.1924
K_FAC_RHINO	–0.382147	0.03929	–9.73	<0.0001*
RU_F_SYSTE_RHINO[U3]	–0.108828	0.204432	–0.53	0.5945
RU_F_SYSTE_RHINO[U4]	2.1510743	0.204999	10.49	<0.0001*
RU_F_SYSTE_RHINO[U5]	1.2176352	0.291323	4.18	<0.0001*

Note: An asterisk (*) denotes statistical significance.

Figure 16 illustrates the predicted speeds from the rural and urban models compared to the measured average speed. In both cases, the match appears to be good, with root mean square errors of 2.8 and 3.6 mph for the rural and urban models, respectively.

Figure 17 illustrates the cumulative speed distribution curves for the on-site and INRIX speed data and the predicted speeds. Visually, the predicted speeds match the on-site speeds well for rural non-freeway corridors. For roadways in urban areas, some differences exist, especially between the 50 and 60 mph range.



Rural **Urban**

Figure 16. SpdAve_Onsite-R Predicted Versus SpedAve_Onsite_R Actual for Non-freeway Model Using 85th Percentile Speed (Model Yr-7-3).

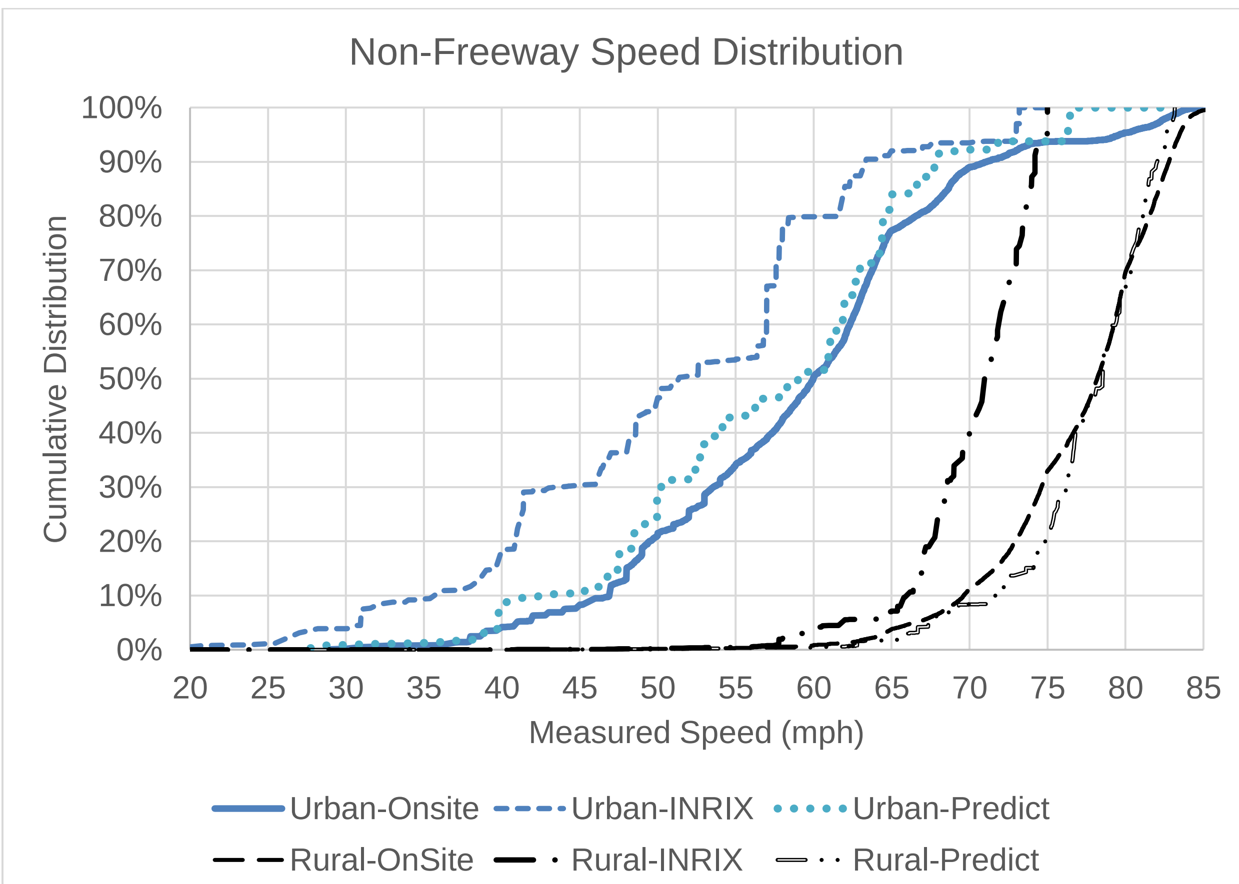


Figure 17. Speed Distributions Using On-Site and INRIX Speed Data and Predicted Values for Urban and Rural Non-freeway Sites.

Conversion of Yearly Data to Average Value

To use the NCHRP 17-76 SSL-Tool, average speeds were required. Therefore, additional models using average speed instead of 85^{th} percentile speed were developed to provide these predictions. For the rural sites, Table 52 describes the overall fit of the model, and Table 53 details the parameter estimates for the selected model.

Table 52. Summary of Fit for Rural Non-freeway Model Using Average Speed (Model Yr-7-3-Average).

Measure	Value
RSquare	0.714248
RSquare Adj	0.713909
Root Mean Square Error	2.898299
Mean of Response	70.27295
Observations (or Sum Wgts)	9,292
AIC	46,159.27
BIC	46,252.01

Table 53. Parameter Estimates for Rural Non-freeway Model Using Average Speed (Model Yr-7-3-Average).

Fixed Effects	Estimate	Standard Error	t-statistic	Prob>|t|
Intercept	7.5660247	0.972022	7.78	<0.0001*
SpdAve_All_INRIX-YrData	0.9737073	0.009207	105.75	<0.0001*
SigDen_SiteChar	–2.534899	0.174093	–14.56	<0.0001*
DrvUsigPerMileBoth_Site Char	–0.217971	0.006775	–32.17	<0.0001*
AADT/Lane_SiteCharRhino	6.9456e-5	4.05e-5	1.72	0.0864
AvgLaneWidth_SiteChar	–0.089474	0.071317	–1.25	0.2097
Curb-1yes_SiteChar[0]	0.2830251	0.11329	2.50	0.0125*
Miles_INRIXSeg	–0.558039	0.245573	–2.27	0.0231*
K_FAC_RHINO	–0.105323	0.015939	–6.61	<0.0001*
RU_F_SYSTE_RHINO[R3]	1.1465132	0.198712	5.77	<0.0001*
RU_F_SYSTE_RHINO[R4]	0.3639189	0.196076	1.86	0.0635
RU_F_SYSTE_RHINO[R5]	–1.214852	0.238232	–5.10	<0.0001*

Note: An asterisk (*) denotes statistical significance.

Similarly, for the urban sites, Table 54 describes the overall fit of the model, and Table 55 details the parameter estimates for the selected model.

Table 54. Summary of Fit for Rural Non-freeway Model Using Average Speed (Model Yr-7-3-Average).

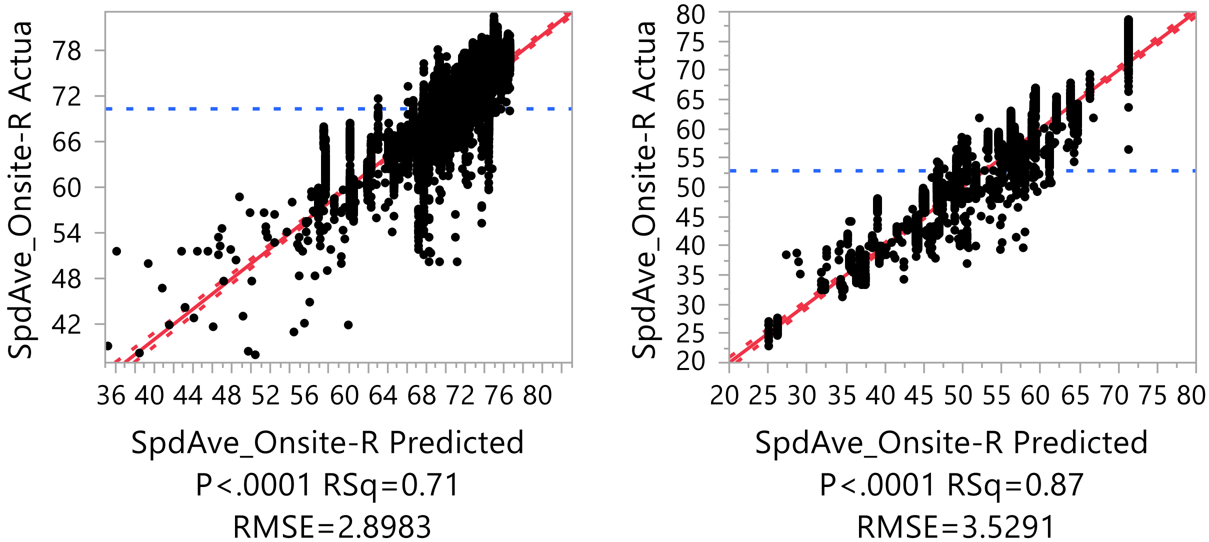
Measure	Value
RSquare	0.872459
RSquare Adj	0.87209
Root Mean Square Error	3.529054
Mean of Response	52.80511
Observations (or Sum Wgts)	3473
AIC	18628.13
BIC	18701.88

Table 55. Parameter Estimates for Rural Non-freeway Model Using Average Speed (Model Yr-7-3-Average).

Fixed Effects	Estimate	Standard Error	t-statistic	Prob>|t|
Intercept	28.92418	1.210032	23.90	<0.0001*
SpdAve_All_INRIX-YrData	0.7214956	0.008844	81.58	<0.0001*
SigDen_SiteChar	–0.440416	0.048596	–9.06	<0.0001*
DrvUsigPerMileBoth_Site Char	–0.014152	0.003309	–4.28	<0.0001*
AADT/Lane_SiteCharRhino	–0.000193	6.67e-5	–2.90	0.0038*
AvgLaneWidth_SiteChar	–0.397873	0.091738	–4.34	<0.0001*
Miles_INRIXSeg	1.0593201	0.440767	2.40	0.0163*
K_FAC_RHINO	–0.47978	0.039075	–12.28	<0.0001*
RU_F_SYSTE_RHINO[U3]	–0.854911	0.212498	–4.02	<0.0001*
RU_F_SYSTE_RHINO[U4]	1.7049728	0.213332	7.99	<0.0001*
RU_F_SYSTE_RHINO[U5]	1.9501183	0.302792	6.44	<0.0001*

Note: An asterisk (*) denotes statistical significance.

Figure 18 illustrates the predicted speeds from the urban and rural models compared to the measured average speed. In both cases, the match appears good, with root mean square errors of 2.9 and 3.5 mph for rural and urban non-freeway corridors, respectively.



Rural **Urban**

Figure 18. SpdAve_Onsite-R Predicted Versus SpedAve_Onsite_R Actual for Rural Non-freeway Model Using Average Speed (Model Yr-7-3-Average).

Conversion Equations

The modeling efforts produced a series of equations that can be used to convert INRIX segment speed data to 85th percentile and average spot speeds along rural and urban non-freeways. These conversion equations are described next.

Equation to Predict 85th Percentile Speed on Rural Non-freeways

The equation to predict the 85th percentile spot speed for a rural corridor using INRIX yearly speed is as follows:

$$\begin{aligned} \text{Spd85(RuralPredicted)} &= 9.6910 + 1.0213 \times \text{Spd85(YrDataINRIX)} - \\ &2.4241\ \text{SigDen} - 0.1920 \times \text{DrvUsigPerMileBoth} + 0.000101 \times \\ &\text{AADT/Lane} - 0.3492 \times \text{AvgLaneWidth} - 0.6686 \times \text{Curb(1yes)} - \\ &0.4915 \times Miles(INRIXseg) - 0.0762 \times KFAC + 1.4641 \times R3 + \\ &1.1702 \times R4 - 0.5285 \times R5 - 0.8189 \times R6 - 1.2869 \times R7 \end{aligned} \quad \text{Equation 5}$$

where:

Spd85(RuralPredicted)	=	Predicted 85th percentile speed (mph) for rural non-freeways
Spd85(YrDataINRIX)	=	85th percentile speed (mph) using non-zero INRIX XD hourly (daytime and nighttime) speed data for up to 8,760 hourly speed readings for the segment's year of interest
SigDen	=	Signals per mile for the corridor

DrvUsigPerMileBoth	=	Driveways and unsignalized intersections (both directions) per mile for the corridor
AADT/Lane	=	Average annual daily traffic per lane
AvgLaneWidth	=	Average lane width for the corridor
Curb(1yes)	=	Presence of curb and gutter within the corridor (1 = Yes, 0 = Otherwise)
Miles(INRIXSeg)	=	Number of miles for the INRIX segment
KFAC	=	Peak factor (%)
R3	=	Rural other principal arterial indicator (1 = Yes, 0 = Otherwise)
R4	=	Rural minor arterial indicator (1 = Yes, 0 = Otherwise)
R5	=	Rural major collector indicator (1 = Yes, 0 = Otherwise)
R6	=	Rural minor collector indicator (1 = Yes, 0 = Otherwise)
R7	=	Rural local indicator (1 = Yes, 0 = Otherwise)

Equation to Predict Average Speed on Rural Non-freeways

The equation to predict the average spot speed for a rural corridor using INRIX yearly speed is as follows:

$$\text{SpdAve(RuralPredicted)} = 7.5660 + 0.9737 \times \text{Spd85(YrDataINRIX)} - 2.5349\ \text{SigDen} - 0.2180 \times \text{DrvUsigPerMileBoth} + 0.000069 \times \text{AADT/Lane} - 0.0895 \times \text{AvgLaneWidth} - 0.2830 \times \text{Curb(1yes)} - 0.5580 \times Miles(INRIXseg) - 0.1053 \times KFAC + 1.1465 \times R3 + 0.3639 \times R4 - 1.2149 \times R5 - 0.0000 \times R6 - 0.2956 \times R7 \quad \text{Equation 6}$$

where:

SpdAve(RuralPredicted)	=	Predicted average speed (mph) for rural non-freeways
Spd85(YrDataINRIX)	=	85^{th} percentile speed (mph) using non-zero INRIX XD hourly (daytime and nighttime) speed data for up to 8,760 hourly speed readings for the segment's year of interest
SigDen	=	Signals per mile for the corridor
DrvUsigPerMileBoth	=	Driveways and unsignalized intersections (both directions) per mile for the corridor
AADT/Lane	=	Average annual daily traffic per lane
AvgLaneWidth	=	Average lane width for the corridor
Curb(1yes)	=	Presence of curb and gutter within the corridor (1 = Yes, 0 = Otherwise)
Miles(INRIXSeg)	=	Number of miles for the INRIX segment
KFAC	=	Peak factor (%)
R3	=	Rural other principal arterial indicator (1 = Yes, 0 = Otherwise)
R4	=	Rural minor arterial indicator (1 = Yes, 0 = Otherwise)
R5	=	Rural major collector indicator (1 = Yes, 0 = Otherwise)
R6	=	Rural minor collector indicator (1 = Yes, 0 = Otherwise)

R7	=	Rural local indicator (1 = Yes, 0 = Otherwise)

Equation to Predict 85th Percentile Speed on Urban Non-freeways

The equation to predict the 85th percentile spot speed for an urban corridor using INRIX yearly speed is as follows:

$$\text{Spd85(UrbanPredicted)} = 27.7463 + 0.7738 \times \text{Spd85(YrDataINRIX)} - 0.4612\ \text{SigDen} - 0.0095 \times \text{DrvUsigPerMileBoth} + 0.000271 \times \text{AADT/Lane} - 0.2743 \times \text{AvgLaneWidth} - 0.575 \times Miles(INRIXseg) - 0.3821 \times KFAC - 0.1088 \times U3 + 2.1511 \times U4 + 1.2176 \times U5 - 3.2599 \times U7 \quad \text{Equation 7}$$

where:

Spd85(UrbanPredicted)	=	Predicted 85th percentile speed (mph) for an urban non-freeway
Spd85(YrDataINRIX)	=	85th percentile speed (mph) using non-zero INRIX XD hourly (daytime and nighttime) speed data for up to 8,760 hourly speed readings for the segment's year of interest
SigDen	=	Signals per mile for the corridor
DrvUsigPerMileBoth	=	Driveways and unsignalized intersections (both directions) per mile for the corridor
AADT/Lane	=	Average annual daily traffic per lane
AvgLaneWidth	=	Average lane width for the corridor
Curb(1yes)	=	Presence of curb and gutter within the corridor (1 = Yes, 0 = Otherwise)
Miles(INRIXSeg)	=	Number of miles for the INRIX segment
KFAC	=	Peak factor (%)
U3	=	Urban other principal arterial (1 = Yes, 0 = Otherwise)
U4	=	Urban minor arterial (1 = Yes, 0 = Otherwise)
U5	=	Urban major collector (1 = Yes, 0 = Otherwise)
U7	=	Urban local (1 = Yes, 0 = Otherwise)

Equation to Predict Average Speed on Urban Non-freeways

The equation to predict the urban average spot speed for a corridor using INRIX yearly speed is:

$$\text{SpdAve(UrbanPredicted)} = 28.9242 + 0.7215 \times \text{Spd85(YrDataINRIX)} - 0.4404\ \text{SigDen} - 0.0014 \times \text{DrvUsigPerMileBoth} + 0.000193 \times \text{AADT/Lane} - 0.3979 \times \text{AvgLaneWidth} + 1.0593 \times Miles(INRIXseg) - 0.4798 \times KFAC - 0.8549 \times U3 + 1.7050 \times U4 + 1.9501 \times U5 - 2.8001 \times U7 \quad \text{Equation 8}$$

where:

SpdAve(UrbanPredicted)	=	Predicted average speed (mph) for urban non-freeways
Spd85(YrDataINRIX)	=	85th percentile speed (mph) using non-zero INRIX XD hourly (daytime and nighttime) speed data for up to 8,760 hourly speed readings for the segment's year of interest
SigDen	=	Signals per mile for the corridor
DrvUsigPerMileBoth	=	Driveways and unsignalized intersections (both directions) per mile for the corridor
AADT/Lane	=	Average annual daily traffic per lane
AvgLaneWidth	=	Average lane width for the corridor
Miles(INRIXSeg)	=	Number of miles for the INRIX segment
KFAC	=	Peak factor (%)
U3	=	Urban other principal arterial (1 = Yes, 0 = Otherwise)
U4	=	Urban minor arterial (1 = Yes, 0 = Otherwise)
U5	=	Urban major collector (1 = Yes, 0 = Otherwise)
U7	=	Urban local (1 = Yes, 0 = Otherwise)

Suggested Default Values for Equations to Predict Speed on Non-freeways

The research team developed suggested default values by considering the variable averages in the databases when developing the regression equations and applying engineering judgement. Table 56 lists these suggested default values for select variables.

Table 56. Suggested Default Values when Actual Values are Not Available or Difficult to Obtain for Non-freeway Corridors.

Variable	Urban	Rural
SigDen_SiteChar	1.3	0.1
DrvUsigPerMileBoth_Site Char	17.3	3.9
AADT/Lane_SiteCharRhino	2,600	2,000
AvgLaneWidth_SiteChar	11.5	11.8
K_FAC_RHINO	10.1	10.1
RU_F_SYSTE_RHINO	U3	R3
Curb-1yes_SiteChar	No suggestion needed/not in model	0

Assessment of Equations to Predict Speed on Non-freeways

Table 57 presents a summary of statistical measures for assessing the prediction accuracy of the non-freeway equations. The two statistical measures that are used include the adjusted R-squared and the root mean square error. According to the summary in Table 57, the adjusted R-squared values for the regression equations ranged from 0.71 to 0.89, which indicate that the independent variables used in the models explain between 71 and 89 percent of the variability in the observed speed. The implication is that the developed models will generate a reasonably predicted speed. Further, the values for the root mean square error range from 2.8 to 3.5 mph. These values imply that, on average, the predicted speeds are off by 2.8 to 3.5 mph. These differences are lower than the suggested incremental speed limits (5 mph) but high enough to potentially affect the outcome of the speed zone study. These results support the use of probe speed data via a predicted speed in a speed zone study. However, because the predicted speed may result in a different suggested speed limit (by 5 mph), some caution needs to be exercised when using the predicted speed rather than a measured on-site speed in a speed zone study.

Table 57. Summary of Statistical Measures for Non-freeway Equations.

Context (Urban or Rural)	Measure	Adjusted R-squared	Root Mean Square Error
Rural	85th Percentile	0.7273	2.82
Rural	Average	0.7139	2.90
Urban	85th Percentile	0.8812	3.56
Urban	Average	0.8721	3.53

Suggested Speed Limits

Inputs

The research team used the following methodologies to identify a suggested speed limit for each site-period:

- TxDOT SZM for upper and lower levels.
- NCHRP's SLS-Tool developed in Project 17-76 and described in Report 966 (*7*).

The suggested speed limit methodologies produced three suggested speed limits:

- SSL_SZM_Lower represents the suggested speed limit using TxDOT's SZM when speed limits are lower because one or more of the SZM criteria are met.
- SSL_SZM_Upper represents the suggested speed limit using TxDOT's SZM when assuming none of the SZM criteria are met.
- SSL_17-76 represents the suggested speed limit using the NCHRP's SSL-Tool.

Rounding the 85th percentile speed to the nearest 5-mph increment generated the SSL_SZM_Upper value. For the non-freeway sites, the research team used various thresholds to determine when the 85th percentile speed should be reduced by 10 mph (or 12 mph based on crash history) to generate the SSL_SZM_Lower value. For sites considered to be in an urban (developed) area, the following thresholds were used:

- Narrow roadway pavement widths (i.e., average lane widths of less than 11 ft).
- Excessive horizontal curves (proportion of speed zone length that contains curves with radii less than 750 ft exceeds 0.2).
- High driveway densities (i.e., driveway density exceeds 25 driveways per mile).
- Lack of striped, improved shoulders (i.e., no paved shoulders or shoulder widths of less than 2 ft). If curb and gutter was present, the speed was not lowered.

- High crash history (i.e., rate of KABCO or KABC crashes in the speed zone of interest exceeds relevant statewide average rate computed by Fitzpatrick et al. (*6*) using 2019 CRIS and RHiNO data).

For sites considered to be in a rural (undeveloped) area, the following thresholds were used:

- Narrow roadway pavement widths (i.e., average lane widths of less than 11 ft.)
- Excessive horizontal curves (i.e., proportion of speed zone length that contains curves with radii less than 750 ft exceeds 0.2).
- High driveway density (i.e., driveway density exceeds 15 driveways per mile).
- Lack of striped, improved shoulders (i.e., no paved shoulders or shoulder widths of less than 4 ft for a dived roadway, 8 ft otherwise). If curb and gutter was present, the speed was not lowered.
- High crash history (i.e., rate of KABCO or KABC crashes in the speed zone of interest exceeds relevant statewide average rate computed by Fitzpatrick et al. (*6*) using 2019 CRIS and RHiNO data).

Table 58 summarizes these threshold assumptions. The selected thresholds reflected the research team's judgment based on experience and reviews of previous research, especially NCHRP Report 966 (*7*). Further examination of appropriate thresholds has been identified as a research need. For example, the driveway density threshold could also be influenced by the type of driveways along the corridor. The potential for encountering entering and turning vehicles is considered within the high driveway density factor; however, the SZM does not provide advice on the levels of driveway density that should trigger the consideration of lowering the speed limit or how to count driveways.

Research has demonstrated that driveway types and quantities have different effects on safety. The *Highway Safety Manual* (HSM) (*36*), published by the American Association of State Highway Transportation Officials, defines seven different driveway types to be counted for the purpose of applying the safety prediction models for urban and suburban arterials. These driveway types are defined based on land use and parking lot size and include major commercial, minor commercial, major industrial-institutional, minor industrial-institutional, major residential, minor residential, and other. Major driveways are defined as having more than 50 parking spaces, while minor driveways are defined as having fewer than 50 parking spaces. The HSM crash prediction models require the inputs of driveway count or density by type. HSM models that are calibrated using Texas crash data are available, along with calibrated spreadsheet tools to facilitate implementation of the models (*37*). A 2014 paper by Williamson and Zhou (*38*) compared the mean crash frequency and crash rates among different driveways for a selection of sites in Illinois. The results showed that driveways with access to commercial property with a drive-through, such as a fast-food restaurant, have the highest crash rates. The second highest crash rates occurred for commercial properties followed by industrial-institutional properties. Residential driveways had the lowest crash rates among all types tested in the study.

Table 58. Threshold Assumptions by Number of Lanes and Median Type Based on TxDOT Speed Zone Method Factors.

Factors	Variable	Lanes and Median Abbreviation	Undeveloped Threshold	Developed Threshold
Narrow pavement	Minimum lane width (ft)	2	11	11
Narrow pavement	Minimum lane width (ft)	MD	11	11
Narrow pavement	Minimum lane width (ft)	MU	11	11
Narrow pavement	Minimum lane width (ft)	OW	NA	11
Curves	Percent of segment length	2	20	20
Curves	Percent of segment length	MD	20	20
Curves	Percent of segment length	MU	20	20
Curves	Percent of segment length	OW	NA	20
Driveways	Density per mile	2	15	25
Driveways	Density per mile	MD	15	25
Driveways	Density per mile	MU	15	25
Driveways	Density per mile	OW	NA	25
Shoulders	Minimum width (ft)	2	8	2
Shoulders	Minimum width (ft)	MD	4	2
Shoulders	Minimum width (ft)	MU	8	2
Shoulders	Minimum width (ft)	OW	NA	2

Note: 2 = 2 lanes, MD = Multilane divided, MU = Multilane undivided, and OW = One-way traffic.

The methodology documented in NCHRP Report 966 (*7*) was used to generate the SSL_17-76 values. This methodology required identifying whether the site was in an area considered to be developed or undeveloped. If the posted speed limit was 50 mph or less, the site was considered to be in a developed area. The suggested speed limit methodologies were applied to each site-period using the following speed measures:

- Spd85_Onsite-Spd-R.
- Predicted 85th percentile speed based on Model Yr-7-3 using Spd85_AllHrAllDay_INRIX(YrData).

A prediction model was also used to calculate the average speed for use in NCHRP's SSL-Tool.

Results

A statutory speed limit of 75 mph was assumed for both non-freeway and freeway conditions except when the existing posted speed limit was 80 or 85 mph. In such cases (always associated with freeways), the assumed statutory speed limit was 80 or 85. Table 59 shows the percentage of non-freeway site-periods with a suggested speed limit based on the Spd85_Onsite-R speed measurement that was equivalent to the existing posted speed limit. The suggested speed limit was both higher and lower than the current existing posted speed limit except for those sites with a posted speed limit of 75 mph. Table 60 shows the results when a predicted speed based on the INRIX data, Spd85_AllHrAllDay_INRIX(YrData), was used. Table 61 compares the suggested speed limits generated based the on-site data (Spd85_Onsite-R) versus the INRIX data (Spd85_AllHrAllDay_INRIX(YrData)). For 86 percent of the rural site-periods, the two speed measures generated the same suggested speed limit. This same equivalency was observed for only 42 percent of the urban site-periods. For the urban site-periods, 93 percent of the site periods had suggested speed limits within 5 mph.

Table 59. Percentage of Non-freeway Site-Periods with Suggested Speed Limit Based on Spd85_Onsite-R Equivalent to Existing Posted Speed Limit.

R or U SSL	PSL= 30	PSL= 35	PSL= 40	PSL= 45	PSL= 50	PSL= 55	PSL= 60	PSL= 65	PSL= 70	PSL= 75
R: 30	**0%**	0%	50%	10%	0%	0%	0%	0%	0%	0%
R: 35	0%	**0%**	50%	10%	7%	0%	0%	0%	0%	0%
R: 40	0%	0%	**0%**	60%	11%	0%	0%	0%	0%	0%
R: 45	0%	0%	0%	**20%**	7%	3%	1%	0%	0%	0%
R: 50	0%	0%	0%	0%	**4%**	6%	5%	1%	0%	0%
R: 55	0%	0%	0%	0%	7%	**3%**	1%	1%	0%	0%
R: 60	0%	0%	0%	0%	7%	2%	**0%**	4%	0%	0%
R: 65	0%	0%	0%	0%	0%	42%	2%	**28%**	0%	0%
R: 70	0%	0%	0%	0%	7%	30%	25%	35%	**25%**	2%
R: 75	0%	0%	0%	0%	51%	14%	65%	32%	75%	**98%**
R Site-Periods (Total = 9325)	*0*	*0*	*2*	*10*	*45*	*406*	*470*	*815*	*1849*	*5728*
U: 30	**62%**	0%	0%	0%	0%	0%	0%	0%	0%	0%
U: 35	7%	**23%**	1%	0%	0%	0%	0%	0%	0%	0%
U: 40	28%	31%	**9%**	2%	0%	0%	0%	0%	0%	0%
U: 45	3%	5%	64%	**47%**	7%	0%	0%	0%	0%	0%
U: 50	0%	40%	27%	50%	**20%**	0%	0%	0%	0%	0%
U: 55	0%	1%	0%	2%	5%	**2%**	1%	0%	0%	0%
U: 60	0%	0%	0%	0%	10%	8%	**2%**	0%	0%	0%
U: 65	0%	0%	0%	0%	52%	15%	0%	**13%**	0%	0%
U: 70	0%	0%	0%	0%	6%	27%	29%	43%	**0%**	0%
U: 75	0%	0%	0%	0%	0%	34%	24%	21%	0%	**0%**
U Site-Periods (Total = 3489)	*29*	*336*	*270*	*405*	*100*	*1743*	*327*	*53*	*9*	*217*

Note: Highlighted and bolded cells indicate the same suggested and existing posted speed limits. R=rural. U=urban. SSL=suggested speed limit. PSL=posted speed limit.

Table 60. Percentage of Non-freeway Site-Periods with Suggested Speed Limit Based on Pred-Spd85_AllHrAllDay_INRIX(YrData) Equivalent to Existing Posted Speed Limit.

R or U: SSL*	PSL= 30	PSL= 35	PSL= 40	PSL= 45	PSL= 50	PSL= 55	PSL= 60	PSL= 65	PSL= 70	PSL= 75
R: 30	**0%**	0%	50%	10%	4%	0%	0%	0%	0%	0%
R: 35	0%	**0%**	50%	30%	4%	0%	0%	0%	0%	0%
R: 40	0%	0%	**0%**	0%	0%	0%	0%	0%	0%	0%
R: 45	0%	0%	0%	**20%**	9%	1%	0%	0%	0%	0%
R: 50	0%	0%	0%	30%	**13%**	6%	2%	0%	0%	0%
R: 55	0%	0%	0%	10%	2%	**4%**	6%	1%	0%	0%
R: 60	0%	0%	0%	0%	0%	0%	**0%**	4%	0%	0%
R: 65	0%	0%	0%	0%	9%	43%	43%	**1%**	0%	0%
R: 70	0%	0%	0%	0%	0%	20%	1%	46%	**15%**	0%
R: 75	0%	0%	0%	0%	58%	25%	48%	49%	85%	**99%**
R Site-Periods (Total = 9325)	*0*	*0*	*2*	*10*	*45*	*406*	*470*	*815*	*1849*	*5728*
U: 30	**62%**	0%	0%	0%	0%	0%	0%	0%	0%	0%
U: 35	0%	**3%**	0%	0%	0%	0%	0%	0%	0%	0%
U: 40	7%	18%	**2%**	0%	0%	0%	0%	0%	0%	0%
U: 45	31%	55%	15%	**0%**	2%	0%	0%	0%	0%	0%
U: 50	0%	24%	56%	33%	**4%**	0%	0%	0%	0%	0%
U: 55	0%	0%	26%	63%	11%	**1%**	0%	0%	0%	0%
U: 60	0%	0%	0%	1%	8%	3%	**1%**	0%	0%	0%
U: 65	0%	0%	0%	1%	56%	8%	1%	**0%**	0%	0%
U: 70	0%	0%	0%	0%	4%	25%	1%	0%	**0%**	0%
U: 75	0%	0%	0%	0%	13%	31%	25%	57%	0%	**0%**
U Site-Periods (Total = 3489)	*29*	*336*	*270*	*405*	*100*	*1743*	*327*	*53*	*9*	*217*

Note: Highlighted and bolded cells indicate the same suggested and existing posted speed limits. R=rural. U=urban. SSL=suggested speed limit. PSL=posted speed limit.

Table 61. Percentage of Non-freeway Site-Periods with Suggested Speed Limit Difference Based on Spd85_Onsite-R and Pred-Spd85_AllHrAllDay_INRIX(YrData) Equivalent to Existing Posted Speed Limit.

R or U: SSL Diff	PSL = 30	PSL = 35	PSL = 40	PSL = 45	PSL = 50	PSL = 55	PSL = 60	PSL = 65	PSL = 70	PSL = 75	Total
R: 20	0%	0%	0%	0%	2%	0%	0%	0%	0%	0%	0%
R: 15	0%	0%	0%	20%	4%	0%	0%	2%	0%	0%	0%
R: 10	0%	0%	0%	20%	4%	1%	0%	4%	0%	0%	1%
R: 5	0%	0%	50%	20%	16%	20%	5%	39%	16%	2%	9%
R: 0	**0%**	**0%**	**0%**	**0%**	**60%**	**74%**	**53%**	**50%**	**79%**	**98%**	**86%**
R: 5	0%	0%	50%	30%	7%	4%	25%	5%	6%	0%	3%
R: 10	0%	0%	0%	10%	4%	0%	17%	0%	0%	0%	1%
R: 15	0%	0%	0%	0%	2%	0%	0%	0%	0%	0%	0%
R Site-Periods	*0*	*0*	*2*	*10*	*45*	*406*	*470*	*815*	*1849*	*5728*	*9325*
U: 15	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
U: 10	0%	0%	0%	2%	10%	1%	0%	0%	0%	0%	1%
U: 5	0%	20%	11%	43%	23%	13%	11%	34%	0%	0%	16%
U: 0	**34%**	**17%**	**67%**	**22%**	**14%**	**35%**	**78%**	**64%**	**22%**	**100%**	**42%**
U: 5	66%	38%	21%	31%	51%	44%	10%	2%	78%	0%	34%
U: 10	0%	24%	0%	1%	2%	7%	1%	0%	0%	0%	6%
U: 15	0%	0%	0%	0%	0%	1%	0%	0%	0%	0%	0%
U Site-Periods	*29*	*336*	*270*	*405*	*100*	*1743*	*327*	*53*	*9*	*217*	*3489*

Note: Highlighted and bolded cells indicate the same suggested and existing posted speed limits. Difference in suggested speed limit between suggested speed limit based on Spd85_Onsite-R and suggested speed limit based on Pred-Spd85_AllHrAllDay_INRIX(YrData)..

TxDOT Factors Contributing to Lower Suggested Speed Limits

Table 62 provides an overview of how often a specific TxDOT speed zone factor caused a reduction in the suggested speed limits for non-freeway urban (developed) and rural (non-developed) sites. Among the five factors evaluated, driveway density and lane width were most influential, although crashes also affected 14 percent of the site-periods. For the undeveloped sites, a lack of shoulders influenced the 85th percentile speed adjustment the most.

Table 62. Number and Percentage of Non-freeway Site-Periods Influenced by TxDOT Speed Zone Factors.

Roadside Environment	Factor	No, Site-Periods	Yes, Site-Periods	Total, Site-Periods	No, %	Yes, %	Total, %
Developed	Lane width	2,845	644	3,489	82%	18%	100%
Developed	Horizontal curves	3,489	0	3,489	100%	0%	100%
Developed	Driveway density	2,622	867	3,489	75%	25%	100%
Developed	Shoulders	3,386	103	3,489	97%	3%	100%
Developed	Crash history	2,571	918	3,489	74%	26%	100%
Undeveloped	Lane width	9,263	62	9,325	99%	1%	100%
Undeveloped	Horizontal curves	9,325	0	9,325	100%	0%	100%
Undeveloped	Driveway density	8,890	435	9,325	95%	5%	100%
Undeveloped	Shoulders	8,852	473	9,325	95%	5%	100%
Undeveloped	Crash history	9,259	66	9,325	99%	1%	100%

Note: Sites were identified as Yes when the site's speed zone factor value indicated that the 85^{th} percentile being considered should be reduced by 10 mph (or 12 mph for crash history), No otherwise.

CHAPTER 8: SUMMARY OF FINDINGS, CONCLUSIONS, AND RECOMMENDATIONS

OVERVIEW

Speed limits are among the most visible and routinely enforced traffic control devices motorists encounter in their everyday driving. Speed limits can be set by state law or via engineering speed zone studies. When set via an engineering speed zone study, the operating speed for a site is needed. Currently, operating speeds are obtained in the field where at least 125 free-flowing passenger car speeds are measured. This research project investigated how to make speed zone studies and speed zone decisions more effective and efficient. Databases were developed to explore the use of speeds measured by probes rather than speeds measured in the field for freeway and for non-freeway facilities. As part of the test case evaluations (discussed in Chapter 6 and Chapter 7), the research team applied TxDOT's *Procedures for Establishing Speed Zones* (*2*) methodology to identify appropriate suggested speed limits.

SUMMARY OF FINDINGS

This research project was designed to investigate whether quality data were available for conducting region-wide (rather than single location) speed zone studies. The key findings from this effort follow.

Probe Speed Data

Navigation systems are now standard equipment in many cars or are available via phone apps such as Waze or Google Maps. This greater use of in-vehicle navigation systems, which are reliant on probe data for navigation, demonstrates a general acceptance by the public for the use and accuracy of probe speed data. Whether the accuracy of probe speed data is sufficient for use in a speed zone study was a research question for this project.

This research project used INRIX speed data (now routinely purchased by TxDOT) to evaluate the usefulness of probe data for speed limit studies. Several speed measures are available, such as FFspd (the free-flow mean speed representing the 66^{th} percentile of the 168 hourly speed bins at a given location for the week) and SpdXX (the average speed for a given hour of the day corresponding to XX, where XX is a number from 00 to 23). The research team decided to calculate an INRIX speed measure that represented an entire year rather than focusing on a single hour.

Conversion Equations for Probe Speed Data

The use of probe speed data requires the development of equations that convert an average yearly speed measure into a speed measure representing free-flow conditions for passenger cars. The research team created two databases (freeways and non-freeways) that allowed for comparisons between on-site speed measures (that represent free-flow vehicles) and average annual probe speed data. The analyses were subdivided into rural and urban settings. The goal was to develop regression equations that could convert a probe speed to a predicted speed based on roadway and segment characteristics. The predicted speed would then be used in a TxDOT speed zone study. The following conversion equations were developed (as provided in Chapter 6 and Chapter 7 of this report):

- Equation 1 to predict 85^{th} percentile speed on rural freeways.
- Equation 2 to predict average speed on rural freeways.
- Equation 3 to predict 85^{th} percentile speed on urban freeways.
- Equation 4 to predict average speed on urban freeways.
- Equation 5 to predict 85^{th} percentile speed on rural non-freeways.
- Equation 6 to predict average speed on rural non-freeways.
- Equation 7 to predict 85^{th} percentile speed on urban non-freeways.
- Equation 8 to predict average speed on urban non-freeways.

Prediction Equation Quality

The two statistical measures that are used to describe the quality of the prediction equations include the adjusted R-squared and the root mean square error. Hypothetically, the adjusted R-squared values range from 0 to 1; a value of 0 means that the independent, explanatory variables have no explanatory power, while a value of 1 means the explanatory variables perfectly explain the variability in the dependent variable. The root mean square error provides an appreciation of the potential magnitude of the difference between the observed and predicted speeds. The minimum value for the root mean square error is 0, which implies that the independent variables perfectly explain the variabilities in the dependent variable.

For freeways, the adjusted R-squared values for the regression equations (Adj_Rsq ME) range from 0.77 to 0.92, indicating that the independent variables used in the models can explain between 77 and 92 percent of the variability in the observed speed. The implication is that the developed models will generate a reasonably predicted speed. Further, the values for the root mean square error range from 2.6 to 2.9 mph. These values imply that, on average, the predicted speeds are off by 2.6 to 2.9 mph, which are lower than the suggested incremental speed limits (5 mph).

For non-freeway facilities, the adjusted R-squared for the regression equations range from 0.71 to 0.89, indicating that the independent variables used in the models can explain between 71 and 89 percent of the variability of the observed speed. The implication again is that the developed models will generate a reasonably predicted speed. Further, the values for the root mean square error range from 2.8 to 3.5 mph. These values imply that, on average, the predicted speeds are off by 2.8 to 3.5 mph. These values are lower than the suggested incremental speed limits

(5 mph) but high enough to potentially affect the outcome of the speed zone study. These results support the use of probe speed data via a predicted speed in a speed zone study. However, because the predicted speed may result in a different suggested speed limit (by 5 mph), some caution should be exercised when using the predicted speed rather than a measured on-site speed in a speed zone study.

Suggested Speed Limits Based on Predicted and On-Site Speeds

The research team used the speed zone methodology to independently generate suggested speed limits using on-site and predicted speed data based on probe speed data. To compare the results between on-site and predicted speed data, the suggested speed limit for on-site was subtracted from the suggested speed limit for predicted speed. A 0 result indicates that the speed predicted using the equations developed in this research project generated the same suggested speed limit as the value that would be suggested using on-site data. For the freeway test case, 97 percent of the rural study sites and 88 percent of the urban study sites had the same suggested speed limit when using either the on-site speed data or the predicted speed data. The rural non-freeway test case also had a high match of 86 percent. The urban non-freeway test case did not have as high of a match; only 42 percent of the study sites generated the exact same suggested speed limit. When the range was expanded to be within 5 mph, 93 percent of the study sites were included.

CONCLUSIONS

This research project was designed to investigate whether quality probe speed data were available for use in speed zone studies and, if so, whether it generates suggested speed limits that are similar to those suggested based on speed data collected on site. Currently, probe speed data can be used within the prediction equations developed in this research. When used in the TxDOT speed zone method, the calculated predicted speeds resulted in suggested speed limits that were similar to the suggested speed limit identified using on-site speed data or generally within 5 mph.

RECOMMENDATIONS FOR FUTURE RESEARCH

Suggestions for future research include the following:

- Apply the proposed protocol to a select region and review the findings to determine if the results are defensible. This effort would require identifying the existing speed limits for all roads being considered in the analysis. In addition, the speed zone limits as compared to the INRIX segments would need to be identified. When the existing speed zone limits for a site include several INRIX segments, researchers must decide whether to average the findings from all relevant INRIX segments or review and possibly remove certain INRIX segments (i.e., when an INRIX segment is essentially an intersection). Other similar details regarding implementation of this methodology would need to be identified and considered to result in a protocol that could be effectively used by TxDOT.

- Apply the protocol to a select region and review the findings to explain variations in results and determine whether they can be compensated.
- Explore the thresholds used to identify when to lower the 85th percentile speed within the speed-setting procedure. For this project, the research team used their engineering judgment; however, these assumptions could be improved through discussions with TxDOT staff who are performing speed zone studies.

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