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Analysis of the Shoulder Widening Need on the State Highway System: Technical Report

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16. Abstract

In many rural Texas areas, pedestrians and cyclists have limited trip options and so these travelers often use rural low-speed highways. If these corridors do not have adequate roadway shoulders available, the pedestrians and cyclists cannot travel on the shoulder and instead must occupy an active travel lane. Consequently, the overall objective of this project was to define the criteria for roadway shoulder suitability for pedestrians and bicycles, apply these criteria to Texas highways to determine candidate locations that merit shoulder improvements, identify high use or high demand locations, and develop a candidate list of potential target locations, coupled with the suitability criteria, to be incorporated into a Strategic Corridor Development Plan.

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ANALYSIS OF THE SHOULDER WIDENING NEED ON THE STATE HIGHWAY SYSTEM: TECHNICAL REPORT

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DISCLAIMER

This research was performed in cooperation with the Texas Department of Transportation (TxDOT) and the Federal Highway Administration (FHWA). The contents of this report reflect the views of the authors, who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official view or policies of the FHWA or TxDOT. This report does not constitute a standard, specification, or regulation.

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LIST OF ABBREVIATIONS AND ACRONYMS

Abbreviation or Acronym	Description
AADT	Annual Average Daily Traffic
AASHTO	American Association of State Highway and Transportation Officials
ADT	Average Daily Traffic
CRIS	Crash Records Information System
FHWA	Federal Highway Administration
GIS	Geographic Information System
HCM	Highway Capacity Manual
LOS	Level of Service
NB	Negative Binomial
NCHRP	National Cooperative Highway Research Program
NHTS	National Household Travel Survey
PHini	Pavement Highway Inventory System
RHiNo	Roadway-Highway Inventory Network
ROR	Run-off-road
SVM	Support Vector Machine
SVR	Support Vector Regression
TRB	Transportation Research Board
TxDOT	Texas Department of Transportation
vpd	Vehicles per day

CHAPTER 1. INTRODUCTION

As land development expands into rural areas, pedestrian and bicycle activity increases. It is unlikely that these increased volumes of pedestrians and bicycles were anticipated when many of the highways were originally designed. The shoulders along these rural corridors may not be of suitable quality or widths to safely accommodate this growing activity. One option at these locations is for the pedestrians and bicycles to share the roadway travel lanes; however, this shared lane use introduces substantial speed differentials with motor vehicles. There is a need to systematically establish priorities for improving the safety of all road users, with particular attention to the more vulnerable pedestrians and bicyclists.

One way to accomplish this objective is for a transportation agency to perform cost-effective shoulder improvements along lower volume, higher speed highways located in close proximity to urbanized areas. This report reviews candidate suitability criteria for these rural shoulders, summarizes additional evaluations to assess these locations, and provides a statistically derived recommendation for reconsidering the width of many rural shoulders located along rural two-lane or multilane roadway corridors.

This report includes a literature review (Chapter 2) of published literature that focuses on the various suitability criteria considered during a variety of research efforts. Chapter 2 also summarizes a state-of-the-practice that documents what many other states consider when establishing these suitability thresholds.

Chapter 3 identifies the candidate data collection elements including database assembly and site selection. Chapter 4 includes the detailed analysis of these data. Chapter 5 summarizes the resulting suitability and recommended future research.

Appendix A lists individual state documents included in the state-of-the-practice review summary. Appendix B provides a brief overview of support vector regression (SVR). The project team used this methodology to develop a prediction model for non-motorized trips in rural environments. Appendix C includes a Strategic Corridor Plan that demonstrates how the Texas Department of Transportation (TxDOT) can use the suitability criteria and a six-step process to prioritize candidate improvement corridors for shoulder improvements in these regions with non-motorized user trips.

CHAPTER 2. LITERATURE REVIEW AND STATE-OF-PRACTICE

As land development expands into rural areas, pedestrian and bicycle activity increases. It is unlikely that these increased volumes of pedestrians and bicycles were anticipated when many of the highways were originally designed. The shoulders along these rural corridors may not be of suitable quality or widths to safely accommodate this growing activity. Most roadways are accessible to bicyclists where they share the outside lane with motor vehicles; however, this shared lane may not be appropriate when the bicyclists' travel speed is substantially lower than that of motor vehicles traversing the same corridor. There is a need to systematically make improvements for the safety of all road users, with particular attention to non-motorized traffic. One solution is to perform cost-effective shoulder improvements along roadways located in close proximity to urbanized areas or at locations where bicycle and pedestrian activity can be expected.

This chapter summarizes the published literature and identifies the related state-of-the-practice applications used by departments of transportation in other states that addresses how to accommodate bicycle and pedestrian activities with a focus on these rural locations.

LITERATURE REVIEW

In an effort to evaluate the use of highway shoulders and companion site-specific features for safely and efficiently accommodating pedestrians and bicycles along rural highway corridors, this review briefly explores pedestrian and bicycle characteristics, available facility types and application, physical roadway characteristics, and the associated safety and corridor capacity.

Characteristics of Pedestrians and Bicycles on Rural Highways

Prior to evaluating shoulder use suitability, it is important to first understand pedestrian and bicycle needs and future demands along these rural facilities. Pedestrians and bicyclists are often referred to as vulnerable road users due to their exposure to the weather and to high speed vehicles. Though many of the issues that affect these users are similar, their travel patterns and travel needs vary. These characteristics are reviewed in the following sections.

Pedestrian Characteristics along Rural Highway Corridors

In urban areas, a typical pedestrian trip is a relatively short distance. In fact, about 80 percent of pedestrian trips are less than 0.5-mile long (AASHTO, 2011). Since the densities of origins and destinations for pedestrians are much lower in rural areas than in urban regions, rural pedestrian trips tend to be longer. Unfortunately, sidewalks are also rarely available along rural highway corridors, and the pedestrian is often forced to walk on the shoulder, when available, on the street at locations where paved shoulders are not provided, and in some cases in a roadside ditch.

Pedestrians can be considered as four categories: children, adults, senior citizens, and individuals with special needs. Children are still developing their motor and perceptual skills. Adults represent a significant portion of the population. They have good walking skills and abilities. Senior citizens have longer reaction time and lower walking speeds. Individuals with special needs may require wheelchairs, canes, or other assistance to help them walk (Benz et al., 1997). All four pedestrian categories must be accommodated when designing rural highway shoulders that are expected to accommodate these users.

Bicycle Characteristics along Rural Highways

Bicyclists maintain higher speeds than pedestrians, and bicyclists also require additional space. The bicycles typically have safety equipment such as lights and retroreflective devices that help to make them more visible. In rural settings, bicycle trips have varying purposes. For example, recreation-based bicycle trips may occur at scenic locations with suitable riding environments. Other bicycle trips may be commuter trips with experienced riders who navigate roadways on a regular basis. Consequently, the bicyclists are often divided into the following three categories:

- Proficient (experienced) bicyclists.
- Basic bicyclists.
- Novice bicyclist.

Proficient bicyclists frequently ride bicycles and are skilled riders. This category includes users who regularly commute via bicycles. These bicyclists can maintain moderate to high speeds and are equipped to navigate more challenging riding environments. Most bicyclists are not associated with the experienced or confident category and instead are considered as casual or less confident bicyclists. Basic bicyclists are new or infrequent riders. Basic bicyclists usually travel more slowly than proficient bicyclists and prefer shorter distance trips and safer riding environments. Novice bicyclists have little or no riding experience and can include young children who are learning to ride. A novice bicyclist generally will avoid riding with motor vehicle traffic (Benz et al., 1997). [Note: Bicycle and pedestrian facility criteria continue to evolve in the United States. Reference to a 1997 study is included, along with more recent references, to provide a comprehensive perspective of the available literature. Subsequent recommendations in this report are related to suitability criteria that are based on current standards and practice.]

Selection of Pedestrian and Bicycle Facilities

The criteria for selecting pedestrian and bicycle facilities vary. The following sections briefly describe these prospective facilities.

Criteria for Selecting Pedestrian Facilities

Though pedestrians may not always be expected along rural highway corridors, it is advisable to provide space for the occasional pedestrians and future needs. In the American Association of State Highway and Transportation Officials (AASHTO) *Guide for the Development of Bicycle Facilities* (2011), a minimum paved shoulder width of 4 ft is recommended to accommodate the pedestrian activity along rural roadways; however, this width may not be appropriate on high speed roadways. When the demand increases, a shoulder may not be the most appropriate facility to accommodate pedestrians (especially when the corridor motor vehicle speeds are high).

Other facilities, including a sidewalk and shared use path, may be used in these cases. Criteria suitable for urban roadways should be considered in rural regions if the population (including tourist and seasonal population and/or employment) exceeds approximately 1000 persons per square mile (AASHTO, 2004).

Criteria for Selecting Bicycle Facilities

Since the early 1970s, there has been an upward trend in bicycle use for commuting purposes (AASHTO, 2012). Paved shoulders or wider outside traffic lanes (greater than 12 ft and less than or equal to 15 ft) can be provided to meet this increasing demand along rural highways (ITE, 2010). In general, rural facilities with shoulder or outside lane widths suitable for bicycle use are also able to accommodate pedestrian activity. To better understand the rural roadway requirements for bicycles, Table 1 identifies three potential rural bicycle facility types and companion characteristics. Though the focus of this research effort is on shoulder use for bicycles, it is also important to understand the shared lane as it is often the available and much less desirable alternative. Bike lane information has also been included in this bicycle facility introduction because the paved shoulder, in a few rural locations, may be striped as a bike lane in an effort to provide priority to the bicyclist.

Table 1. Candidate Rural On-Road Bicycle Facility Types.

Type	Characteristics
Shared lane	Bicycles share a travel lane with motorized vehicular traffic (TRB, 2010). In some cases, this shared lane is wider than 12 ft.
Paved shoulder	Paved shoulders are often used along rural highways, providing space for disabled vehicles and bicycles (AASHTO, 2012).
Bicycle lane	Bicycle lanes are a portion of roadway that have been designated by striping, signage, and pavement markings for the preferential or exclusive use of bicyclists (NACTO, 2012).

Table 2 summarizes general criteria, based on information from the 1997 Benz et al. study for on-road bicycle facilities. Note that definitions of low or moderate, as depicted in this table, were not clearly defined in the report. In addition, the proficient bicyclist user group noted in the 1997 study is today more commonly referred to as the experienced or confident bicyclist. This user is contrasted to the casual or less confident bicyclist (AASHTO, 2012).

Table 2. General Criteria for Planning On-Road Bicycle Facilities.

Criteria	Type of On-Road Bicycle Facility		
	Shared Lane	Paved Shoulder	Bicycle Lane
Traffic volumes	Low	Moderate	Moderate
Truck volumes	Low	Moderate	Moderate
Motor vehicles speed	Low	Moderate	Moderate
Bicycle use	Low/moderate	Low/moderate	Moderate/high
Trip purpose	Commuting	Commuting/recreational	Commuting/recreational
User groups	Proficient bicyclists	Proficient bicyclists	Proficient and basic bicyclists

Source: Based on Table 1, page 14 of Guidelines for Bicycle and Pedestrian Facilities in Texas (Benz et al., 1997)

Table 3 provides a more recent summary of applications to consider when facilitating bicycle use of shared lanes and paved shoulders. This table indicates that paved shoulder use for bicycles should be considered when the posted speed limits generally range from 40 to 55 mph and for varying traffic volume thresholds. Table 3 also notes that the best locations to use paved shoulders for bicycles are where the road is a rural highway that connects town centers or other major attractors.

Table 3. General Considerations for Bicycle Facilities (Shared Lane and Paved Shoulder).

Application	Type		
	Shared lanes (no special provisions)	**Shared lanes (wide outside lanes)**	**Paved shoulders**
Best Use	Minor roads with low volumes, where bicyclists can share the road with no special provisions.	Major roads where bike lanes are not selected due to space constraints or other limitations.	Rural highways that connect town centers and other major attractors.
Width	Typical width (usually 12 ft).	14 ft or greater to allow motorists to pass bicycles without encroaching into the adjacent lane (may be 15-ft wide in the presence of steep grade, obstructions, or on-street parking). *[Note: 16-ft wide lanes should be avoided as they could accommodate side-by-side motor vehicles.]*	Based on road's context and conditions in adjacent lane. A 4-ft width is a minimum value required to accommodate bicycle travel, but 5-ft widths are recommended near obstructions such as guardrail, curb, or other roadside barriers. Additional shoulder width is also desirable when adjacent motor vehicle speeds exceed 50 mph.
Motor Vehicle Design Speed	Speeds vary based on location (rural or urban).	Variable. Use as the speed differential increases. Generally any road where the design speed is greater than 25 mph.	Variable. Typical posted rural highway speeds (generally 40–55 mph).
Traffic Volume	Generally less than 1000 vehicles per day.	Generally more than 3000 vehicles per day.	Variable.
Classification or Intended Use	Rural roads, or neighborhood or local streets.	Arterials and collectors intended for major motor vehicle traffic movements.	Rural roadways; inter-city highways.
Other Considerations	Can provide an alternative to busier highways or streets. May be circuitous, inconvenient, or discontinuous.	Explore opportunities to provide marked shared lanes, paved shoulder, or bike lanes for less confident bicyclist.	Provides more shoulder width for roadway stability. Shoulder width should depend on characteristics of the adjacent motor vehicle traffic, (i.e., wider shoulders on higher-speed and/or high-volume roads).

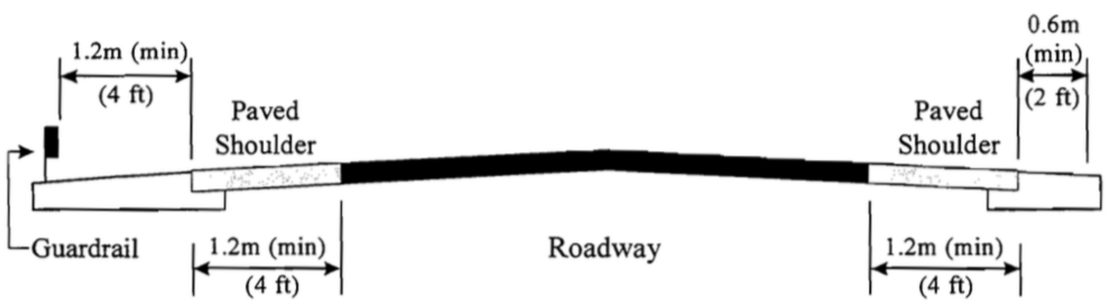
Source: Based on Table 2-3, pp. 2-17 to 2-20 in the Guide for the Development of Bicycle Facilities (AASHTO, 2012)

Rural Highway Shoulder Design for Pedestrians and Bicycles

At rural locations where bicyclists are expected to use the roadway shoulder, the shoulder should be paved and well maintained. In addition, it is important to assess shoulder widths, longitudinal rumble strips, and other site-specific features in consideration of pedestrians and bicyclists. The following sections review the recommendations as presented in the published literature. A subsequent section of this chapter reviews state-of-the-practice applications and so state-specific shoulder design information is not repeated in this literature review section.

Shoulder Width

From the older 1997 study by Benz et al., Figure 1 illustrates an example of providing paved shoulders for bicycles. The minimum shoulder width of 4 ft should be considered for bicycle use if the uncurbed roadway cross section does not include any vertical obstruction immediately adjacent to the roadway. If there is a curb, guardrail, or other roadside barrier (such as a ditch, guardrail, or roadside sign), a minimum clearance of 4 ft from the pavement edge to the plane of the obstruction should be provided. Additional shoulder width is desirable according to the context and environment, especially when the vehicle speeds are above 35 mph, or the volumes of trucks and buses are high (Benz et al., 1997). [Note: As previously indicated, the older 1997 study did not define what volume level is considered to be high.]



Source: Guidelines for Bicycle and Pedestrian Facilities in Texas, Figure 13 (Benz et al., 1997)
[Note: Dimensions from this original figure that are shown as (4 ft) actually represent (4-ft min.) and when the speed limit exceeds 35 mph a wider shoulder width is recommended.]

Figure 1. Example of Bike Use of Shoulders.

AASHTO's *Guide for the Development of Bicycle Facilities* (2012) provides a somewhat different recommendation. A minimum clearance of one additional foot beyond the shoulder, instead of 4 ft, is required adjacent to barriers at uncurbed (shoulder) locations. AASHTO also recommends additional width when the vehicle speeds are above 50 mph.

Rumble Strips

Federal Highway Administration (FHWA) Technical Advisory T 5040.39 titled *Shoulder and Edge Line Rumble Strips* (2011) indicates the following:

> Where any width paved shoulder exists beyond the rumble strip and bicycles are allowed to ride, **recurring short gaps should be designed** in the continuous rumble strip pattern to allow for ease of movement of bicyclists from one side of the rumble to the other. A typical pattern is gaps of 10 to 12 feet between groups of the milled-in elements at 40 to 60 feet.

Longitudinal rumble strips are effective in reducing run-off-road (ROR) crashes for motorists and should help to protect bicyclists riding on the paved shoulders. When a rumble strip is placed on a roadway, a minimum clearance of 4 ft should be provided laterally from the rumble strip to the outside edge of a paved shoulder or 5 ft to other obstructions to accommodate bicyclists (AASHTO, 2012).

The use of a continuous rumble strip is often recommended. A rumble strip with periodic gaps can allow bicycles to enter or exit the shoulder area and provide an opportunity for bicyclists to pass slower bicycles or pedestrians. Moeur (2000) determined that rumble strips on uncontrolled-access highways should have periodic gaps of approximately 12 ft placed at intervals of 40 to 60 ft, a recommendation that is similar to the 2011 FHWA Technical Advisory. O’Brien et al. supported the use of these rumble strip gaps and determined that bicyclists are inclined to increase their travel speed when the gap lengths are longer. O’Brien et al. (2015) suggested that agencies should consider increasing the gap size (above the current 12-ft practice) for roadways with speed limits of 35 mph or greater. Note that most of the research related to the use of rumble strips at locations with bicycle activity focused on milled rumble strips. Profile rumble strips are likely to have a different set of issues associated with them.

Other Shoulder Considerations

The shoulder should meet requirements for accessible design if it is expected to function as a component of a pedestrian access route (TxDOT, 2014). A paved shoulder should be provided on both sides of the rural highway or, when the pavement width is limited, a wider shoulder on one side of the highway (rather than two very narrow shoulders on both sides). Additional width is recommended at steep vertical grades or at horizontal curve locations (AASHTO, 2012).

Safety Concerns for Shoulder Use for Pedestrians and Bicycles

As rural area populations increase, the number of pedestrians and bicyclists using roadways can also be expected to increase. Pedestrians and bicyclists are more vulnerable and have unique needs that should be addressed as part of roadway design.

Rural highways rarely provide dedicated facilities for pedestrians and bicyclists. Research indicates that the rural road environment generally does not include critical elements that help ensure the safety of a pedestrian. Factors common to a rural highway location that contribute to pedestrian crashes include the absence of a shoulder or sidewalk, high motor vehicle volumes and speeds, and narrower paved (or unpaved) shoulders (McMahon et al., 2000).

While most crashes related to bicycles in urban streets occur near driveways or intersections, rural crashes involving bicyclists vary. Overtaking or being struck from behind accounts for a small number of bicycle crashes in urban areas; however, being struck from behind is a common pedestrian or bicycle crash type along higher speed rural roads. The addition of wide paved shoulders offers bicyclists a substantially safer transportation option. For example, of all of the bicycle-motor vehicle crashes that occurred in North Carolina from 2005 to 2009, 62.2 percent occurred when the bicycle was in the active travel lane. Only 4.7 percent of the collisions involved a bicyclist positioned in a bike lane or on a paved shoulder.

To prevent vehicles from inadvertently drifting off the road, shoulder rumble strips may be used as one of the possible treatments, though these treatments also can create safety issues for bicyclists when periodic gaps are not spaced appropriately for the roadway design (TRB, 2010).

The AASHTO *Highway Safety Manual* does not provide predictive information that explicitly addresses the pedestrian and bicycle crashes at rural locations, but does recommend wider lane and shoulder widths as a way of reducing the total number of crashes. A notable difference between urban and rural roads is nighttime lighting. Street lights are not commonly provided along rural highways; drivers are faced with the added challenge of seeing pedestrians and bicyclists in a timely manner. The *Highway Safety Manual* indicates that pedestrian crashes walking along roadway are more likely to occur at night where street lights are not available.

Capacity Concerns for Shoulder Use for Pedestrians and Bicycles

In recent years, the level of service (LOS) concept common to evaluating motor vehicle operations has been extended to include the consideration of pedestrians and bicyclists. The process for determining LOS for pedestrians and bicyclists is presented in the Transportation Research Board *Highway Capacity Manual* (HCM) (TRB, 2010).

The **pedestrian** LOS measures are currently available for urban street designs, urban street segments, signalized intersections, off-street pedestrian accommodations, etc. Because pedestrian density is often low in the rural areas, rural facility pedestrian LOS is not currently addressed in the 2010 HCM.

The HCM recognizes five road characteristics to establish its **bicycle** LOS. These characteristics are listed in order of importance as follows:

- Average effective width of the outside through lane.
- Motorized vehicle volumes.
- Motorized vehicle speeds.
- Heavy vehicle (truck) volumes.
- Pavement condition.

STATE-OF-PRACTICE

The use of highway shoulders for walking or bicycling in rural regions varies by state. In general, shoulder widths suitable for bicycling should accommodate pedestrians. Minimum shoulder widths vary depending on speed and traffic volume and type. This section reviews site-specific characteristics and example bicycle and pedestrian suitability criteria used by states.

Shoulder Widths to Accommodate Bicycles in Rural Areas

Most states require a minimum usable shoulder width of 4 ft to accommodate bicycle travel (with a minimum width of 5 ft adjacent to longitudinal barriers). Shoulder widths less than 4 ft are generally designed to support the roadway pavement and provide refuge space for distressed vehicles. Table 4 shows specific minimum shoulder width information for 20 states that have criteria different than the common 4 ft width values. These minimum shoulder width thresholds range from widths as narrow as 2 ft up to and including widths of 8 ft.

Table 4. Minimum Shoulder Width Requirements in Rural or Rural Transition Locations.

State	Conditions for Minimum Shoulder Width (ft)				
	3	4	5	6	8
Alabama[1]	---	[SL < 30] **or** [(30 ≤ SL ≤ 40) & (AADT ≤ 10,000)]	---	[(30 ≤ SL ≤ 40) & (AADT > 10,000)] **or** [40 < SL ≤ 50]	(SL > 50) & (AADT ≥ 2000)
Alaska	---	---	---	All	---
Connecticut	---	---	All	---	---
Florida	---	Truck, bus, or RVs > 10%	---	---	---
Idaho[2]	---	Special exception for severe width limitations	--	All others	---
Illinois	---	[(SL < 30) & ADT ≥ 2000)] **or** [(30 ≤ SL ≤ 35) & (ADT ≤ 8000)]	---	[(30 ≤ SL ≤ 35) & ADT > 8000)] **or** [SL = 40] or [(SL ≥ 45) & (ADT < 2000)]	(SL ≥ 45) & (ADT ≥ 2000)
Kansas[3]	ADT ≤ 2000	---	---	---	---
Kentucky	---	---	SL ≥ 30 **or** AADT > 10,000	---	---
Massachusetts	---	---	SL > 50 **or** trucks & buses > 30 vph	---	---
Minnesota[4]	---	SL ≥ 25	---	[(SL ≥ 30) & (AADT > 5000)] **or** [(35 ≤ SL ≤ 40) & (1000 ≤ AADT ≤ 10,000)] **or** [(SL ≥ 45) & (1000 ≤ AADT ≤ 2000)]	[(35 ≤ SL ≤ 40) & (AADT > 10,000)] **or** [(SL ≥ 45) & (2000 ≤ AADT ≤ 10,000)]
New Jersey	[(30 ≤ SL ≤ 40) & (2000 ≤ AADT ≤ 10,000)] **or** [(40 < SL ≤ 50) & (1200 ≤ AADT ≤ 2000)]	[(30 ≤ SL ≤ 40) & (AADT > 10,000 or trucks over 5%)] **or** [(40 < SL ≤ 50) & (2000 ≤ AADT ≤ 10,000)] **or** [SL > 50]	---	[(40 < SL ≤ 50) & (AADT > 10,000 or trucks over 5%)] **or** [(SL > 50) & (AADT ≥ 2000)]	AADT > 10,000
North Carolina	---	---	SL > 50	---	---
Oregon	---	Special exception for severe width limitations	--	All others	---
South Carolina[5]	---	ADT > 500	---	ADT > 500 & trucks, buses, and RVs are at least 5% of ADT	---
Tennessee[6]	---	---	---	---	SL > 50

Table 4. Minimum Shoulder Width Requirements in Rural or Rural Transition Locations (Continued).

State	Conditions for Minimum Shoulder Width (ft)				
	3	4	5	6	8
Texas	---	SL > 35	Rural locations with 400 ADT or more and bridge decks are being replaced	---	---
Vermont[7]	RPA: DS = 45; RMA: [(DS = 45) & (1500 ≤ ADT ≤ 2000)] **or** [(50 ≤ DS ≤ 55) & (ADT < 1500)] RC: Facilities above 2' shoulder criteria	RPA: DS = 50; RMA: [(50 ≤ DS ≤ 55) & (1500 ≤ ADT ≤ 2000)]	RPA: DS = 55	---	---
Washington	---	SL > 25 and ADT > 2000	---	---	---
Wisconsin[8]	(1500 < ADT ≤ 3500) & (< 25 bicycles per day)	[(700 ≤ ADT ≤ 1500) & (≥ 25 bicycles per day)] **or** [(1500 < ADT ≤ 3500) & (< 25 bicycles per day)]	(1500 < ADT ≤ 4500) & (≥ 25 bicycles per day)	(ADT > 4500) & (≥ 25 bicycles per day)	---
Wyoming	---	ADT < 2000	---	ADT > 2000	---

Footnotes:

[1] Alabama recommended values are based on basic (Type B) bicyclists and child (Type C) bicyclists.

[2] Colorado and Idaho have additional recommendations based on varying bicycle levels of service, speed limit (or design speed), and percent heavy vehicles.

[3] Kansas bicycle facilities should be considered for locations with ADT values less than 1000 vehicles per day (vpd) and less than 100 trucks daily.

[4] In Minnesota, AADT thresholds represent 2-lane highways so multiply AADT thresholds by 2 for 4-lanes. In addition, roadways with a 2-lane volume of 10,000 vpd or a 4-lane volume of 20,000 vpd should have 1' wide shoulders or a shared-use path to accommodate bicycles.

[5] In South Carolina, 2' wide shoulders are permitted at locations with ADT < 500 vpd.

[6] Tennessee has a bicycle suitability rating that rates bicycle favorability based on shoulder widths ranging from 2' up to 8'

[7] Vermont permits 2' wide shoulders for all rural roadways with design speeds of ≤ 40 mph and ADT values less than 2000 vpd. For rural minor arterials, the 2' shoulders are also permitted for design speeds of 45 mph and ADT values < 1500 vpd. The 2' shoulders can also be used on rural collector roadways with a design speed up to 50 mph and an ADT < 1500. RPA = Rural Principal Arterial, RMA = Rural Minor Arterial, RC = Rural Collector.

[8] Wisconsin does not require paved shoulders (for bicycle activity) at corridors with ADT under 700 vpd. In addition, if the daily bicycle activity is 24 or less, paved shoulders ranging from 0 to 3' are allowed if the motor vehicle ADT is less than 1,500 vpd. At higher volume thresholds, the 6' shoulder is advisable but the 5' shoulder is allowed.

Supplemental Table Notes:

Cell is not applicable if it includes “---”

SL = Posted Speed Limit; DS = Design Speed

Units for Annual Average Daily Traffic (AADT) and Average Daily Traffic (ADT) are vpd.

Units for speed are mph.

Other Site-Specific Characteristics

In addition to the shoulder width, many states consider bicycle and pedestrian connectivity, land use, vertical grade, rumble strips, and elimination of barriers. Specific ways that states consider these needs are identified in the following sections.

Traffic Operation

The prevailing speeds and the percentage of large vehicles are common considerations when determining shoulder widths at locations with bicycle activity. Nationally, the recommended shoulder width is 5 ft minimum for rural highways with speed limits of 50 mph or greater. In addition, Texas requires a base shoulder width of at least 4 ft if the motor vehicle speeds exceed 35 mph. In South Carolina, if the truck, bus, or recreational vehicle traffic is greater than 5 percent, a 4-ft shoulder should be constructed. Similarly, Florida requires a 4-ft wide shoulder when the truck, bus, or recreational vehicle traffic exceeds 10 percent of the total motor vehicle volume.

Connectivity

Connectivity refers to a continuous and traversable pathway for pedestrians and bicycles. Several states specifically note how this connectivity can be evaluated (see Table 5). Wisconsin, for example, uses connectivity as a priority for constructing a bicycle accommodation where small gaps of 3 miles or less are noted.

Land Use

Some states specifically link shoulder width use by bicycles and pedestrians to the surrounding land use. Table 6 summarizes how five states address this land use consideration.

Table 5. Bicycle and Pedestrian Considerations Related to Connectivity.

State	Connectivity Recommendation
Connecticut	The statewide route network plan should include the identification of missing links between network facilities and ways to prioritize them for improvements.
Kentucky	Factors that should be considered when determining the need for pedestrian/bicycle facilities for active projects include: • Evaluate future connections to close gaps in parallel connectivity between projects and developed areas. • Community destinations or existing pedestrian facilities within 300 ft beyond normal project limits and within existing publicly owned rights of way. Consider the incorporation of pedestrian facilities when: • Gaps in connectivity exist between two or more developed areas. • Community destinations currently separated by no more than 1.5 miles.
Maine	A pavement preservation project can be used to pave shoulders to complete gaps on highway segments where the majority of shoulders are already paved and where the design summer ADT is less than 4000.
Washington	Shoulders may serve as a pedestrian facility when sidewalks are not provided. If pedestrian generators, such as bus stops, are present and pedestrian usage is evident, a 4-ft paved shoulder width is adequate. Note that detectable warning surfaces should not be installed where a sidewalk ends and pedestrians are routed onto a shoulder since the shoulder is not a vehicular traveled way.
Wisconsin	Bicycle accommodations should be considered at locations that will complete short gaps in an otherwise continuous bicycle route or where short connections between communities of up to 3 miles are not currently provided.

Table 6. Bicycle and Pedestrian Considerations Related to Land Use.

State	Land Use Considerations
Alabama	Designs should accommodate advanced (proficient) bicyclists in rural areas. In addition, bicycle facilities should be provided for cross-state routes with low traffic volumes and adequate space.
Georgia	At a minimum, shoulders widths should be at least 5 ft on both sides of the road for school walk routes or at least 8-ft wide if constructed on only one side. Shoulder areas located at school bus stops need to be widened to accommodate children waiting at the roadside for the bus.
Kentucky	• Consider incorporating pedestrian facilities at locations where the project limits are adjacent to planned or anticipated development (within the next 20 years) for residential subdivisions; commercial, industrial, institutional, public, or semi-public use areas; or other projects requiring pedestrian connectivity. • Consider incorporating bicycle facilities at locations where the project limits are adjacent to an existing residential, commercial, office, industrial, institutional, public, or semi-public use area or adjacent to an area planned to develop into one of these uses within the next 20 years.
Maine	Paved shoulders should be included for pavement preservation projects where the design ADT is less than 4000 vpd and occurs at: • Recreational use highways, or • In villages, or adjacent to parks, schools, beaches, fairgrounds, recreation facilities, work centers, or other built-up areas to accommodate pedestrian and bicycle usage. This may include extending paved shoulders to a facility adjacent to the village.
Tennessee	Cities/counties/state should provide wider shoulders or bike lanes for scenic route and/or city locations.

Vertical Grade

Steeper vertical grades can create additional challenges for bicyclists and pedestrians. Often there is a need for a bicyclist to pass a slower bicyclist or pedestrian. Table 7 identifies specific recommendations used by eight states. These recommendations generally include wider shoulders when uphill vertical grades exceed 5 percent or when downhill grades are at least 0.6 miles long.

Table 7. Bicycle and Pedestrian Considerations Related to Vertical Grade.

State	Vertical Grade Considerations
Minnesota	To better accommodate a pedestrian access route, a desirable longitudinal grade is 5 percent or less (a maximum grade is equal to that of the road).
New Jersey	Where the uphill grade exceeds 5 percent, a minimum of a 5-ft wide shoulder is desirable to help support shared use without compromising the facility's LOS.
New York	At downhill locations up to 0.6 miles in length, a paved shoulder that is a minimum of 6-ft wide should be provided.
North Carolina	Where funding is limited, adding or improving shoulders on uphill sections first will give slow-moving bicyclists needed maneuvering space and decrease conflicts with faster-moving motor vehicle traffic.
Ohio	On uphill roadway sections, a shoulder may be provided to give slow-moving bicyclists additional maneuvering space.
Oregon	On steep uphill grades, it is desirable to maintain shoulder widths of 6 ft (with a minimum width of 5 ft).
Tennessee	The cost to retrofit many of the state highways in Tennessee, particularly in the more mountainous regions, means that narrower shoulders or a shoulder on the uphill travel side are a more practical solution. A shoulder on the uphill side allows bicyclists, who are moving considerably slower than motor vehicles while climbing, to be separated from the travel way. In areas of rugged topography or other constraints, wide shoulders are simply not practical except where there are appreciable traffic volumes.
Vermont	A 5-ft wide paved shoulder can be used as an on-road bicycle facility at steep upgrades where bicyclists require maneuvering room or where downgrades exceed 5 percent for up to 0.6 miles.

Rumble Strips

The use of shoulder rumble strips can create challenges for bicycles when periodic gaps are not designed appropriately. Nationally, rumble strip designs should include a minimum clear path of 1 ft from the rumble strip to the traveled way, 4 ft from the rumble strip to the outside edge of paved shoulder, or 5 ft to adjacent guardrail, curb, or other obstacle. If these minimum desirable clearance values cannot be achieved, the rumble strip may be decreased or alternative solutions considered. Table 8 summarizes additional ways that several states address this rumble strip issue.

Table 8. Bicycle Considerations Related to Rumble Strips.

State	Rumble Strip Considerations
Colorado	Rumble strips should not be used on roadways designated as bicycle routes. At locations where permitted, rumble strips should be placed as closely as possible to the right edge of the roadway edge line. A minimum of 4 ft clear shoulder should be available to the right of the rumble strips.
Illinois	When rumble strips are installed in a paved shoulder that is also used by bicycles and the width of the paved shoulder is 6 ft or less, an 8-in. wide rumble strip design should be used to minimize the impact to the bicycles.
Kansas	The rumble strip design provides a smooth riding space of 5 ft in width to the right of rumble strips on 10-ft wide concrete shoulders. A riding space of 3 ft in width will be available on 8-ft wide concrete shoulders.
Louisiana	A 12-ft longitudinal rumble strip gap every 40 to 60 ft should be provided to enable bicyclists to avoid debris in the shoulder and to pass other bicyclists.
Minnesota	For compatibility with bicycle transportation, rumble strips should be installed in an alternating on/off pattern within 0.5 ft of the edge of travel lane or fog line (1-ft wide), with a minimum 4 ft width of smooth pavement for bicycles on the shoulder. Periodic rumble strip gaps, every 40 to 60 ft, should be provided to allow bicyclists to move across the strip when needed. A gap length of at least 12 ft allows most bicyclists to leave or enter the shoulder without crossing the rumble strip. Longer gaps should be provided on steep downhill paths.
New Jersey	Use of rumble strips should be avoided on all land service roadways for bicyclists.
Ohio	In areas designated as bicycle routes or having substantial volumes of bicycle traffic, the rumble strip pattern should not be continuous but should consist of an alternating pattern of gaps and strips, each 10 ft in length. Gaps should also be provided in the rumble strip pattern ahead of intersections, crosswalks, driveway openings, and at other locations where bicyclists are likely to cross the shoulder.
Oregon	A minimum of 4 ft of ridable shoulder is required and rumble strips recommendations include 12-ft gaps on 40- to 60-ft intervals.
Tennessee	If rumble strips are necessary, they should follow bicycle-friendly guidelines and provide an unobstructed travel way and clear zone of at least 4 ft. Gaps should be provided every 25 ft to allow ease of access through the line of strip.
Texas	On roadways with high bicycle activity, consideration should be given before the installation of rumble strips. Things to consider include size of rumble strips, rumble strip material, and location of rumble strips due to bicycle use of the road, then follow the requirements shown in FHWA Technical Advisory T5040.39 or latest version. A detail of the spacing shall be included in the plans.
Wisconsin	Paved shoulder, AADT, adjacent travel lane width, and bicycle conditions requirements are used in conjunction with the presence of rumble strips to evaluate bicycle accommodation. Table 9 and Table 10 demonstrate how Wisconsin defines a bicycle accommodation condition and how this condition, along with the presences of rumble strips, can affect the shoulder width decisions.

Table 9. Wisconsin Conditions Requiring Bicycle Accommodations.

Number	Condition
1	Identified in the Wisconsin Bicycle Transportation Plan or another Wisconsin Department of Transportation-endorsed or supported bicycle plan.
2	The two-way bicycle traffic volume is (or is expected to be) 25 per day or more during peak travel days for cycling (average of the 10 most traveled days for bicycling for the year).
3	To complete short gaps in an otherwise continuous bicycle route.
4	To make short connections from communities or urban areas of up to approximately 3 miles to the town or county roadway network (not to a dead-end roadway).
5	If bicycle accommodation projects were proposed and funded as bikeways under the Transportation Enhancement, Congestion Mitigation and Air Quality, or Safe Routes to School programs, a minimum 5' shoulder shall be provided. For projects funded under these programs, 4' paved shoulders may be used only when ADTs are less than 1500 in the design year or there are extenuating circumstances that will not permit 5' or wider paved shoulders. Appropriate justification and documentation of the extenuating circumstances must be developed and maintained in the project file.

Table 10. Wisconsin Minimum Paved Shoulder Width for On-Road Bike Accommodation on Rural Roads.

Design Year AADT	Conditions from Table 9	Adjacent Travel Lane Width (ft)	Paved Shoulder Width (ft)	
			Without Shoulder Rumble Strip	With Shoulder Rumble Strip
< 750	Does not meet any of the conditions	10	4	5
		11 or 12	3	5
	Meets 0 or more of conditions 1, 2, 3 or 4 and does meet condition 5	10, 11, or 12	4	5
≥ 750	Does not meet any of conditions 1, 2, 3, 4, or 5	10	4	5
		11 or 12	3	5
750–1499	Meets 1 or more of conditions 1, 2, 3, 4, or 5	10 or 11	4	5
	Meets 1 or more of conditions 1, 2, 3, or 4 and does not meet condition 5	12	3	5
	Meets 0 or more of conditions 1, 2, 3, or 4 and meets condition 5	12	4	5
1500–1900	Meets 1 or more of conditions 1, 2, 3, 4, or 5	11	5	5
	Meets 1 or more of conditions 1, 2, 3, or 4 and does not meet condition 5	12	4	5
	Meets 0 or more of conditions 1, 2, 3, or 4 and meets condition 5	12	5	5
≥ 2000	Meets 1 or more of conditions 1, 2, 3, 4, or 5	11 or 12	5*	5*

***** When AADT exceeds 4500, a 6' paved shoulder is advisable.

Barrier

The placement of longitudinal barriers adjacent to a shoulder will generally result in a bicyclist shifting away from the barrier and toward the adjacent travel lane. As a result, locations where longitudinal barriers are required often have wider shoulders of at least one additional foot. Arizona, Ohio, and Nevada require an additional minimum 2-ft offset to the face of the barrier to better accommodate bicycles. In North Carolina, Texas, Vermont, and Wisconsin, a 4-ft offset is recommended adjacent to guardrail, curb, or other roadside barriers.

Suitability Criteria for Individual States

Many states have developed a variety of ways to evaluate suitability criteria for pedestrians and bicyclists. The following state summaries of suitable shoulder widths for bicyclists are based on ADT.

Connecticut Bicycle Suitability Matrix

Connecticut uses a matrix (see Table 11) to classify shoulder suitability based on ADT and available shoulder width. The color coded matrix uses the color red to indicate less suitable and green to indicate more suitable.

Table 11. Connecticut Roadway Bicycle Suitability Matrix.

ADT	Shoulder Width (ft)			
	0	1–3	3–6	> 6
<2500	Red	Olive	Green	Green
2500–5000	Red	Blue	Olive	Green
5000–7500	Red	Yellow	Olive	Green
7500–10,000	Red	Yellow	Blue	Green
>10,000	Red	Yellow	Blue	Olive

Red	Less suitable
Yellow	
Blue	
Olive	
Green	More suitable

Tennessee Suitability Matrix

The Tennessee 2005 Long-Range Transportation Plan uses a color coded suitability matrix (see Table 12) based on shoulder width and ADT to determine if bicycle use of shoulders is favorable. The ADT applications included:

- ADT > 2000: Paved shoulders should be provided. If bicyclists were currently using or anticipated to use the roadway, wider paved shoulders were needed. A suitability valuation of blue will be considered a threshold for evaluating the need for the addition of shoulders or widened outside lanes.
- ADT < 2000: If paved shoulders were not present, an analysis should be performed to determine if the addition of a shoulder will improve bicycling conditions to green (in the matrix). If wide shoulders are already present, there are no special improvements needed to accommodate bicyclists.

Table 12. Tennessee Bicycle Suitability Index Matrix.

		Dirt/Gravel	**Paved Shoulder Width (ft)**			
			< 2	2–4	4–8	>8
ADT	> 10,000	Red	Red	Blue	Blue	Purple
	2000–10,000	Orange	Orange	Blue	Green	Purple
	< 2000	Blue	Green	Green	Green	Purple

Source: Tennessee Long-Range Transportation Plan, Bicycle and Pedestrian Element, December 2005.

In 2011, Tennessee updated their State Bicycle Route Plan and evaluated the merits of continuing to use the bicycle suitability index from 2005 or a bicycle LOS method based on the 2010 HCM LOS procedures. Ultimately, Tennessee determined that expanding the analysis beyond the suitability index has merit as many of their urban areas were already applying the 2010 procedure. Table 13 depicts the updated rating system for Tennessee. Grade A is desirable; however, Grade B is also acceptable for locations with bicycle and pedestrian activity.

Table 13. Tennessee Bicycle Level of Service Rating.

Grade	Score	Description
A	≤ 1.5	Occurs where there are bike lanes or wide paved shoulders, moderate traffic volumes, and low to moderate speeds.
B	> 1.5 and ≤ 2.5	Occurs where there are wide shoulders, moderate traffic volumes, and moderate to low speeds.
C	> 2.5 and ≤ 3.5	Occurs where there are wide outside lanes, low to moderate traffic volumes, and low to moderate speeds.
D	> 3.5 and ≤ 4.5	Occurs where there are lane widths of at least 12 ft, no shoulders or limited shoulder width, moderate to high traffic volumes, and low to moderate speeds.
E	> 4.5 and ≤ 5.5	Occurs where lane widths are 12 ft or less, no shoulders, moderate to high traffic volumes, and moderate to high speeds.
F	> 5.5	Occurs where there are no shoulders, lane widths of 12 ft or less, usually high traffic volumes, and moderate to high speeds.

Source: Update of Tennessee's State Bicycle Route Plan, Technical Memorandum 1, Data collection and Bicycle-Suitability Methodology, October 2011.

Indiana Suitability Rating Criteria

Indiana uses a rating system to evaluate suitability of a facility for use by bicycles. Their four suitability categories are depicted in Table 14 and include:

- Suitable: A basic level rider would be able to travel with a moderate level of comfort, while an advanced rider would be very comfortable.
- Moderately Suitable: A basic level rider would be somewhat uncomfortable, while an advanced rider would be moderately comfortable.
- Not Suitable: The roadway is not suitable for bicycle travel. The basic level riders should not travel on this type of facility and advanced riders should use extreme caution.
- Prohibited: Bicycles are not allowed on this facility.

Indiana does not encourage bicycle activity along corridors with speed limits greater than 55 mph.

Table 14. Indiana Bicycle Suitability Criteria.

Characteristic	Suitable	Moderately Suitable	Not Suitable (Not Recommended)	Prohibited
Access Control and Freight Traffic	No Access Control	Partial Access Control	Partial Access Control	Interstate, freeway, expressway, corridors with interchange access only, or corridors scheduled to be upgraded to freeways
Lane Configurations	2-lanes (depending on speed, traffic volume, shoulders, and roadway geometrics)	2-lanes to 4-lane undivided or 4-lane divided (if speed, traffic volume, and commercial freight volume is low)	> 4 lanes or 4-lane divided (except for conditions noted in moderately suitable category)	--
Lane Width	12' or greater	11'–12'	< 11'	--
Shoulder Type	Paved (depending on shoulder width)	Curb (depending on speed limit and lane width)	Gravel	--
Paved Shoulder Width	> 3'	1'–3'	< 1' or shoulder rumble strips	--
Speed Limit	≤ 55 mph (depends on lane configuration, shoulder width, access control, shoulder type, and traffic control)		> 55 mph	--
Traffic Volume	Multilane with 0 to 24,999 vpd; 2-lane with 0 to 5999 vpd	Multilane with 25,000 to 40,000 vpd; 2-lane with 6000 to 10,000 vpd	Multilane with >40,000 vpd; 2-lane with > 10,000 vpd	--
Commercial Veh. Volumes	0–5% Buses, RVs, and all trucks	5–10% Buses, RVs, and all trucks	> Buses, RVs, and all trucks	--
Roadway Geometrics	Good sight distance	Moderate sight distance	Poor sight distance	--
Pavement Quality Maintenance	Excellent to Good	Fair	Poor	--

Source: Indiana State Route Bicycle Suitability Rating Criteria (undated) and the 2014 Indiana State Roadway Bicycle Suitability Map

Wisconsin Suitability Index

Wisconsin generally categorizes bicycle suitability by assessing the traffic volume, road width, and shoulder configuration information as depicted in Table 15. In this table, green shading indicates preferred conditions, while the blue represents moderate conditions. The yellow color represents higher volume locations with wider paved shoulders. The red indication represents undesirable conditions.

Table 15. Generalized Bicycle Conditions.

Traffic per Day		Width of Roadway (ft)				
		Narrow (≤ 22)	Moderate (23–24)	Wide (25–28)	Paved Shoulders (29–30)	Wide Paved Shoulders (≥ 31)
Low	750	Green				
	1000	Green				
		Blue				
	1500					
		Red				
Moderate	2000					
	2500					
	3500					Green
High	5000				Red	Blue
						Yellow

Suitability Criteria for National Consideration

In April 2015, the National Cooperative Highway Research Program (NCHRP) published a report titled *Pedestrian and Bicycle Transportation Along Existing Roads – ActiveTrans Priority Tool Guidebook* (Lagerway et al., 2015). This publication provided one recommended procedure for a step-by-step prioritization methodology for pedestrian and bicycle facilities. Though the focus of the study was on the complete street concept and targeted to urban conditions, the procedure does introduce steps that helped to identify issues to consider when assessing suitability and prioritization. The NCHRP report summarized the following nine factors:

- Stakeholder Input.
- Constraints.
- Opportunities.
- Safety.
- Existing Conditions.
- Demand.

- Connectivity.
- Equity.
- Compliance.

SUMMARY OF LITERATURE AND STATE-OF-PRACTICE REVIEW

The use of a highway shoulder for pedestrian and bicycle activity varies across the nation. Common thresholds include extra lateral space when rumble strips are present. Agencies also provide wider shoulder widths when speeds exceed 55 mph or when corridors have steep grades, high traffic volumes, or moderate percentages of heavy vehicles (usually at least 5 percent of the prevailing traffic). Though recommendations differ, agencies generally agree that additional shoulder width should be provided adjacent to roadside barriers. Finally, several states use improved connectivity as a way of prioritizing shoulder widening projects for the purpose of enhancing bicycle and pedestrian safety along the affected corridors.

CHAPTER 3. PRELIMINARY SUITABILITY CRITERIA AND ASSOCIATED DATA COLLECTION

As a first step toward identifying the required data necessary for evaluating the suitability of a corridor for bicycle and pedestrian shoulder activity, the project team developed a preliminary suitability criteria list that was largely based on the literature review, state-of-the-practice review, and common Texas practices. Using these initial suitability criteria as an indication of the type of data needed for subsequent analysis, the project team then assembled data suitable for this evaluation. This chapter summarizes the preliminary suitability criteria and the subsequent data collection activities.

PRELIMINARY SUITABILITY CRITERIA

As a result of the literature review and state-of-the-practice evaluation, the project team developed a list of preliminary criteria to use for the purposes of evaluating potential suitability of rural two-lane highway shoulders for pedestrian and bicycle use for Texas roadways. On April 6, 2015, the project team met with the TxDOT advisory panel and project manager. At that meeting, the project team was instructed to focus on rural two-lane highways but note where applications could also be extended to rural multilane facilities. Table 16 identifies the potential characteristics or elements considered as candidate suitability criteria. The table also identifies the potential data source for evaluating these items for Texas facilities. In many cases, the individual elements are easily acquired from a convenient data source. In other cases, however, the data may not be as easy to determine without a site visit or physical inspection of site aerials. This level of detail, though important, may also introduce a challenge for a wide-scale corridor screening activity. Examination of candidate criteria must also focus on how available an individual element is for the overall network evaluation.

Table 16. Preliminary Suitability Criteria and Potential Data Source.

Characteristic/Element	Potential Data Sources
Physical Site Feature	
Functional Classification/Road Type Number of Lanes Lane Widths Shoulder Widths Shoulder Type (paved, unpaved) Presence of Sidewalk Pavement Quality and Type Available Stopping Sight Distance Sight Distance around Horizontal Curves Posted Speed Limit Presence, Type, and Configuration of Rumble Strip Vertical (Steep) Grades Travel Lane Cross Slopes Shoulder Cross Slopes Presence of Barriers/Guard Rails Presence of Street Lights Drainage Features Crash History	Roadway-Highway Inventory Network (RHiNo), Pavement Highway Inventory System (PHini), Crash Records Information System (CRIS), Aerial Photographs, Video, Site Visit
Operational Characteristic	
Motor Vehicle Traffic Volume (AADT) Percent Heavy Vehicles, Buses, RVs Pedestrian Volume Bicycle Volume	Historic Traffic Counts, RHiNo, Estimates using Census Data, Travel Demand Models, etc.
Unique Bicycle or Pedestrian Requirements	
Designated Bicycle Route? Scenic Route? School Bus Route? Connectivity	Local and TxDOT Websites, School District Information, Aerial Photography, etc.

KEY DATA ELEMENTS

The general list of preliminary suitability criteria, as shown in Table 16, includes elements that are critical to the evaluation of pedestrian and bicycle roadway shoulder use as well as several potential elements that, if the information is available, could enhance the analysis. The following summary considers two distinct data types: 1) critical data elements and 2) secondary data elements. The critical data elements represent roadway features that must be considered for functional purposes (i.e., a bicycle could not use if this roadway element is not suitable). The secondary data elements are then additional variables that affect the user demand or facility configuration that may directly influence user route choice. The data elements consist of specific features that can ultimately be included in the suitability criteria and items that are not specifically criteria but that provide defining information for establishing suitability. An example of this distinction is the functional classification. This data element is needed for screening candidate sites but is not an actual suitability criterion.

The project team considered a variety of potential data sources for evaluating this information, but ultimately elected to use the TxDOT RHiNo as the primary source of data when possible. Though, in many cases, alternative data sources can provide enhanced information, the use of one primary source of roadway data (when suitable) helps to streamline any system-wide suitability evaluations. The following summaries identify the primary data source and present alternative recommendations that can be used to confirm the information when evaluating at the more detailed project level.

Critical (Primary) Data Elements

A roadway shoulder can only accommodate bicycle and pedestrian activity if the facility includes suitable shoulder widths and paved surfaces that can facilitate this type of use. Consequently, critical data elements that are essential for bicycle and pedestrian use include shoulder width and shoulder type. Because the prevailing operating speed for motor vehicles and traffic volume can also influence the recommended shoulder width, the posted speed limit and AADT value should be included as additional critical data elements. The type of road should also be included when evaluating the context of the study area. Rural locations proximate to urbanized regions can be expected to have elevated needs for this expanded shoulder use. Though shoulder use can occur on a variety of roadways, the definitions of the critical elements for this research effort focus on the rural two-lane highway (see Table 17); the number of lanes is also considered a critical data element.

Table 17. Critical Data Elements to Accommodate Bicyclist and Pedestrian Roadway Shoulder Use (Rural Two-Lanes).

Critical Data Elements	Value	RHiNo Column Name	Secondary Source of Information
Left Shoulder Width	4-ft min. if speed limit is >35 mph (5 ft at rural locations with ADT > 400 vpd and where bridge decks are being replaced)*	HP_SWL or S_WID_I	Aerial Photographs
Right Shoulder Width		HP_SWR or S_WID_O	Aerial Photographs
Left Shoulder Type (paved or unpaved)	Paved	S_TYPE_I	Aerial Photographs
Right Shoulder Type (paved or unpaved)		S_TYPE_O	Aerial Photographs
Posted Speed Limit (mph)	Varies**	SPD_MAX and SPD_MIN	Video of street
Functional Classification	Rural, Non-Interstate**	FUN_SYS	Regional Maps and Aerial Photographs
Motor Vehicle Traffic Volume (AADT)	Varies	ADT_CUR with ADT_YEAR	---
Number of Lanes	2 (focus for this analysis)**	NUM_LANES	Aerial Photographs

* Shoulder width values based on Table 3-8 and content in Section 6 of the TxDOT *Roadway Design Manual* (2014)
** May vary but values will influence the minimum and recommended shoulder widths.

As noted in Chapter 2, the AASHTO *A Policy on Geometric Design of Highways and Streets* (2011) recommends a minimum paved shoulder width of 4 ft for pedestrian activity along rural roadways; however, this width may not be appropriate for higher speed roadways. When the demand increases, a shoulder may not be the most appropriate facility to accommodate pedestrians (especially when the corridor motor vehicle speeds are high).

The AASHTO *Guide for the Development of Bicycle Facilities*, 4th edition (AASHTO, 2012) indicates that a 4-ft width is a minimum value required to accommodate bicycle travel, but 5-ft widths are recommended near obstructions such as guardrail, curb, or other roadside barriers. **Additional shoulder width is also desirable when adjacent motor vehicle speeds exceed 50 mph.** The AASHTO guide also indicates that the best use of roadway shoulders for bicycle and pedestrian activity occurs at rural highways that connect town centers and other major attractors.

As shown in Table 17, the Texas shoulder width requirements for rural 2-lane highways, and as noted in the TxDOT *Roadway Design Manual*, have a 4-ft minimum width for speed limits greater than 35 mph. When the traffic volume is greater than 400 vpd for a rural highway and a bridge deck is being replaced, a 5-ft wide shoulder should be used. Note that the required "when bridge decks are being replaced" is specific to the TxDOT *Manual* and would require specific site and project knowledge by the individual district engineers performing a detailed analysis. The Texas thresholds do not currently recommend wider shoulders simply due to corridor speeds above 50 mph as suggested in the 2012 AASHTO guidance.

An additional item that could substantially influence shoulder suitability but that is not readily available in a database is the cross slope of the paved shoulder. Unless a road has been designed to specifically accommodate future widening, the shoulder cross slope is often steeper than the adjacent lane cross slope. This design helps to accommodate inclement weather conditions by helping to more quickly drain the paved shoulder area (and minimize the risk of standing water). This steeper cross slope will create challenges for pedestrians in wheelchairs and could also present issues for bicycles. In addition, the cross slope change at the edge of the travel lane may result in a ridge effect that can pose a challenge to a bicyclist attempting to enter or exit the shoulder area. Because this data element is not currently available in a database, it has been included in the secondary data elements that do not have readily available data sources; however, priority should be placed on assessment of this slope once a candidate project has been identified.

Secondary Data Elements

In addition to critical data elements that must be achieved for roadway shoulder accommodation of bicycles and pedestrians to be possible, several secondary data elements should be considered that may enable priority corridor identification and enhanced facility configuration. These secondary data elements generally capture the prevailing roadway conditions (width of lanes, pavement quality, percent of heavy vehicles, and crash history) as they collectively influence the practical use of roadway shoulders by bicyclists and pedestrians. Corridors that are designated bicycle routes should also be prioritized.

In many cases, a roadway characteristic or operational data item would further enhance the evaluation, but the information is not readily available in a database. This constraint will initially limit including the item in the preliminary screening activities but does not diminish its importance. Table 18 includes a list of these additional secondary elements.

Table 18. Secondary Data Elements to Accommodate Bicyclist and Pedestrian Roadway Shoulder Use (Rural 2-Lanes).

Critical Data Elements	Value/ Configuration	Primary Source of Information	Secondary Source of Information
Elements with Known Data Sources			
Lane Widths	12 ft preferred	SUR_W ÷ NUM_LANES value (Source: RHiNo)	Aerial Photographs
Pavement Quality	> 70 (extends up to 100)	Highway Pavement Management System database or Pavement Highway Inventory System (PHini)	http://maps.dot.state.tx.us/rider55/
Percent Heavy Vehicles	Varies	TRK_AADT (Source: RHiNo)	---
Crash History	Clusters of Bicycle or Pedestrian Crashes	CRIS	Medical Databases (not currently available, but actively under development)
Designated Bicycle Route?	Yes – Higher Priority	SEC_BIC value (Source: RHiNo)	https://www.biketexas.org/infrastructure/texas-bicycle-route-maps
Secondary Data Elements without Readily Available Data Sources			
Pedestrian volume	Pedestrians per design hour	Site Visit	Estimation Methods based on Land Use
Bicycle volume	Bicycles per design hour	Site Visit	Estimation Methods based on Land Use
Travel lane cross slope	Percent grade	Site Visit or As-Built Construction Plans	---
Shoulder cross slope	Percent grade	Site Visit or As-Built Construction Plans	---
Presence of Barriers/Guard Rails	Add additional lateral space to shoulder	Aerial Photographs or Video	Site Visit
Presence, Type, and Configuration of Rumble Strip	Provide gaps to accommodate bicycles	Aerial Photographs or Video	Site Visit
Vertical (Steep) Grades	Widen shoulder to enable passing	Site Visit or As-Built Construction Plans	---
Connectivity	Assess overall (continuous) access for bicycles and pedestrians	Aerial Photographs or Video	Site Visit

These six elements include 1) pedestrian volume, 2) bicycle volume, 3) the presence of a barrier or guard rail, 4) evaluation of rumble strip presence, type, and configuration, 5) consideration of roadway vertical grade, and 6) connectivity of usable roadway shoulder for bicycle and pedestrian activities. These six elements should be assessed at the individual project level.

Active national research efforts are currently exploring estimation techniques for pedestrian and bicycle volumes. The project team also explored ways to incorporate estimation methods into this research effort. Chapter 4 provides a review of the models developed to predict pedestrian and bicycle trips.

Chapter 2 noted that for Texas roadways with high bicycle activity, consideration should be given before the installation of rumble strips. Things to consider include size of rumble strips, rumble strip material, application of rumble strip (milled versus profile), and location of rumble strips due to bicycle use of the road. Texas follows the requirements shown in FHWA Technical Advisory T5040.39 or latest version.

Supplemental Data Elements

In addition to the critical (primary) and secondary data elements, the literature review identified a variety of potential data elements that would further enhance roadway shoulder accommodations for bicyclists and pedestrians. These remaining data elements require individual site evaluation and assessment or warrant unique consideration for the specific roadway context. As a result, these elements are not included in the list of primary or secondary data elements but could be considered, where possible, for an individual project. These include:

- Available stopping sight distance.
- Sight distance around horizontal curves.
- Presence of street lights.
- Percent buses and RVs (data not readily available).
- Scenic route.
- School bus route.

DATA COLLECTION AND DATABASE DEVELOPMENT

Based on the preliminary list of suitability criteria, the project team identified a need to explore the following tasks:

- Assemble a database to assess how road characteristics relate to the probability of a bicycle or pedestrian crash.
- Explore ways to sample shoulder suitability that may help determine presence of rumble strips, pavement edge drop-offs, and pavement quality.
- Conduct select field observation studies.
- Develop a method to estimate the number of non-motorized trips expected along a corridor.

To identify characteristics of pedestrian and bicycle crashes associated with geometric features of different rural roadway types and to estimate the number of non-motorized trips for a corridor location, the project team obtained key information from the following databases: 1) TxDOT RHiNo, 2) Texas CRIS, 3) 2010 U.S. Census Geographic Information System (GIS) data for block group level, and 4) the 2009 National Household Travel Survey (NHTS) data. The following information reviews the data acquired during this database development task.

TxDOT Roadway Inventory Database

The project team considered a variety of potential data sources for evaluating this information, but ultimately elected to use RHiNo as one of the primary sources of data. TxDOT has defined criteria for many of the candidate elements identified in this analysis. For example, currently the minimum widths of the roadway shoulders are affected by speed limit, traffic volume, and bridge reconstruction (shifting barriers away from the road). The project team considered these established variables as a starting point for assessing candidate suitability criteria data elements. The criteria listed in Table 19 identify existing TxDOT recommendations for bicycle usage (Barton, 2011). Table 20 and Table 21 depict the typical shoulder widths as recommended in the TxDOT *Roadway Design Manual*.

The project team identified a total length of 10,357 miles of rural paved roadways. Approximately 56 percent of the total roadways are rural two-lane roadways. The average shoulder width ranges from 0 to 28 ft for the rural two-lane roadways. For rural multilane roadways, the average shoulder width ranges from 0 to 32 ft. Figure 2 illustrates the Texas roadway network for rural two-lane and rural multilane roadways.

Table 19. Existing Suitability Criteria and Supporting Data.

Existing Suitability Criteria	Supporting Data
• **Shoulder Width**: 4 ft min. if speed limit is >35 mph (5 ft at rural locations with ADT > 400 vpd and where bridge decks are being replaced) • **Paved Shoulder**	• Speed Limit • Functional Classification • Traffic Volume • Number of Lanes

Source: TxDOT Internal Memorandum to District Engineer from John A. Barton, P.E. (March 23, 2011)

Table 20. 4R TxDOT Width of Shoulders for Rural Two-Lane Highways.

Functional Class	Design Speed (mph)	Minimum Width (ft) for ADT of			
		< 400	400–1500	1500–2000	> 2000
Arterial	All	4[a]	4 or 8[a]	8[a]	8–10[a]
Collector	All	2[b,c]	4[c]	8[c]	8–10[c]
Local	All	2	4	4	8

[a] On arterials, shoulders fully surfaced.
[b] On collectors, use minimum 4-ft shoulder width at locations where roadside barrier is used.
[c] For collectors, shoulders fully surfaced for 1500 or more ADT. Shoulder surfacing not required but desirable even if partial width for collectors with lower volumes and all local roads.

Source: Based on Table 3-8, p. 3-27 TxDOT (2014).

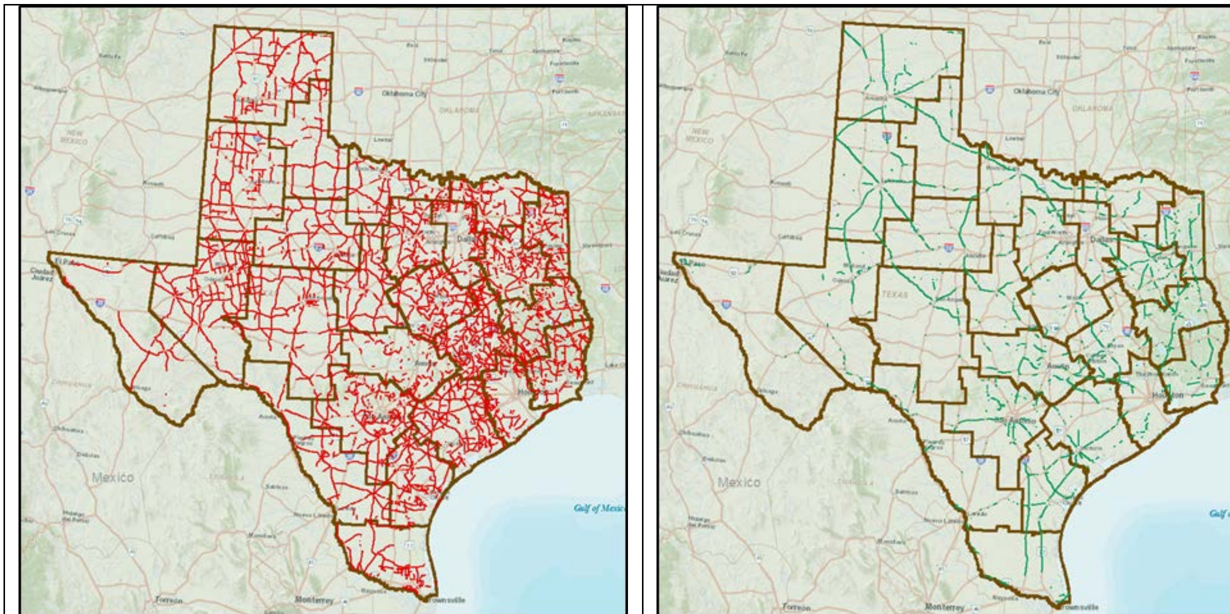
Table 21. 4R TxDOT Width of Shoulders for Rural Multilane Highways.

Type of Facility	Four-Lane Undivided	Four-Lane Divided	Six-Lane Divided
Shoulder Width (ft)	8[a] to 10	8[a] to 10	8[a] to 10

[a] Applies to collector roads only. On four-lane undivided highways, outside surfaced shoulder width may be decreased to 4 ft where flat (1V:10H), sodded front slopes are provided for a minimum distance of 4 ft from the shoulder edge.

Source: Based on Table 3-12, p. 3-37 TxDOT (2014)

Note that the shoulder widths reflected in Table 20 and Table 21 represent 4R projects that include new locations or reconstruction for rural two-lane and rural multilane highways, respectively. Projects designated as 3R (thin overlays and minor safety upgrades on existing alignments) are not expected to accommodate bicycle shoulder activity as the 3R multilane rural highways can have 4 ft minimum width shoulders with 11 ft lanes. The 3R two-lane highways can have minimum shoulder widths ranging from 0 ft up to 3 ft with travel lanes as low as 10 ft wide.



Rural two-lane roadways | **Rural multilane roadways**

Figure 2. Texas Rural Two-Lane and Multilane Roads of Interest.

Pedestrian and Bicycle Crash Data

One objective of this research effort was to investigate the association between shoulder width and frequency of crashes. For this analysis, the project team acquired three years (2011 to 2013) of pedestrian and bicycle crash data from the TxDOT CRIS database. CRIS consists of three separate datasets: crash data, person data, and vehicle data. Next, the project team prepared a merged dataset for non-motorized crashes by combining all of these three tables. As an example, Table 22 lists yearly crash data for three TxDOT districts (Austin, San Antonio, and Bryan) for both rural two-lane and multilane roadways. The frequency of crashes was higher for rural two-lane highways in all three districts.

Table 22. Pedestrian and Bicycle Crashes in Three Districts (Based on Roadway Type).

District Name	Roadway Type	Pedestrian Crashes			Bicycle Crashes			Pedestrian and Bicycle Crashes		
		2011	2012	2013	2011	2012	2013	2011	2012	2013
Austin	Rural Two-Lane	5	6	13	3	1	2	8	7	15
	Rural Multilane	7	3	8	2	9	3	9	12	11
San Antonio	Rural Two-Lane	4	13	12	5	3	4	9	16	16
	Rural Multilane	2	4	4	0	1	0	2	5	4
Bryan	Rural Two-Lane	5	5	6	2	1	3	7	6	9
	Rural Multilane	2	2	1	0	2	0	2	4	1

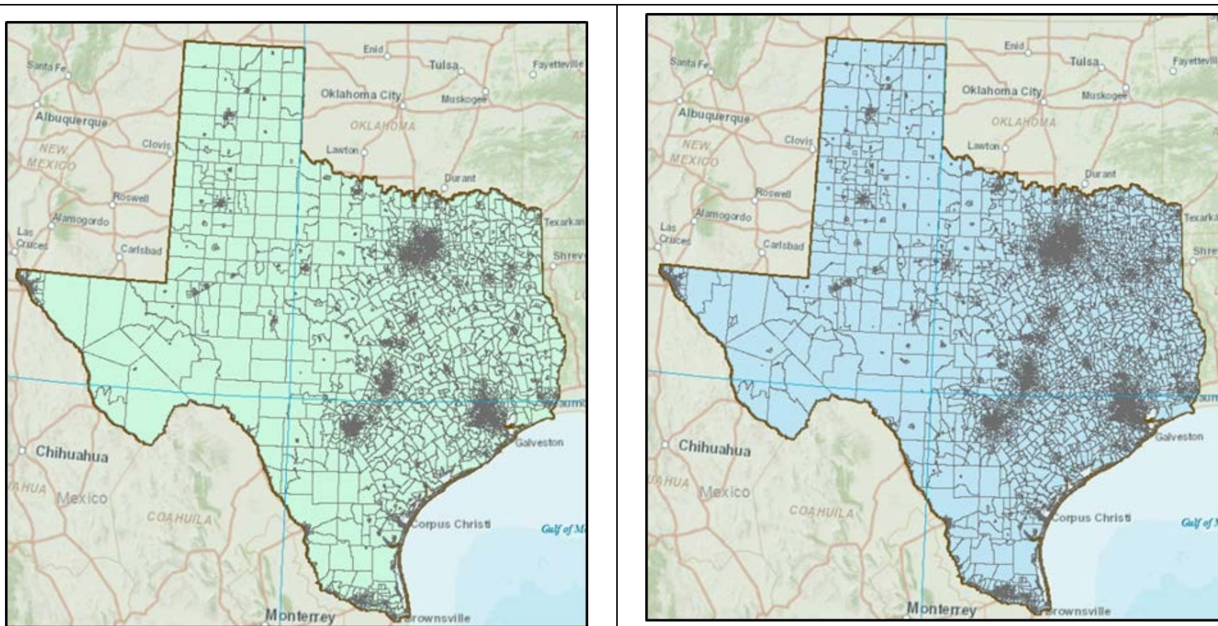
The project team contrasted the bicycle and pedestrian crashes to motor-vehicle-only crashes in an effort to identify differences in these target crash conditions. This detailed analysis is reviewed in Chapter 4.

U.S. Census Data

The project team obtained 2010 Census demographic and geographic data from two sources: the demographic information from the American FactFinder, and the block shapefiles from the 2015 Topologically Integrated Geographic Encoding and Referencing (TIGER). Census data are generally subdivided into three major units:

- Tract: The highest-level geographic unit, relatively permanent statistical subdivisions of a region, generally defined to contain 1200 to 8000 people, identified with an integer number of up to four digits.
- Block Group: The intermediate-level geographic unit, the division of tracts, and clusters of blocks, generally defined as containing 600 to 3000 people, identified as first digit of the block code.
- Block: The lowest-level geographic unit, the division of block groups, generally small statistical areas bounded by visible features such as roads, streets, small bodies of water, or railroad tracts.

The project team collected both tract level and block group level Census data for Texas. Figure 3 shows a map comparing two of the census geographic subdivisions (tracts and block groups) for Texas.



U.S. Census Tracts for Texas **U.S. Census Block Groups for Texas**

Figure 3. U.S. Census Data Analysis Units for Texas.

The amount of available demographic and economic data from the census website is based on the geographic unit. More data are readily available at the tract level. While data at the census block level are more accurate than the data at the tract level due to its small spatial size, the number of data items at the bock level is considerably limited.

National Households Travel Survey Data

Data associated with non-motorized travel are very limited. One of the principal sources for data of non-motorized trips available to transportation professionals is the NHTS database. FHWA conducts the NHTS every five to seven years to provide data on daily travel for different transportation modes. Over the years, the program has grown from the initial 15,000 household samples in 1969 to 150,147 household samples in 2009. Out of 150,147 households, 46,423 household samples were taken from Texas.

DATA SAMPLING FOR SHOULDER SUITABILITY ANALYSIS

As part of the data collection activities, the project team determined that TxDOT does not maintain a comprehensive database that documents the shoulder condition, presence of rumble strips, or pavement edge drop-offs. Consequently, the project team performed a sampling activity for the Houston and San Antonio Districts to help determine if any conclusions could be drawn regarding shoulder suitability conditions that are not directly documented in the RHiNo file. This sampling activity was ultimately applied to a more robust probability sampling activity as summarized in Chapter 4.

Prior to collecting data, it is not feasible to know the accuracy for an exact sample estimate for a given population parameter of interest. Based on previous experience, the project team targeted a sample size of 100 homogeneous segments from each of the two districts. The actual number of segments ultimately (and randomly) selected was 103 for Houston and 102 for San Antonio Districts.

For each selected segment, the project team collected details about the shoulder and median characteristics using aerial photographs from Google Earth. These data were later used to construct sampling estimates of the state of the shoulders at the district level using the probabilities of selection assigned during the sampling stage.

When appropriate, the project team acquired multiple measurements from the same segments. An example, shown in Figure 4, represents a segment from the Houston District that has rumble strips for only a portion of the segment. The homogeneous segment selection could not include rumble strips as they were not reported in the RHiNo database.

Figure 4. Segment in Houston District with Varying Shoulder Condition.

The data collected for this activity included: median width, median type, number of lanes, shoulder condition, shoulder type, presence of rumble strips, presence of shoulder pavement edge drop-off, and shoulder width (to confirm the width available in the RHiNo database). Table 23 and Table 24 show summary statistics for the data collected from each of the two districts.

Table 23. Summary Statistics for Data Collected in Houston District Sample (nHOU=103).

Number of Lanes and Median Type	Number of Measure-ments	Usable Left Shld. (%)	Left Edge Stripe (%)	Left Rumble Strip (%)	Mean Left Shld. Width (ft)	Usable Right Shld. (%)	Right Edge Stripe (%)	Right Rumble Strip (%)	Mean Right Shld. Width (ft)
2	**139**	**25**	**60**	**11**	**7.4**	**38**	**86**	**14**	**7.2**
Painted	136	24	60	10	7.3	37	85	14	7.1
TWLTL	3	100	100	33	9.3	100	100	0	8.7
4	**26**	**73**	**77**	**27**	**9.3**	**92**	**100**	**31**	**9.0**
Painted	6	50	67	0	7.6	83	100	0	7.8
TWLTL	5	20	20	0	7.8	80	100	0	7.8
Raised	6	100	100	0	8.7	100	100	0	9.0
Separated	9	100	100	78	11.3	100	100	89	10.2
5	**3**	**100**	**100**	**67**	**11.7**	**100**	**100**	**67**	**10.3**
Separated	3	100	100	67	11.7	100	100	67	10.3
6	**3**	**67**	**67**	**0**	**9.5**	**67**	**67**	**0**	**9.0**
TWLTL	2	100	100	0	9.5	100	100	0	9.0
Raised	1	0	0	0	NA	0	0	0	NA
8	**1**	**100**	**100**	**0**	**5.0**	**100**	**100**	**0**	**5.0**
Separated	1	100	100	0	5.0	100	100	0	5.0
Grand Total	**172**	**35**	**64**	**14**	**8.11**	**48**	**88**	**17**	**7.84**

Note: TWLTL refers to a 2-way left-turn lane.

Table 23 and Table 24 show that, in general, the condition observed on the right-side shoulder does not necessarily match the condition observed on the left-side. Additionally, the columns labeled “Usable Left Shld.” and “Usable Right Shld.” represent the percentage of measurements where the shoulder width was at least 3 ft (much narrower than recommended for usability).

Although the differences between Table 23 and Table 24 are informative, the intent of producing probability samples is to characterize the districts from where they were drawn. Chapter 4 presents additional detail about the district level sampling sites and the resulting estimates of district-wide conditions computed from each of the probability samples summarized in Table 23 and Table 24.

Table 24. Summary Statistics for Data Collected in San Antonio District Sample (n_{SAT}=102).

Number of Lanes and Median Type	Number of Measure-ments	Usable Left Shld. (%)	Left Edge Stripe (%)	Left Rumble Strip (%)	Mean Left Shld. Width (ft)	Usable Right Shld. (%)	Right Edge Stripe (%)	Right Rumble Strip (%)	Mean Right Shld. Width (ft)
2	**140**	**72**	**89**	**0**	**7.9**	**74**	**89**	**0**	**7.6**
Painted	133	71	88	0	7.8	72	89	0	7.6
TWLTL	7	100	100	0	8.6	100	100	0	7.4
3	**9**	**78**	**100**	**33**	**6.9**	**78**	**100**	**0**	**7.4**
Painted	8	75	100	38	6.3	75	100	0	8.0
TWLTL	1	100	100	0	10	100	100	0	4.0
4	**43**	**88**	**95**	**53**	**9.4**	**93**	**95**	**56**	**9.1**
Painted	7	71	86	0	6.6	71	86	0	6.2
TWLTL	6	67	100	0	10.5	100	100	0	7.7
Separated	30	97	97	77	9.7	97	97	80	9.9
5	**2**	**100**	**100**	**0**	**11.5**	**100**	**100**	**0**	**7.0**
Painted	1	100	100	0	14	100	100	0	5.0
Separated	1	100	100	0	9.0	100	100	0	9.0
Grand Total	**194**	**76**	**91**	**13**	**8.24**	**78**	**91**	**12**	**7.94**

Note: TWLTL refers to a 2-way left-turn lane.

FIELD DATA OBSERVATIONS

The project team identified a variety of rural two-lane and multilane state roads with shoulders and performed field evaluations to determine what type of facilities with paved shoulders were commonly used by bicyclists. As part of this effort, team members contacted local bicycle clubs to determine preferred route choices. Common preferences appear to be as follows:

- Wider shoulders (greater than the 4 ft in width).
- Shoulders with pavement that does not include loose aggregate or slippery conditions due to a combination of seal coat, leaves, and weather conditions.
- Facilities with lower speed limits and/or lower operating speeds.

Because this analysis was a simple observational evaluation to determine example bicyclist behavior patterns, the project team acquired data in close proximity to the Bryan/College Station region. In the Bryan/College Station region, there are a limited number of rural two-lane locations with paved shoulders that also experience substantial bicycle activity. Based on feedback from local cycle clubs, the project team investigated popular recreational bicycle routes at the following three locations:

- Site 1: Rural two-lane roadway with 1-ft shoulders on both sides.
- Site 2: Rural two-lane roadway with 2-ft shoulders on both sides.
- Site 3: Rural two-lane roadway with 2-ft shoulders on both sides.

Note that any shoulder width less than 4 ft is assumed to be an artifact of pavement marking practices, as these narrow dimensions do not provide suitable minimum values for bicycle use.

Table 25 lists a summary of the selected sites. Length of the sites varied from 0.4 miles to 11.7 miles, and average shoulder width varied from 1 ft to 6 ft.

Table 25. Summary of Study Sites.

Condition	Site 1	Site 2	Site 3
Length (mile)	11.7	3.2	0.4
Starting Point	(30.7438,-96.2383)	(30.4018,-96.1953)	(30.3010, -94.8749)
Ending Point	(30.7287,-96.2006)	(30.5025,-96.1974)	(30.3026, -94.8813)
Highway	FM0159	FM1179, FM2038	SH0105
AADT	524	1063, 469	5010
Truck AADT	11.4	15.1	21.4
Avg. Surface Width (ft)	22	23	24
Avg. Shoulder Width (ft)	1	2	6
Max. Speed (mph)	70	70	65
Min. Speed (mph)	0	0	0

As one of the key goals was to investigate the lateral placements of vehicles and bicycles, the project team considered video recording as the most viable data collection approach. Members of the project team followed bicycles at safe distances (using a video camera mounted in their vehicle) and recorded the bicycle interactions with motor vehicles. The field observer selected the bicycle riders randomly. The equipment required for this effort included a video camera and a flexible camera tripod.

Prior to starting on-site data collection, the field observer established both starting and ending points at a given site. As the sites were selected from the recreational bicycle routes, three types of bicycle riders were observed:

- Group 1: Single bicycle rider.
- Group 2: Smaller group (two to three bicycle riders).
- Group 3: Medium group (four to 11 bicycle riders).

Table 26 summarizes this data collection effort. The project team observed more than 30 instances where bicyclists were passed by motor vehicles.

Table 26. Summary of Field Evaluation Data Collection.

Site No.	Data Collection Duration (Minutes)	Number of Interactions	Groups	Number of Groups
1	45	14	Group 2, Group 3	7
2	9	5	Group 1, Group 3	2
3	5	12	Group 1	1

Chapter 4 further reviews the observations resulting from this limited field study. The project team also attempted to observe bicycle activity on higher speed rural roads with wider shoulders and determined that bicycles tended to avoid these higher speed conditions.

SUMMARY OF CHAPTER CONTENT

Based on a preliminary list of suitability criteria, the project team assembled data that included road characteristic data, crash information, census data, and travel survey information. In addition, the project team performed a probability sampling activity using online aerial and street view information. The project team also conducted an observational study of bicycle use along select rural corridors. Chapter 4 reviews the data summary statistics and analysis for these key data elements.

CHAPTER 4. DATA ANALYSIS

The data analysis for this effort included a safety assessment of roadway conditions contrasted to observed injury crashes, a shoulder suitability assessment, an observational operational analysis, and a non-motorized vehicle trip prediction activity. Collectively, the project team used these research tasks to develop the resulting final suitability criteria recommendations (see Chapter 5). This comparison helped to identify specific thresholds that could enable TxDOT to define candidate corridors where shoulder conditions, based on width, speed, crash history, surface condition, and potential bicycle and pedestrian trips, warrant additional enhancements.

This chapter begins with an overview of the merged roadway and crash data descriptive statistics followed by an analysis of roadway conditions related to crashes. Next, the chapter summarizes the shoulder suitability analysis. The chapter then reviews findings from the field operational observations. Finally, the chapter concludes with a review of a trip prediction model for estimating these non-motorized trips.

CRASH ANALYSIS

The initial task in the evaluation of non-motorized crashes included an examination of the data for a variety of key elements. Following the descriptive statistics summary, this section further reviews a probability analysis of crashes related to these key elements of speed, shoulder width, traffic volume, and crash severity.

Descriptive Statistics

This research used the state maintained crash data compiled from 2011 through 2013. The project team prepared the primary dataset by merging three different tables (crash table, unit table, and primary person table) from the Texas CRIS. The team next merged the TxDOT RHiNo with the crash database to prepare the final dataset for the safety assessment.

The project team selected a set of key variables, included in the merged database, for detailed evaluation. These elements included: roadway geometrics (shoulder width, surface condition, and lighting), speed limit, traffic volume, environmental factors (weather), and pedestrian and bicyclist related factors (severity and predicted trips per week). Variable selection was based on key elements as identified in previous published research and factors related to current TxDOT practices and data elements identified in the available merged database.

The descriptive statistics explore variable relationships based on facility type (rural two-lane and rural multilane) and crash type (bicycle and pedestrian crashes and other ROR crashes). The roadway network for the rural two-lane and rural multilane roadways was previously depicted in Chapter 3 (see Figure 2).

An initial examination of the data indicated that some variables are highly skewed. For example, at least 90 percent of the crashes involved dry roadway surface and tangent roadway alignments, and 80 percent of the crashes occurred during clear weather for both facility types. At least 55 percent of pedestrians (up to a maximum of 73 percent) who were involved in crashes were male, and 63 percent of the pedestrians (up to a maximum of 85 percent) were white.

Figure 5 illustrates a slope graph that depicts contrasts between injury versus no injury crashes for rural two-lane roadways based on the average shoulder width. The graphic clearly shows that pedestrian and bicycle injury crashes decreased for roadways with wider shoulders (shoulder widths greater than 5 ft). This finding suggests that the current Texas recommendation of 4 ft or 5 ft for bicycle and pedestrian purposes merits additional scrutiny (see Table 19 in Chapter 3).

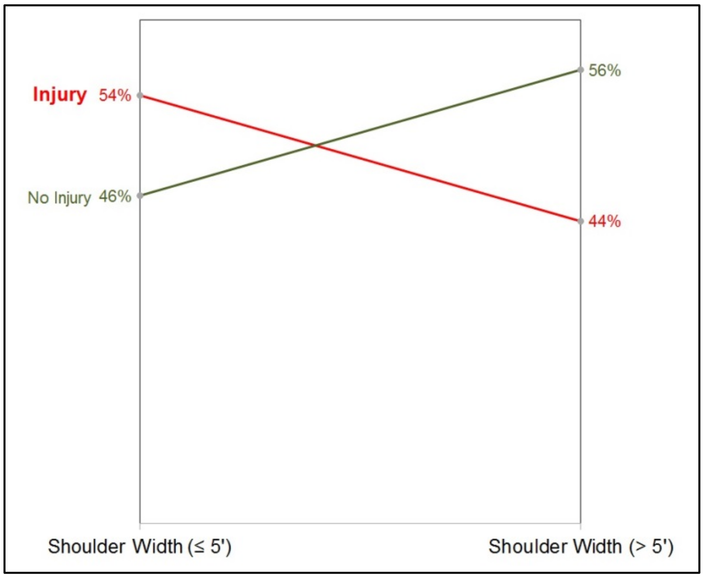


Figure 5. Slope Graph Showing Differences in Injury Types (Rural Two-Lane Roadways).

Table 27 lists the percentage of roadway and environmental factors for rural two-lane roadways with different shoulder widths. The table shows a higher percentage of pedestrian and bicycle crashes when lighting conditions were dark. It also demonstrates that a large number of the crashes occurred during normal conditions (such as daytime and clear weather conditions). These normal conditions are more likely to correspond with common time periods when recreational bicyclists are likely to be active. The percent of crashes was also greater for locations with narrower shoulders.

Table 27. Distribution of Factors for Rural Two-Lane Roadways.

Factor	Category	Shoulder Width ≤ 5' (Percent)	Shoulder Width > 5' (Percent)
Roadway Alignment	Curve	9.3	7.4
	Straight	90.7	92.7
Surface Condition	Dry	95.4	92.7
	Wet	4.7	7.4
Lighting Condition	Dark	55.8	63.7
	Day	44.2	36.3
Weather Condition	Clear	86.1	81.9
	Cloudy	10.5	12.8
	Rain	3.5	5.4

Figure 6 similarly depicts a slope graph showing the difference between injury versus non-injury for rural multilane roadways. It demonstrates that pedestrian and bicycle injury crashes significantly decreased for roadways with wider shoulders (shoulder width greater than or equal to 5 ft). These two slope graphs demonstrate that the injury severity levels for the pedestrian and bicyclists are associated with the shoulder width for both facility types.

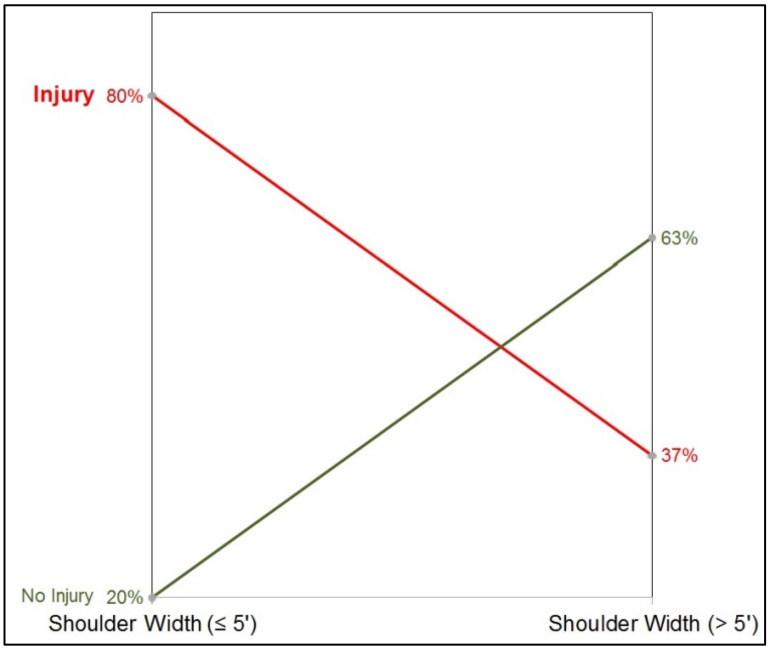


Figure 6. Slope Graph Showing Differences in Injury Types (Rural Multilane Roadways).

Table 28 lists the percentage of roadway and environmental factors for rural multilane roadways with different shoulder widths. The findings are similar to those for the rural two-lane roadways.

Table 28. Distribution of Factors in Rural Multilane Roadways.

Factor	Category	Shoulder Width ≤ 5' (Percent)	Shoulder Width > 5' (Percent)
Roadway Alignment	Curve	0.0	3.5
	Straight	100.0	96.6
Surface Condition	Dry	85.7	89.7
	Wet	14.3	10.4
Lighting Condition	Dark	57.1	55.2
	Day	42.9	44.8
Weather Condition	Clear	85.7	82.8
	Cloudy	0.0	13.8
	Rain	14.3	3.5

Table 29 provides descriptive statistics for AADT, speed limit, and shoulder width for rural two-lane and multilane facilities. These variables are further explored in the density plots shown in Figure 7 through Figure 10.

Table 29. Descriptive Statistics of the Continuous Variables.

Factors	Statistics	Rural Two-Lane	Rural Multilane
Annual Average Daily Traffic (vpd)	Minimum	404	2814
	1st Quantile	2649	4664
	Median	4475	8302
	Mean (Average)	5448	11,767
	3rd Quantile	7078	18,249
	Maximum	23,416	29,957
Speed Limit (mph)	Minimum	40	40
	1st Quantile	55	55
	Median	55.00	62.50
	Mean (Average)	59.78	61.53
	3rd Quantile	65	70
	Maximum	75	75
Shoulder Width (ft)	Minimum	1.0	1.0
	1st Quantile	4.0	5.1
	Median	8.0	7.8
	Mean (Average)	6.6	6.8
	3rd Quantile	9.0	9.3
	Maximum	10.0	10.0

In Figure 7 and Figure 8, density plots for three key factors (shoulder width, AADT, and speed limit) are illustrated for rural two-lane and rural multilane roadways, respectively, where pedestrian and bicycle crashes have occurred. The average speed limit for rural multilane roadways shows higher trends compared to that for rural two-lane roadways. The trend of AADT is also similar to the trend of the speed limit. The density plots for shoulder widths do not show significant differences for the two facility types.

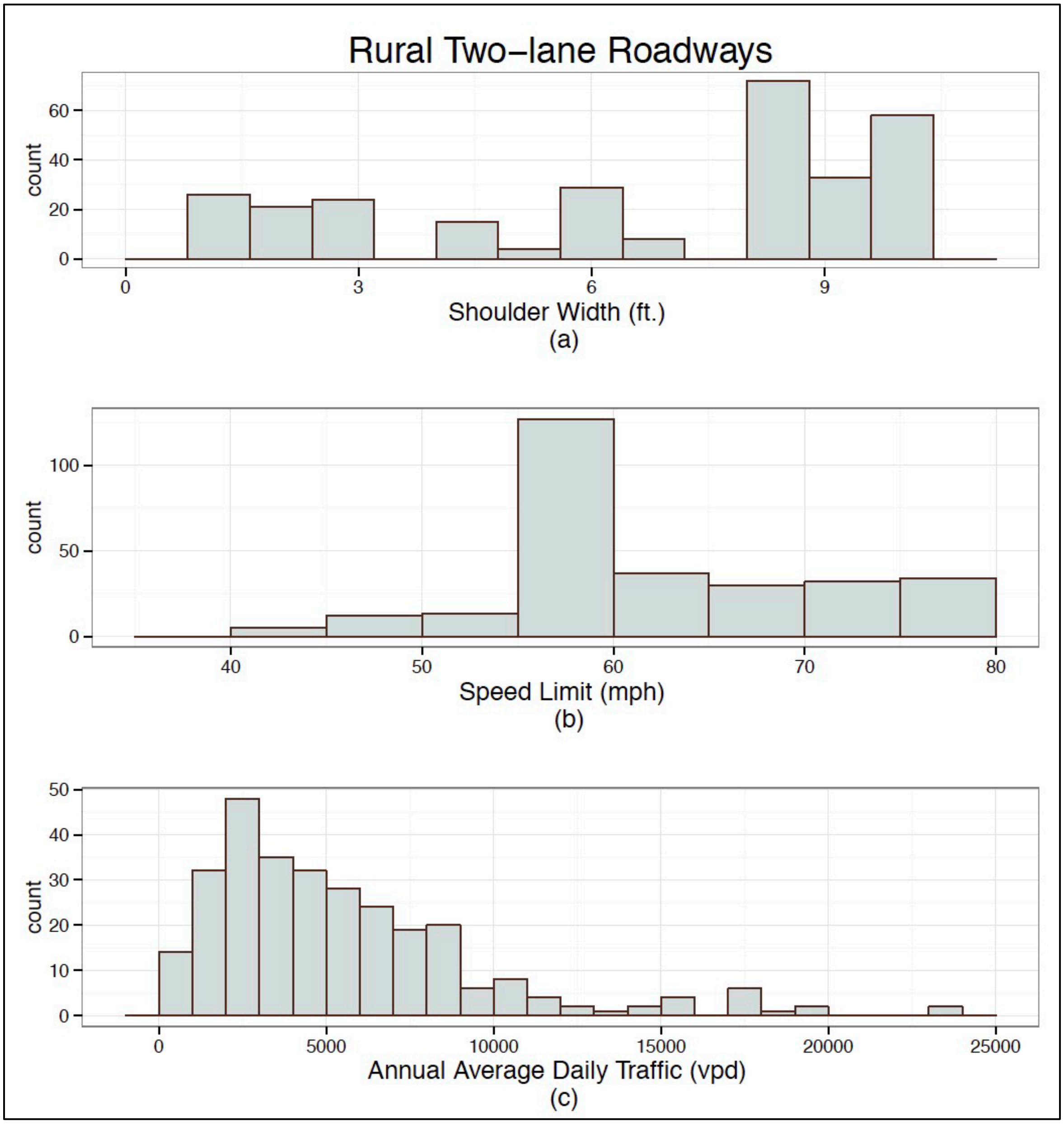


Figure 7. Shoulder, Speed Limit, and AADT Density Plots for Rural Two-Lane Roadways.

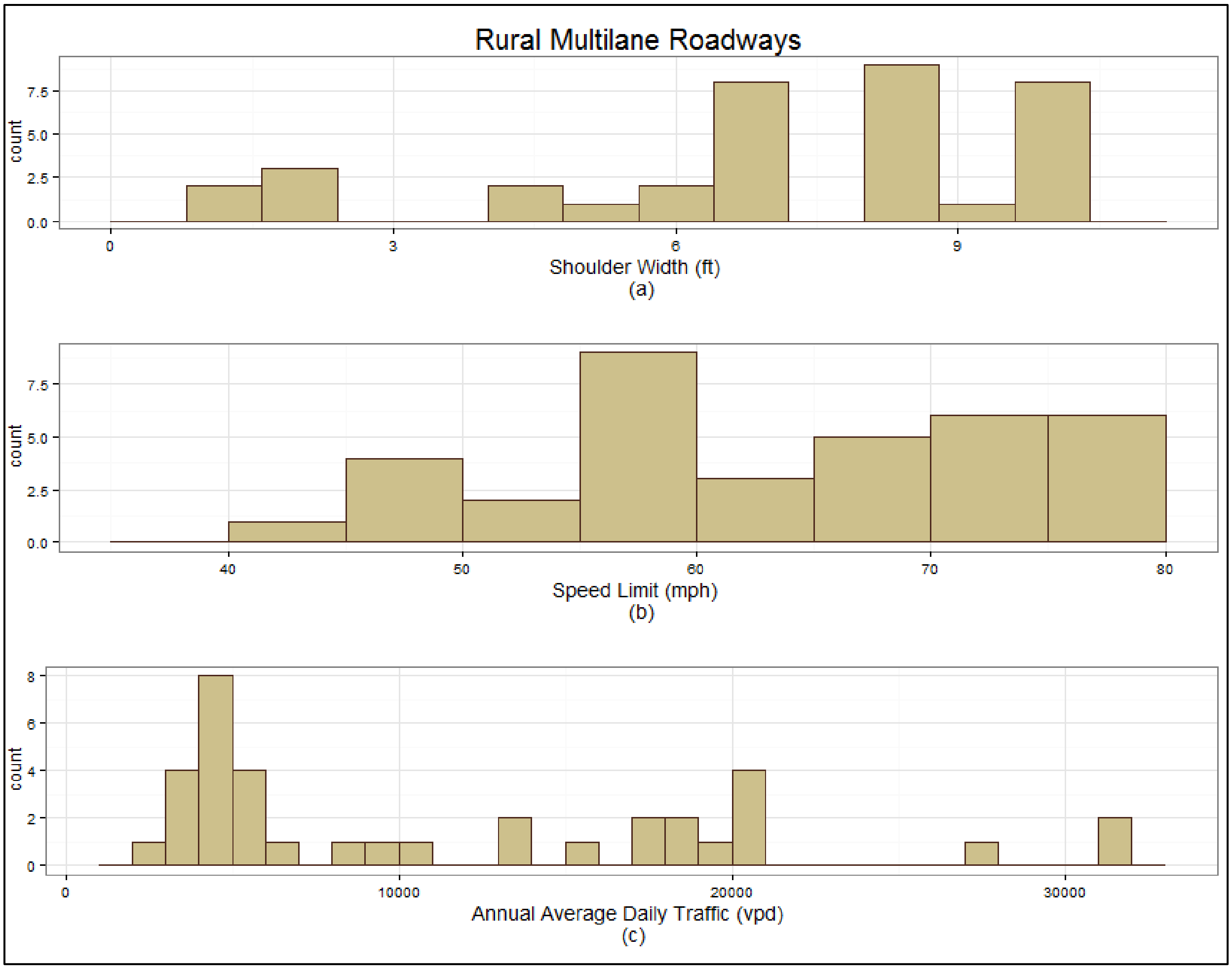


Figure 8. Shoulder, Speed Limit, and AADT Density Plots for Rural Multilane Roadways.

It is also interesting to inspect the distribution of the same key factors for similar facility types where crash types such as ROR crashes have occurred. In Figure 9 and Figure 10, density plots of the same three factors are illustrated for rural two-lane and rural multilane roadways involved with pedestrian and bicycle crashes versus ROR crashes, respectively. Roadways with observed ROR crashes appear to occur more often at roadway segment locations with speed limits greater than 60 mph. This may be due to a self-regulating behavior of bicyclists (who are avoiding higher speed roads due to the greater level of risk). Shoulder widths and AADT do not show significant differences for both roadways with different crash types.

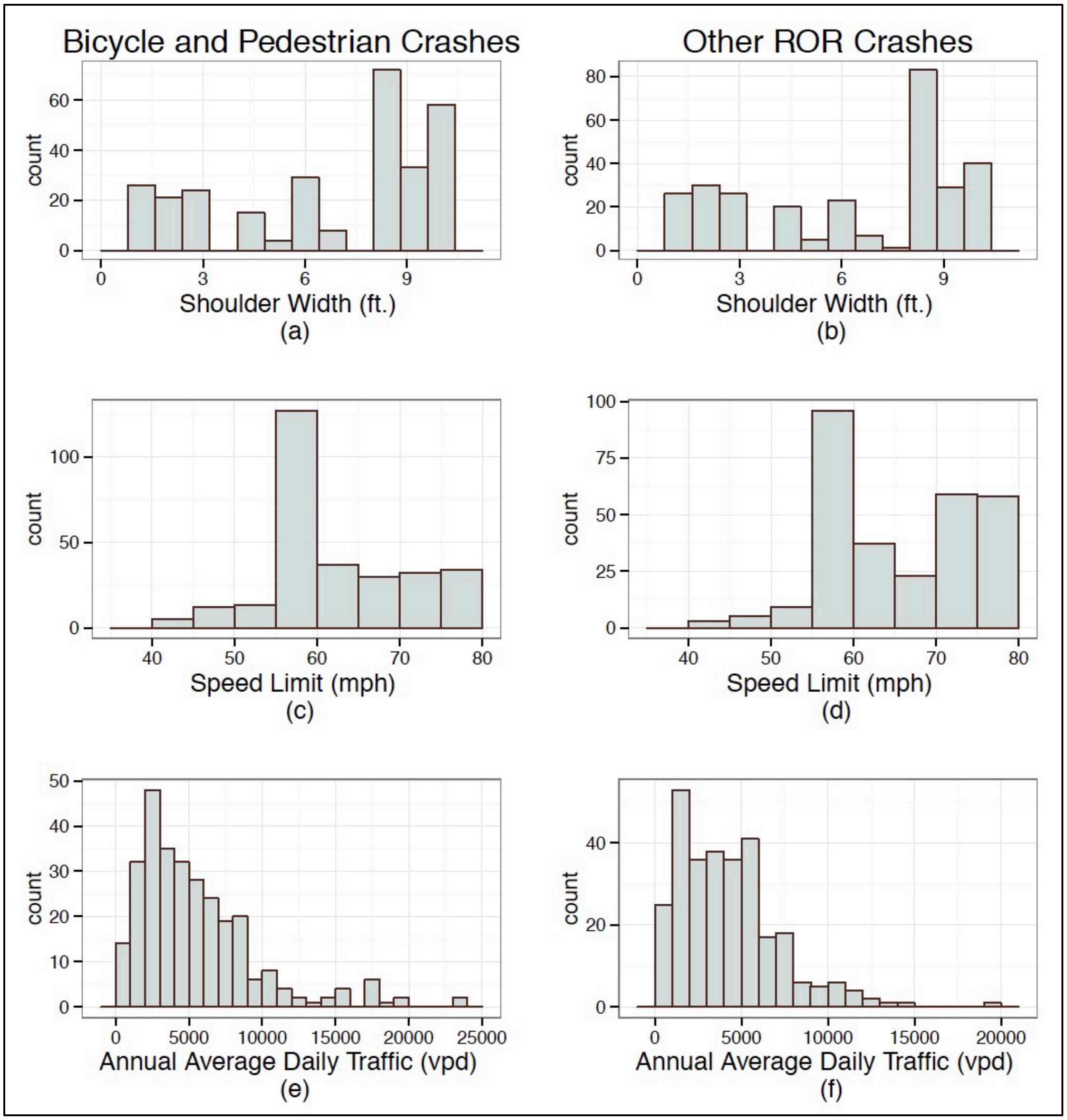


Figure 9. Density Plot Crash Type Comparisons for Rural Two-Lane Roadways.

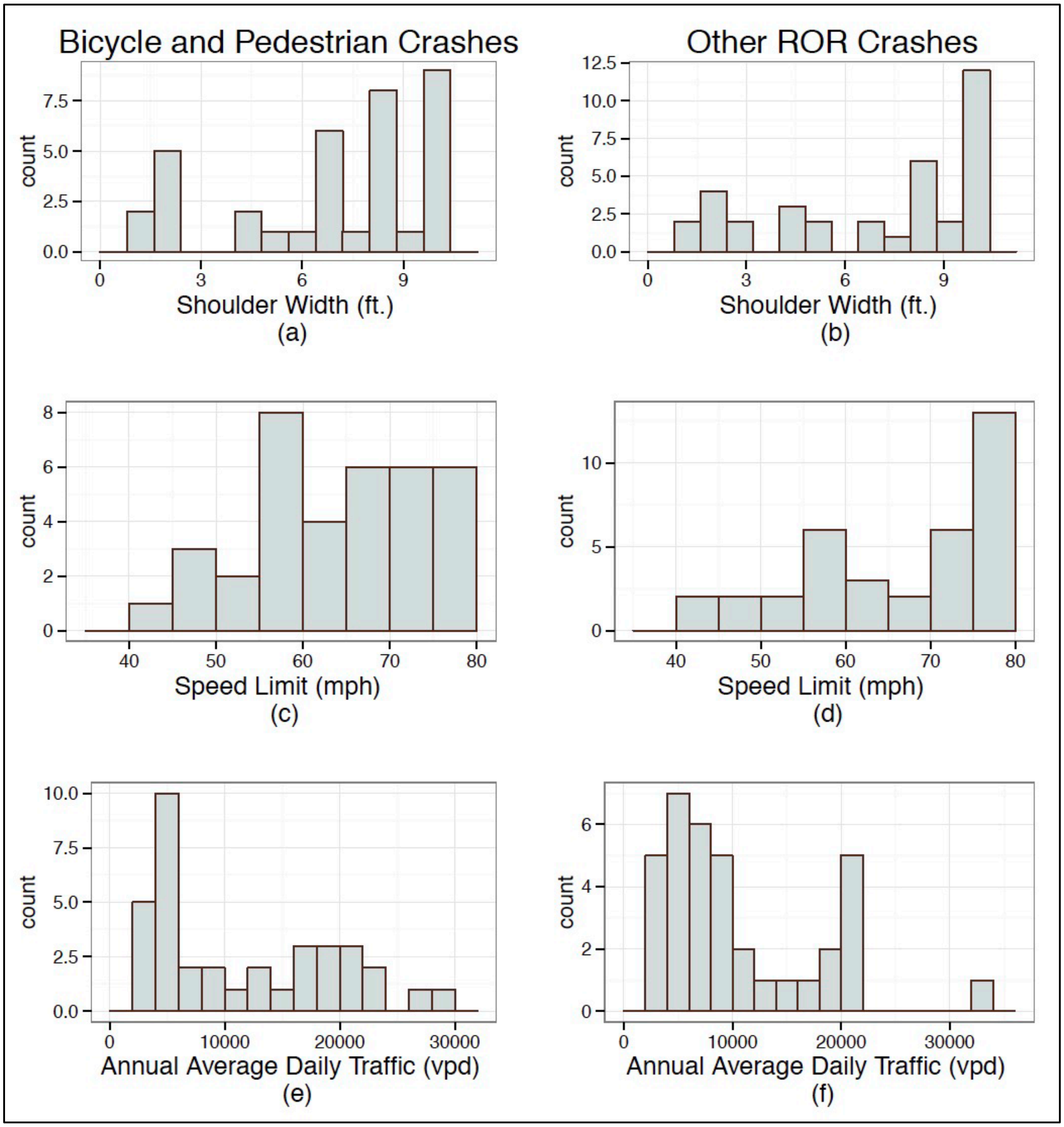


Figure 10. Density Plot Crash Type Comparisons for Rural Multilane Roadways.

Statistical Evaluation of Key Characteristics

The project team selected a probability analysis for a statistical evaluation of non-motorized crashes. This approach permits a more robust evaluation when a sample size is relatively small and can be contrasted to an alternative type of crash such as the ROR collision. The model determines that in the event a crash occurs, what is the probability that the crash will involve a bicycle or pedestrian? An analysis of all non-motorized crashes can be useful in identifying influential factors such as speed limit or functional classification; however, the goal of this research effort was to evaluate how the shoulder width and companion characteristics can influence corridor operations and safety. It is important to assess injury level non-motorized crashes as they relate to the facility type and characteristics.

Rural Two-Lane Highways

A generalized linear mixed model for non-motorized injury crashes is the optimal probability model solution for the rural two-lane roadway (see Figure 11). As shown, key variables include the speed limit and the shoulder width. Based on the signs for these variables, as the speed limit increases the non-motorized crashes also increase. The negative sign for the average shoulder width variable can be interpreted that for each additional foot of shoulder width, there is a reduction in the odds of bicycle or pedestrian injury crashes by a factor of approximately $e^{(-0.10743)} = 0.898$. **In other words, as speed limits increase and shoulder widths remain constant, crashes involving bicycles or pedestrians will increase. As speed limits are held constant and shoulder widths are increased, the bicycle or pedestrian injury crashes will decrease.** It is possible to determine the optimal effect of speed limit and shoulder width by calculating a balancing point between these two road characteristics. For each speed limit increase of 5 mph, there is an increase in bicycle or pedestrian crash severity equal to $e^{(0.03609 \times 5)} = 1.19776$. These increased odds of bicycle or pedestrian crash severity can be offset by a multiplicative decrease of 0.83489 (equivalent to 1 ÷ 1.19776). This value corresponds to an additional 1.68 ft of shoulder width. Consequently, for each 5 mph increase in speed limit, the shoulder width for a rural two-lane roadway should be increased by approximately 1.68 ft to offset safety issues introduced from the increased speed limit.

```
Generalized linear mixed model fit by maximum likelihood (Laplace Approximation) ['glmerMod']
 Family: binomial ( logit )
Formula: FplusI ~ Crash_Speed_Limit + ave.Shld + (1 | SEGMENT)
 Data: mdat

 AIC BIC logLik deviance df.resid
 381.0 395.6 -186.5 373.0 277

Scaled residuals:
 Min 1Q Median 3Q Max
-1.4650 -0.9512 -0.5644 0.9585 1.9392

Random effects:
 Groups Name Variance Std.Dev.
 SEGMENT (Intercept) 0 0
Number of obs: 281, groups: SEGMENT, 268

Fixed effects:
 Estimate Std. Error z value Pr(>|z|)
(Intercept) -1.54789 0.68122 -2.272 0.02307 *
Crash_Speed_Limit 0.03609 0.01141 3.163 0.00156 **
ave.Shld -0.10743 0.04121 -2.607 0.00914 **
---
Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

Figure 11. Rural Two-Lane Severity Model for Crashes Involving Bicycles or Pedestrians.

The mosaic plot shown in Figure 12 further depicts the relationship of shoulder width (depicted in 2-ft intervals) to the probability that a crash will involve an injury or fatality. These plots are based on a total of 281 crashes involving a bicycle or pedestrian. To interpret a mosaic plot, the width of each bar represents the number of observations. For example, shoulder widths 8-ft wide are associated with more crashes, but the probability that those crashes involve an injury or fatality is less than for narrower shoulder widths. Figure 13 similarly depicts the relationship of speed limit to pedestrian or bicycle crash severity. Note that the very small sample sizes at the lower speed thresholds result in a less stable observation, particularly at the 35 mph speed limit where only six crashes were observed.

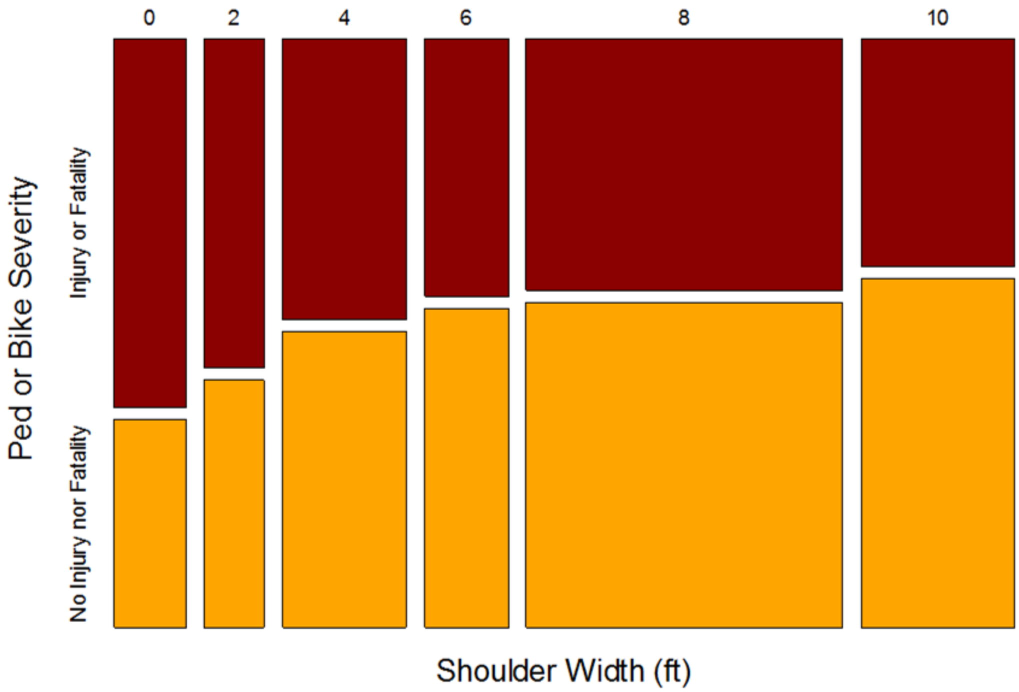


Figure 12. Mosaic Plot for Two-Lane Highway Shoulder Width Contrasted with Pedestrian and Bicycle Crash Severity.

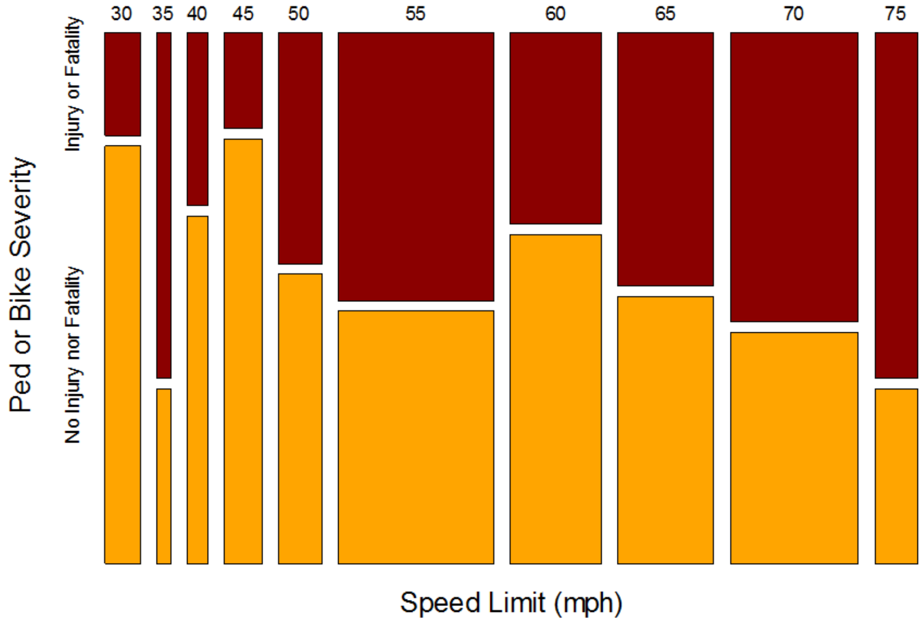


Figure 13. Mosaic Plot for Two-Lane Highway Speed Limit Contrasted with Pedestrian and Bicycle Crash Severity.

Rural Multilane Highways

For a similar analysis of rural multilane highways, the project team identified 94 injury crashes involving pedestrians or bicycles for 87 separate roadway segments. The inverse relationship between speed limit and average shoulder width is again present for multilane highways. For the multilane rural highways, the computational balance of these two variables indicates that there should be a 1-ft shoulder widening to offset each increase in speed limit of 5 mph.

```
Generalized linear mixed model fit by maximum likelihood (Laplace Approximation) ['glmerMod']
 Family: binomial ( logit )
Formula: FplusI ~ Crash_Speed_Limit + ave.Shld + (1 | SEGMENT)
 Data: mdat

 AIC BIC logLik deviance df.resid
 124.1 134.3 -58.1 116.1 90

Scaled residuals:
 Min 1Q Median 3Q Max
-3.2220 -0.8667 0.3766 0.7923 1.6404

Random effects:
 Groups Name Variance Std.Dev.
 SEGMENT (Intercept) 0.2013 0.4486
Number of obs: 94, groups: SEGMENT, 87

Fixed effects:
 Estimate Std. Error z value Pr(>|z|)
(Intercept) -1.13034 1.71351 -0.660 0.5095
Crash_Speed_Limit 0.05666 0.02598 2.180 0.0292 *
ave.Shld -0.31225 0.13279 -2.352 0.0187 *
---
Signif. codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

Figure 14. Rural Multilane Severity Model for Crashes Involving Bicycles or Pedestrians.

Mosaic plots for the multilane highway depict similar trends as noted for two-lane highways. One notable difference is the shoulder width threshold of zero to 1.5 crashes. Only two bicycle or pedestrian related crashes occurred for this condition (one crash with injury and one without). This very small sample size should be considered in conjunction with the recognition that the number of crashes for this narrow shoulder is likely low due to minimal usage by bicycles and pedestrians because of the associated narrow (dangerous) driving conditions.

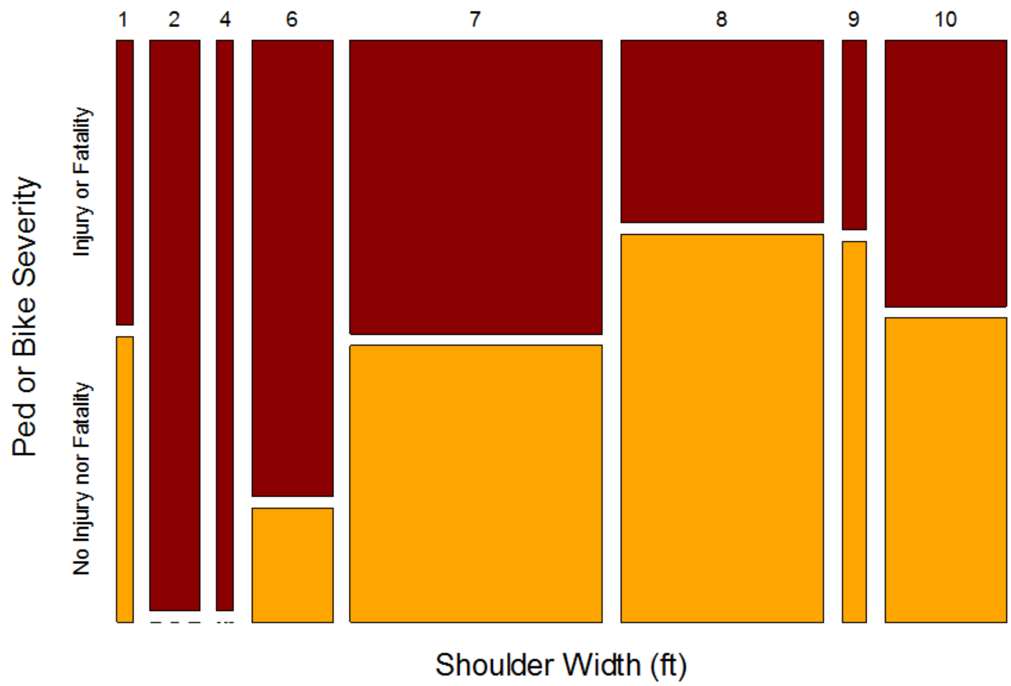


Figure 15. Mosaic Plot for Multilane Highway Shoulder Width Contrasted with Pedestrian and Bicycle Crash Severity.

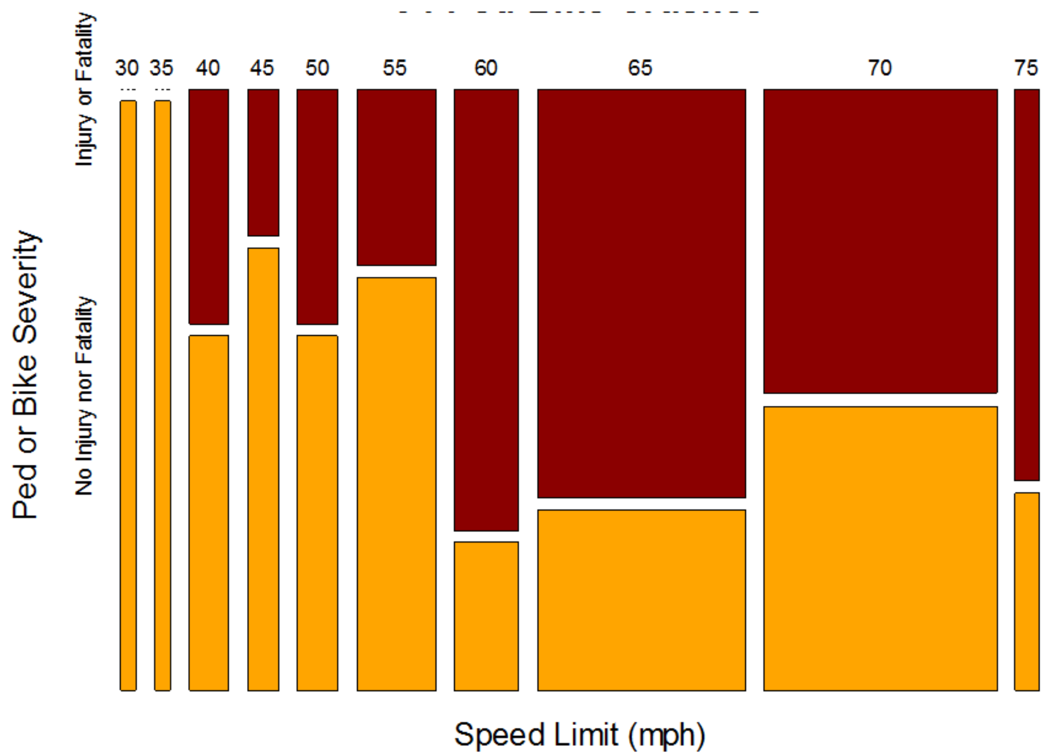


Figure 16. Mosaic Plot for Multilane Highway Speed Limit Contrasted with Pedestrian and Bicycle Crash Severity.

ASSESSING SHOULDER SUITABILITY FOR STATE MAINTAINED HIGHWAYS

The RHiNo database contains detailed characteristics of roadways maintained by TxDOT. The latest version (2013) also contains information for local roads. Despite abundant information that can be derived from this file, there are road characteristics of interest to this research that are not available from RHiNo. Presence of rumble strips and shoulder pavement edge drop-offs are of particular interest, because these factors reduce the usability of a shoulder for pedestrians and bicyclists. Additionally, discrepancies between the variables in the RHiNo database and actual conditions observed may occur from time to time. Although it is desirable to collect detailed data on shoulder conditions, the size of the Texas roadway network presents a significant challenge to develop a census of shoulder conditions for the entire roadway system.

For the above reasons, the project team collected detailed data for a subset of sites. Since it is desirable to make statements about the larger population of sites from where the sample is to be drawn, the methodology selected for this task was that of a probability sample. A probability sample allows constructing estimates for population-level variables from a subset of that population. The following probability sample section describes the application of this methodology to the particular research question: How many miles of roadway have shoulders that can be used by pedestrians and bicyclists in the Houston and San Antonio Districts? The expectation is then that these districts are representative of the state of Texas and so findings for these districts can be extended to the state level.

Probability Sample

A probability sample *S* from a finite population *Pop* is defined as a subset of elements selected randomly such that $S \subset Pop$, with the following definitions:

$$Pop = (x_i | 1 \leq i \leq N)$$
$$S = \left(x_j \middle| 1 \leq j \leq n\right)$$

Where *i* and *j:* $i \wedge j \subset \mathbb{N}$. If the sample is drawn without replacement, then $j \overset{1:1}{\rightarrow} i$.

For any probability sample, the random mechanism is any selection process that assigns a probability to selecting an element such that prior to drawing *S*, that probability is:

$$P(x_i) > 0 \forall i$$

Where $P(x_i)$ denotes the prior probability of selection to element *i* of *Pop*.

For this research, the random mechanism selected is systematic sampling with unequal probabilities and without replacement. Unequal probabilities arise from the expectation that wider shoulder widths would have a wider range of conditions (i.e., rumble strips, composite paving materials, pavement drop). Probabilities of selection were assigned in direct proportion to the shoulder width recorded in the RHiNo file.

Given the size of Texas, probability samples were limited to the Houston and San Antonio Districts. These districts were found in the exploratory analysis as districts with a relatively high number of non-motorized trips and crashes involving pedestrians and bicyclists. For each of the selected districts, the project team extracted all RHiNo segments for the following rural functional classifications:

- Major Arterial (non-freeways).
- Minor Arterial.
- Major Collector.
- Minor Collector.

Table 30. Summary Statistics of RHiNo Segments in Houston District (N_{HOU}=1947).

	Mean	Standard Deviation	Min	Max	Total
AADT (veh/day)	7498	9904	0	75,817	-
Speed Limit (mph)	42.0	23.6	0.0	70	-
Length (centerline miles)	0.78	1.01	0.001	7.89	1518.88
Average Shoulder (ft)	4.16	3.63	0.00	13.0	-

A larger portion of the Houston District is urbanized when compared to San Antonio District. This difference seems to explain why the number of centerline miles of rural highways in the San Antonio District is roughly twice that of the Houston District.

Table 31. Summary Statistics of RHiNo Segments in San Antonio District (N_{SAT}=4294).

	Mean	Standard Deviation	Min	Max	Total
AADT (veh/day)	5400	7248	20	49,104	-
Speed Limit (mph)	53.5	15.5	0	85	-
Length (centerline miles)	0.73	1.22	0.001	11.60	3116.03
Average Shoulder (ft)	4.46	3.45	0	13.5	-

For each available segment within a district, the project team assigned probabilities of selection based on two parameters: number of segments available for each functional classification and the standard deviation of the shoulder width within each functional classification (as recorded in the RHiNo database). Figure 17 (Houston) and Figure 18 (San Antonio) show the sampled sites for each district. Table 32 and Table 33 show the corresponding summary statistics.

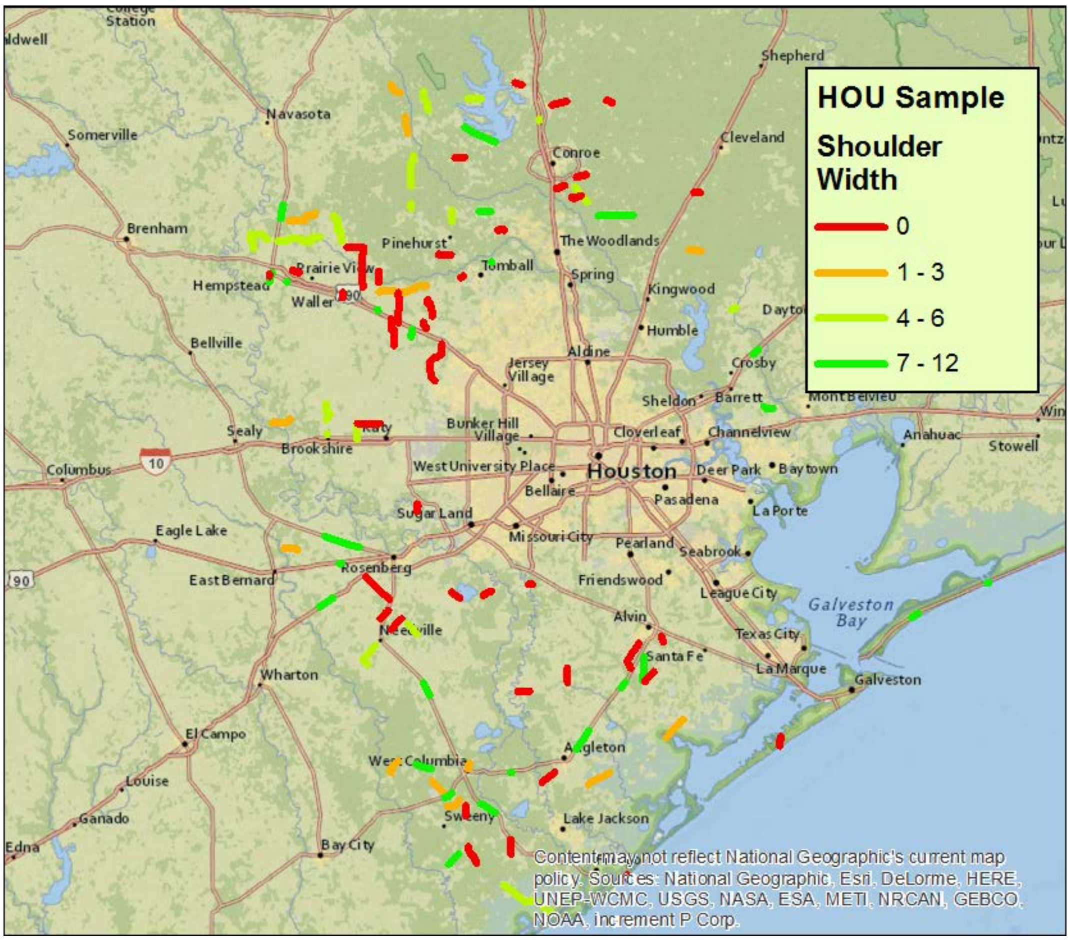


Figure 17. Sample of Segment in Houston District.

There are differences between the summaries in Table 32 and Table 30. It is apparent that the sample of 200 miles of rural roads drawn from the Houston District tends to represent lower speed limits, longer segments, and narrower shoulders.

Table 32. Summary Statistics for Sampled Segments in Houston District (n_{HOU}=103).

	Mean	Standard Deviation	Min	Max	Total
AADT (veh/day)	5284	7267	116	42,341	-
Speed Limit (mph)	33.9	27.6	0	70	-
Length (centerline miles)	1.94	1.37	0.05	6.59	200.20
Average Shoulder (ft)	3.32	3.51	0	11	-

Regardless, unbiased summary statistics of the population (i.e., the complete Houston District) can be derived from the sample because the apparent bias can be controlled using the probability of selection from each segment in the sample.

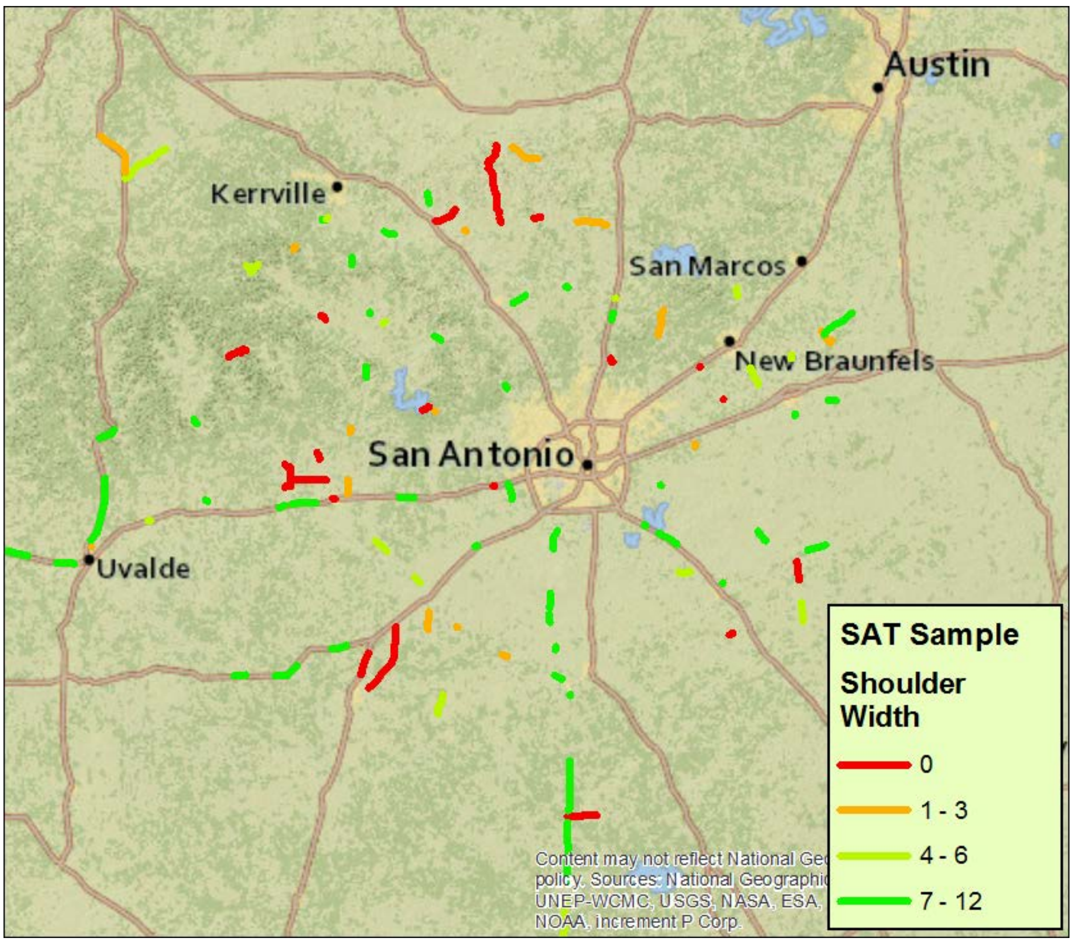


Figure 18. Sample of Segment in San Antonio District.

Similar to the case of Houston District, Table 33 shows slightly different summaries than Table 31, the numbers corresponding to the entire San Antonio District.

Table 33. Summary Statistics for Sampled Segments in San Antonio District (n_{SAT}=102).

	Mean	Standard Deviation	Min	Max	Total
AADT (veh/day)	5314	5625	38	26,710	-
Speed Limit (mph)	60.2	14.9	0	85	-
Length (centerline miles)	2.18	2.25	0.03	10.97	222.65
Average Shoulder (ft)	5.10	3.49	0	10	-

Estimating District-Wide Shoulder Conditions

Combining the data collected from the 422 miles represented in the two probability samples, the project team developed estimates of the quantities of interest. As a quality control of the estimates, the project team computed the sample estimates for the number of miles in the each district.

The project team constructed a 95 percent confidence interval from each sample estimate and verified that such interval contained the parameter being estimated (since this is a known quantity from the RHiNo file). The results of this quality check are shown in the first row of Table 34 and Table 35. In both cases, the parameter of interest is somewhere in between the lower and upper limit of the 95 percent confidence interval.

The remainder of Table 34 and Table 35 shows estimates of other mileage quantities of interest. For each estimate, a standard error and a 95 percent confidence limit is shown. The confidence interval limits for these quantities are different from the confidence interval in the first row because they include a Bonferroni adjustment for multiple comparisons.

Table 34. District-Wide Shoulder Condition Estimates for Houston District.

	Parameter	Estimate	Standard Error	95% Conf. Interval Lower Limit	95% Conf. Interval Upper Limit	95% Bonferroni Lower Limit	95% Bonferroni Upper Limit
Total rural highway miles	1518.9	1445.5	92.6	1264.1	1627.0	NA	NA
Total rural miles with shoulders ≥ 5 ft	NA	1284.3	85.6	NA	NA	1046.9	1521.8
2-lane miles with shoulders ≥ 5 ft	NA	944.4	78.8	NA	NA	726.0	1162.9
Multilane miles with shoulders ≥ 5 ft	NA	339.9	32.2	NA	NA	250.5	429.3
Total rural miles with rumble strips	NA	296.2	35.3	NA	NA	198.3	394.0
2-lane miles with rumble strips	NA	219.5	33.9	NA	NA	125.5	313.5
Multilane miles with rumble strips	NA	76.6	5.6	NA	NA	61.0	92.2
Total rural miles with 5 ft of shoulder beyond rumble strips (with or without rumble strips)	NA	1149.2	79.3	NA	NA	929.3	1369.0
2-lane miles with 5 ft of shoulder beyond rumble strips (with or without rumble strips)	NA	809.3	72.3	NA	NA	608.7	1009.8
Multilane miles with 5 ft of shoulder beyond rumble strips (with or without rumble strips)	NA	339.9	32.2	NA	NA	250.5	429.3

NA = Not Applicable

Table 35. District-Wide Shoulder Condition Estimates for San Antonio District.

	Parameter	Estimate	Standard Error	95% Conf. Interval Lower Limit	95% Conf. Interval Upper Limit	95% Bonferroni Lower Limit	95% Bonferroni Upper Limit
Total rural highway miles	3116.0	3266.9	370.9	2540.0	3993.8	NA	NA
Total rural miles with shoulders ≥ 5 ft	NA	3073.4	361.6	NA	NA	2070.7	4076.2
2-lane miles with shoulders ≥ 5 ft	NA	2751.9	343.2	NA	NA	1800.2	3703.7
Multilane miles with shoulders ≥ 5 ft	NA	321.5	63.3	NA	NA	145.9	497.1
Total rural miles with rumble strips	NA	113.5	2.2	NA	NA	107.4	119.5
2-lane miles with rumble strips	NA	0.0	0.0	NA	NA	0.0	0.0
Multilane miles with rumble strips	NA	113.5	2.2	NA	NA	107.4	119.5
Total rural miles with 5 ft of shoulder beyond rumble strips (with or without rumble strips)	NA	2126.7	315.0	NA	NA	1253.2	3000.2
2-lane miles with 5 ft of shoulder beyond rumble strips (with or without rumble strips)	NA	1814.7	301.5	NA	NA	978.6	2650.7
Multilane miles with 5 ft of shoulder beyond rumble strips (with or without rumble strips)	NA	312.0	63.3	NA	NA	136.5	487.6

NA = Not Applicable

The differences observed between estimates in Table 34 and Table 35 underscore the fact that different districts tend to have different shoulder conditions. This could be due to different maintenance procedures or rumble strip application policies for the individual districts. For example, the estimated number of rural highway miles with rumble strips in Houston (296.2) almost triples the miles with the same type of shoulder for the San Antonio District (113.5). However, a comparison of the proportions of miles with shoulder width appropriate for pedestrian and bicycle use indicates that Houston rural highways tend to be friendlier to bicyclists and pedestrians. For Houston that proportion is 75 percent (calculated as 1149.2 ÷ 1518.9 × 100), whereas in San Antonio it is 68 percent (calculated as 2126.7 ÷ 3116.0 × 100).

This shoulder usability assessment indicates that, based on the Houston and San Antonio Districts, rumple strip placement can vary dramatically. While the Houston District maintains rumble strips on approximately 19.5 percent (calculated as 219.5 ÷ 1518.9 × 100), approximately 74.1 percent (calculated as 219.5 ÷ 296.2 × 100) of the rumble strips are located on rural two-lane facilities. In contrast, the San Antonio District has rumble strips on only 3.6 percent (calculated as 113.5 ÷ 3116.0 × 100) of their rural roads and none of the rumble strips identified in this analysis were located on rural two-lane facilities.

This probability sample of shoulder usability underscores the differences between the two study districts. As a result, general observations can be determined regarding shoulder conditions, but prior to finalizing prioritization of candidate improvement corridors, a field inspection of the shoulder conditions is recommended.

SELECT FIELD EVALUATIONS

The project team attempted to conduct field observational studies of bicycle placement relative to travel lanes and motor vehicles. This effort was met with limited success due to the low number of bicycles who elected to travel on the study corridors. The goal of this effort was to evaluate bicycle placement in the shoulder region. For higher speed facilities, a common recreational bicycle activity includes multiple bicycles that travel together in a group as part of a bicycle club activity. When this occurs, the bicyclists typically use an entire lane. Because of this behavior, groups with more than three bicycles were considered as a separate, medium sized group.

The general observations from the site investigation are:

- Site 1: Smaller (three or fewer) and medium sized rider groups were found in both directions while collecting data. Smaller rider groups usually kept their bicycles closer to the edge line marking (within 1 to 2 ft). Medium rider groups occupied up to half of a travel lane. In the presence of a passing vehicle, the riders tended to shift closer to the edge line markings.

- Site 2: Eleven bicyclists were observed traveling as one group. The clustered group of bicyclists occupied one lane. Vehicles from opposing directions shifted across the edge line markings (around 1 ft) when passing the bicyclists. The bicyclists' selected lateral positions also shifted toward the edge line markings in the presence of vehicles in either direction. One individual bicycle rider was observed during the formal data collection (subsequently several have been observed but were not subjected to video). The individual rider maintained his riding path very close to the edge line marking (within 1 ft).
- Site 3: Only a single bicycle rider was observed during the study. This highway maintained wider shoulder widths (6 ft on both sides). The bicyclist kept his bicycle (within 1 to 2 ft of the edge line marking) on the shoulder throughout his ride.

The goal of this observational study was to attempt to investigate interactions between vehicles and bicyclists for varying shoulder configurations. Using the video data, the project team measured the following three unique lateral distances:

- Lateral Distance 1 (LD1): Lateral distance between the tire of the closest bicycle and the rear tire of the motorized vehicle.
- Lateral Distance 2 (LD2): Lateral distance between the tire of the bicycle and pavement edge line with no presence of passing vehicle.
- Lateral Distance 3 (LD3): Lateral distance between the tire of the bicycle and pavement edge line with presence of passing vehicle.

Table 36 summarizes statistics of these measurements.

Table 36. Summary Statistics of Three Measurements.

Site	Statistics	Lateral Distance (ft)		
		Bicycle Tire to Rear Motorized Vehicle Tire (LD1)	Bicycle Tire to Pavement Edge if No Passing Vehicle (LD2)	Bicycle Tire to Pavement Edge if Passing Vehicle Present (LD3)
1	Minimum	12	1	0.2
	Maximum	14	5	2.5
	Mean	12.5	2.4	1.4
	Std. Dev.	1.2	1.2	0.7
2	Minimum	7	2	0.5
	Maximum	13	5	4
	Mean	11.2	3.1	1.9
	Std. Dev.	1.8	1.0	1.0
3	Minimum	16	1	1
	Maximum	20	2	2.5
	Mean	18.3	1.1	1.5
	Std. Dev.	1.1	0.3	0.4

Principal findings are:

- The distance between the bicycle and the closest wheel of a passing vehicle edge did not vary greatly for the first two sites (ranging from 11.2 to 12.5 ft). The location with wider shoulder widths (Site 3) experienced the highest LD1.
- The distance between the bicycle and the pavement edge did not vary greatly for first two sites (ranging from 2.4 to 3.1 ft). For roadways with narrower shoulder, riders did not use the shoulders. Only one solitary bicyclist was observed at Site 3 and he maintained his bicycles' path on the shoulder the entire time of observation.
- LD3 measures whether there is a change in lateral placement of the bicycles when being passed by motor vehicles. Bicyclists were more likely to ride closer to the edge line in the presence of passing vehicles.

NON-MOTORIZED TRAVEL TRIP MODEL

To help prioritize the selection of potential shoulder widening locations, for the purposes of improving bicycle and pedestrian safety, there is a need to determine the number of predicted non-motorized trips per week. Locations with more of these trips should logically be ranked higher than locations without the prospect of any bicycle or pedestrian activity. Data associated with non-motorized travel are very limited. One of the principal sources for data for non-motorized trips available to transportation professionals is the NHTS database. FHWA conducts the NHTS every five to seven years to provide data on daily travel for different transportation modes. Over the years, the program has grown from the initial 15,000 household samples in 1969 to 150,147 household samples in 2009. Out of 150,147 households, 46,423 household samples were located in Texas.

The 2009 NHTS recorded 100,400 walk trips and 9400 bike trips. For Texas rural roadways, 148 households were surveyed, with a total of 1363 trips. Out of the total trips, the survey recorded 1083 walk trips and 284 bike trips. Table 37 shows the percentage of pedestrian and bike trips per week on the basis five different trip groups.

Table 37. Non-motorized Trips per Week.

Trips per Week	Pedestrian (Percent)	Bicycle (Percent)
0–5.00	43.3	64.0
5.01–10.00	36.7	32.0
10.01–15.00	6.7	0.0
15.01–20.00	3.3	0.0
Above 20.00	10.0	4.0

Table 38 summarizes the four NHTS block group level rural road variables the project team used for this analysis.

Table 38. Summary of Four Explanatory Variables.

Variable Names	Percentage (%)
Population per Sq. Mile-Block Group	
0–99	33.6
100–499	28.9
500–999	14.1
1000–1999	17.2
2000–3999	6.3
Housing Units per Sq. Mile-Block Group	
0–99	44.5
100–499	39.8
500–999	15.6
Percent Renter-Occupier- Block Group (%)	
0–4	7.8
5–14	37.5
15–24	27.3
25–34	17.2
35–44	5.5
45–54	3.1
55–64	1.6
Household Size- Block Group (Number of People)	
1	5.5
2	23.4
3	11.7
4	30.5
5	15.6
6	9.4
7	3.9

The modeling of non-motorized trips has mostly been conducted at the large spatial level (for example, city, county, census tract, or block group). Moreover, limited research has been conducted on rural spatial units. In 1999, FHWA published the "Guidebook on Method to Estimate Non-Motorized Travel" to compare various methods and tools that can be used to forecast non-motorized travel demand or that otherwise support the prioritization and analyses of bicycle and pedestrian facilities. A common approach of estimation on non-motorized trips is to use the NHTS data. Gary and Krizek (2005) used merged census data and NHTS response information to estimate bicycle trips at different geographic levels. Zupan and Pushkarev (1971) used aerial photographs to develop a linear regression model by relating pedestrian volumes per block to commercial spaces with distance to transit stops and density of sidewalk. Behnam and Patel (1977) used linear regression to estimate hourly pedestrian volume per hour in Wisconsin, based on land use characteristics. One of the first attempts of using impact of neighborhood characteristics on trip generation was conducted by Levinson and Wynn (1963). Since non-motorized travel forecasting consists of non-negative integer values and is considered as count data, it is natural to model it with the popular count data models like Poisson and negative binomial (NB). Kim and Susilo (2011) estimated pedestrian volume with Poisson regression. Miranda-Moreno et al. (2010) and Cao et al. (2006) developed a NB regression model to predict pedestrian travel demand. In another study, Hankey et al. (2012) developed NB regression models to estimate 12-hour bicycle and pedestrian count volumes.

In recent years, machine learning has gained popularity in the research community because of its efficient prediction outputs. Research on disaggregate level non-motorized trip generation models using machine learning algorithms was not previously attempted. The project team aimed to develop a method by which non-motorized trips can be predicted at a disaggregate level (on different rural roadway types) using the NHTS and U.S. Census Block Group data. The project team used the SVR techniques to develop the model based on NHTS data and then applied the model to estimate non-motorized trips per week. Appendix B describes a short review on SVR. The review is substantially based on the study of Smola and Scholkopf (1998).

The project team used five block-group level explanatory variables (population density, household size, percent renter-occupied housing, urban-rural code, and housing units per square mile) from the Texas rural roadway NHTS dataset to develop the SVR model. The project team first developed models separately for pedestrian and bicycle trips. Later team members determined that the bicycle mode share is extremely low compared to the pedestrian trips. Finally two models were developed:

- Model 1: Rural model for pedestrian trips per week.
- Model 2: Rural model for non-motorized trips (both pedestrian and bicycle) per week.

The R^2 values for both of the models are 0.92 and 0.63, respectively. The project team then used the developed models to estimate the block group based non-motorized trip counts (using the non-motorized model – Model 2). Upon intersecting the 2009 NHTS block group GIS shapefiles with the RHiNo shapefile, the roadway geometric files were then spatially referenced to the block group and their estimated non-motorized trip counts. By applying this method, the project team determined disaggregate-level non-motorized trip counts for the rural roadways of interest.

The project team ultimately determined that the population density variable was the most influential in predicting non-motorized trips at a block group level. Though variations are associated with the other tested variables, they vary substantially based on the training set sample size. Repeating the application of this SVR procedure is also not practical each time there is a need to predict the number of non-motorized trips. Consequently, the project team developed a graphic, shown in Figure 19, whereby the number of non-motorized trips can be estimated for rural Texas locations. The population density is the key input into this table. Note that the 20th percentile and 80th percentile thresholds are also shown for each population density level to demonstrate the variable nature of this type of data. Future research could further validate this model; however, the estimated thresholds extracted from this graphic do appear to be compatible with the trips per week values identified in Table 37.

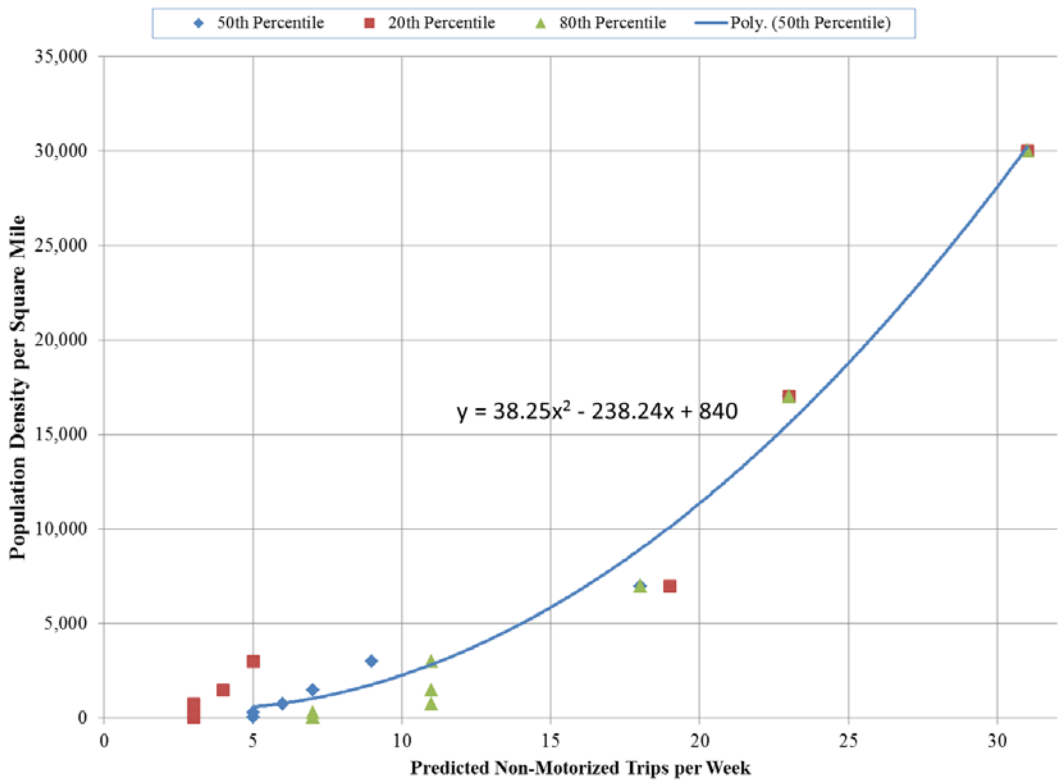


Figure 19. Predicted Number of Non-Motorized Trips per Week for Rural Texas Locations.

SUMMARY OF CHAPTER CONTENT AND FINDINGS

This chapter summarized the following four methods of analysis: crash analysis, shoulder suitability analysis, field operational study findings, and non-motorized travel trip model. Key findings are as follows:

- The majority of rural crashes that involve bicyclists or pedestrians occur during dark conditions at locations where the road is straight and the pavement surface is dry.
- For both rural two-lane and rural multilane highways, the number of bicyclist and pedestrian injuries decreases for shoulder widths greater than 5 ft.
- At rural two-lane roads, for each 5 mph increase in speed limit, the shoulder width should be increased by approximately 1.68 ft to maintain similar safety thresholds.
- At rural multilane roads, for each 5 mph increase in speed limit, the shoulder width should be increased by approximately 1 ft.
- Shoulder usability, including rumble strip presence and placement, varies by TxDOT district. Final corridor prioritization projects should include a site inspection activity to confirm actual shoulder conditions.
- Bicyclists tend to shift away from opposing or passing vehicles, and roadways with narrow shoulders and higher speed limits do not attract solitary bicyclists.
- The population density per square mile can be used to predict the number of non-motorized trips per week for rural Texas locations.

CHAPTER 5. RECOMMENDED SUITABILITY CRITERIA AND CONCLUSIONS

The research effort summarized in this report documents the analyses of bicycle and pedestrian use on rural highway shoulders. Though the criteria in use by states vary dramatically, several recurring observations are noted throughout this report. These include:

- Shoulders must be paved, well maintained, and of a type that facilitates use by bicycles or pedestrians.
- Locations where longitudinal rumble strips are present should allow additional lateral separation on the shoulder and the rumble strips should provide spaces to permit bicycles to safely enter and exit the shoulder region.
- As the risk to non-motorized users increases due to high speeds or volumes, the shoulder widths should increase to accommodate additional space.

Based on these basic observations in combination with the data collection, data analysis, and literature review activities, the project team collectively used this information to define recommended shoulder suitability criteria for bicycle and pedestrian activity. This chapter reviews the final recommended suitability criteria, offers guidance for project prioritization, and provides recommendations for future work to refine the analysis procedures as bicycle and pedestrian activity continues to increase along these rural corridors.

RECOMMENDED SHOULDER SUITABILITY CRITERIA

Many factors should be considered when evaluating if a shoulder along a rural highway is suitable for bicycle and pedestrian use. In many cases, this information can be readily accessed; however, several factors must be estimated or predicted. This section first reviews how the project team developed the shoulder width recommendations. Following the review of deriving the shoulder width, this section presents the final recommended suitability criteria and then reviews how these criteria can be applied to strategic corridor studies.

Considerations for Developing Shoulder Width Recommendations

As noted in Chapter 3, the AASHTO *A Policy on Geometric Design of Highways and Streets* (2011) recommends a minimum paved shoulder width of 4 ft but notes that this value may not be appropriate for higher speeds. The AASHTO *Guide for the Development of Bicycle Facilities* (2012) further clarifies that the 4-ft width is a minimum value, but a 5-ft width is recommended when in the vicinity of roadside obstacles such as guard rail, curb, or barriers. The *Guide* also recommends additional width when adjacent motor vehicle speeds exceed 50 mph (thereby defining the *A Policy on Geometric Design of Highways and Streets'* higher speed threshold).

The TxDOT *Roadway Design Manual* currently recommends a shoulder width of 4 ft up to 10 ft (see Table 20) for two-lane arterial highways depending on the ADT thresholds. Similarly, Table 21 recommends shoulder widths of 8 up to 10 ft for rural multilane highways.

As noted in Chapter 4, shoulder widths greater than 5 ft are shown to have fewer pedestrian or bicyclist injuries. Consequently, a 6-ft wide usable shoulder width is an advisable minimum. As the speed limit increases, however, the risk to the vulnerable users also increases. Table 39 depicts recommended shoulder widths that help to offset these limitations. The use of rumble strips on rural highways generally poses additional navigational challenges to bicyclists, so an additional 1 ft (minimum) of shoulder width is recommended at these locations.

Table 39. Recommended Shoulder Widths to Accommodate Bicycles and Pedestrians.

<table>
<tr><th>Facility</th><th>Speed Limit (mph)</th><th>Calculated Shoulder Width – No Rumble Strips (ft)</th><th>Rounded Shoulder Width – No Rumble Strips (ft)</th><th>Shoulder Width for Locations with Rumble Strips (ft)</th></tr>
<tr><td rowspan="4">Rural Two-Lane Highway (1.68' shoulder width increase for each 5 mph increase)</td><td>≤ 55</td><td>6*</td><td>6</td><td rowspan="4">Add at least 1'</td></tr>
<tr><td>60</td><td>6 + 1.68 = 7.68</td><td>8</td></tr>
<tr><td>65</td><td>6 + 2(1.68) = 9.36</td><td>10</td></tr>
<tr><td>≥ 70</td><td>6 + 3(1.68) = 11.04</td><td>11</td></tr>
<tr><td rowspan="4">Rural Multilane Highway (1.00' shoulder width increase for each 5 mph increase)</td><td>≤ 55</td><td>8 (minimum)*</td><td>8</td><td>9</td></tr>
<tr><td>60</td><td>8 + 1.00 = 9.00</td><td>9</td><td>10</td></tr>
<tr><td>65</td><td>8 + 2(1.00) = 10.00</td><td>10</td><td>10 to 11**</td></tr>
<tr><td>≥ 70</td><td>8 + 3(1.00) = 11.00</td><td>10 to 11**</td><td>10 to 12**</td></tr>
</table>

* Based on TxDOT (2014), Table 3-8, p. 3-27 and companion content
** A range of shoulder widths is presented because shoulders wider that 10 ft often will be used by motor vehicles as secondary lanes (particularly at intersection locations) and create additional problems

Final Suitability Criteria Recommendations

The shoulder width recommendations are important components of the final suitability criteria; however, the presence of rumble strips and the pavement surface condition are also critical elements for suitability. Consequently, Table 40 summarizes the final suitability criteria recommendations for the shoulder characteristics.

Table 40. Final Shoulder Suitability Criteria Recommendations.

<table>
<tr><th>Description</th><th>Speed Limit (mph)</th><th>Rural Two-Lane Roadway*</th><th>Rural Multilane Roadway*</th></tr>
<tr><td rowspan="4">Shoulder Width (No Rumble Strips Present) (ft)</td><td>≤ 55</td><td>6</td><td>8</td></tr>
<tr><td>60</td><td>8</td><td>9</td></tr>
<tr><td>65</td><td>10</td><td>10</td></tr>
<tr><td>≥ 70</td><td>10 to 11**</td><td>10 to 11**</td></tr>
<tr><td rowspan="4">Shoulder Width (Rumble Strips Present and/or Vertical Grades ≥ 5%) (ft)</td><td>≤ 55</td><td rowspan="4">May add 1' at locations with these features**</td><td>9</td></tr>
<tr><td>60</td><td>10</td></tr>
<tr><td>65</td><td>10 to 11**</td></tr>
<tr><td>≥ 70</td><td>10 to 12**</td></tr>
<tr><td>Adjacent Motor Vehicle Travel Lane (ft)</td><td>All</td><td>11 to 12</td><td>11 to 12</td></tr>
<tr><td>Rumble Strip Configuration</td><td>All</td><td colspan="2">Where present, rumble strips should have 12' periodic gaps at intervals of 40 to 60'</td></tr>
<tr><td>Shoulder Surface Type and Quality</td><td>All</td><td colspan="2">Fully paved with surface similar to that of adjacent motor vehicle lane</td></tr>
<tr><td>Pavement Maintenance</td><td>All</td><td colspan="2">Routine maintenance required to maintain debris free riding surface</td></tr>
<tr><td colspan="4">*Add an additional 1' shoulder width at locations where roadside obstacles such as guardrails or barrier are present.
** A range of shoulder widths is presented because shoulders wider that 10 ft often will be used by motor vehicles as secondary lanes (particularly at intersection locations) and create additional problems</td></tr>
</table>

Criteria Application and Prioritization for Strategic Corridor Studies

The final shoulder suitability criteria depicted in Table 40 can be systematically applied to corridor locations when determining priority for improvement projects; however, additional considerations must also be addressed. When identifying candidate locations for shoulder upgrades that are targeted specifically for bicycle and pedestrian users, the following steps are recommended:

- Step 1: First, select the type of road and study area of interest. For the study regions, determine the household population density or future expected land use density as this density information can be used to directly predict the number of non-motorized trips (by using the graphic shown in Figure 19).

- Step 2: Determine the lane and shoulder width and shoulder pavement type.
- Step 3: Narrow down the list of candidate corridors that have paved shoulder widths that are less than the recommended widths based on the suitability criteria. *Note that rumble strip and barrier information may not be known at this stage as this activity is best accomplished by sorting the data of interest.*
- Step 4: Sort the corridors identified in Step 3 based on total number of non-motorized trips.
- Step 5: Examine and prioritize the remaining corridors by performing a more detailed examination of the individual locations. This should include determining locations with rumble strips, guardrail or barrier, and steep vertical grades. This information will be used to identify the final recommended shoulder width. Also, examine locations with gaps where shoulders do not meet the criteria for sections of the road. This connectivity evaluation should also include short connections between communities of up to 3 miles.
- Step 6: Rank the resulting corridors.

Appendix C includes a *Strategic Corridor Development Plan* that demonstrates how these basic steps can be directly applied to determining priority locations for shoulder improvements that will accommodate bicycle and pedestrian safety.

ADDITIONAL RECOMMENDATIONS

The procedure for predicting non-motorized trips in rural regions holds promise; however, future refinement of the procedure for additional census variables may further improve the prediction capability. In addition, validation of the method in a future study is also recommended.

The recommended shoulder widths do not directly correspond with those currently available in TxDOT standard guideline documents. The project team further recommends that the design guidance include a focused discussion on rural locations with pedestrian and bicycle activity and how the shoulders should be designed to better accommodate this need.

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APPENDIX A – REFERENCES FROM STATE-OF-PRACTICE SECTION

In an effort to systematically evaluate how each state considers pedestrians and bicycles at rural roadway shoulder locations, the project team identified related procedures in use by each state transportation agency. This information is available via the individual transportation agencies' websites for all but four states. Table 41 summarizes the individual state documents included in the state-of-practice review summary.

Table 41. State-of-Practice Source Material for Individual States.

State	Relevant Document
Alabama	• *Alabama Department Of Transportation Bicycle And Pedestrian Plan(2010),* https://www.dot.state.al.us/moweb/doc/ALDOT_Bike_Ped.pdf
Alaska	• *Highway Preconstruction Manual (2005),* http://dmkd.cs.wayne.edu/Compendium/Compendium_Files/4/4-46.pdf • *Alaska Bicycle And Pedestrian Plan(1995),* http://ntl.bts.gov/DOCS/IGLOO.html
Arizona	• *ADOT Bicycle Policy(2007),* http://azdot.gov/docs/business/adot-bicycle-policy.pdf • *Roadway Design Guidelines (2012),* https://www.azdot.gov/docs/default-source/business/roadway-design-guidelines.pdf?sfvrsn=8
Arkansas	• *Roadway Design Plan Development Guidelines (2002),* http://www.arkansashighways.com/roadway_design_division/Roadway%20Design%20Plan%20Development%20Guidelines.pdf • *Arkansas State Bicycle And Pedestrian Transportation Plan (1998),* https://www.arkansashighways.com/planning_research/statewide_planning/bicycle_pedestrian_planning/Statewide%20Bike-Ped%20Trans%20Plan.pdf
California	• *Highway Design Manual (2012),* http://www.dot.ca.gov/hq/oppd/hdm/pdf/english/HDM_Complete_07Mar2014.pdf
Colorado	• *Roadway Design Guide (2005),* http://www.coloradodot.info/business/designsupport/bulletins_manuals/roadway-design-guide
Connecticut	• *Highway Design Manual (2003),* http://www.ct.gov/dot/lib/dot/documents/dpublications/highway/cover.pdf • *Connecticut Statewide Bicycle and Pedestrian Transportation Plan(2009),* http://www.ct.gov/dot/cwp/view.asp?a=3531&q=259656

State	Relevant Document
Delaware	• *Road Design Manual (2004)*, http://www.deldot.gov/information/ pubs_forms/manuals/road_design/index.shtml • *Delaware Bicycle Facility Master Plan (2005),* http://www.deldot.gov/information/projects/bike_and_ped/bike_facilities/ pdfs/pdf-oct-05/full_report-oct2005_rev.pdf • *Delaware Statewide Pedestrian Action Plan (2007),* http://www.deldot.gov/information/projects/bike_and_ped/delaware_ped/ pages/ped_action_plan.shtml
Florida	• *The Florida Green Book (2011),* http://www.dot.state.fl.us/rddesign/FloridaGreenbook/FGB.shtm • *Florida's Pedestrian and Bicycle Strategic Safety Plan(2013),* http://www.alerttodayflorida.com/resources/Florida_PBSSP_Feb2013.pdf
Georgia	• *Design Policy Manual (2014)*, http://www.dot.ga.gov/doingbusiness/ PoliciesManuals/roads/DesignPolicy/GDOT-DPM.pdf • *Georgia Bicycle and Pedestrian Safety Action Plan (unknown),* http://www.dot.ga.gov/travelingingeorgia/bikepedestrian/Documents/Bike PedSAP.pdf • *Georgia Pedestrian &Streetscape Guide (2003),* http://www.dot.ga.gov/travelingingeorgia/bikepedestrian/Documents/ped_ streetscape_guide_june05.pdf • *Georgia Bicycle and Pedestrian Plan Statewide Route Network (1997),* http://www.dot.ga.gov/travelingingeorgia/bikepedestrian/Documents/Geo rgia_bicycle_and_pedestrian_plan.pdf
Hawaii	• *Statewide Pedestrian Master Plan (2013),* http://hidot.hawaii.gov/highways/files/2013/07/Pedest-Plan-PedMP.pdf • *Bike Plan Hawaii Master Plan (unknown),* http://hidot.hawaii.gov/highways/bike-plan-hawaii-master-plan/
Idaho	• *Roadway Design Manual (2013),* http://itd.idaho.gov/manuals/ Manual%20Production/RoadwayDesign/files/Roadwaydesignprintable.pd f • *Idaho Bicycle and Pedestrian Transportation Plan(1995),* http://itd.idaho.gov/bike_ped/IDT.pdf • *Idaho Statewide Bicycle and Pedestrian Transportation Plan(2014),* file:///C:/Users/y-dai/Downloads/Statewide+Bicyle+and+Pedestrian+ Plan_041014PM.PDF
Illinois	• *Bureau of Design and Environment Manual-Chapter 35 Access Control/ Access Management (2010),* http://www.dot.state.il.us/desenv/BDE%20Manual/BDE/pdf/Chapter%20 35%20Access%20Control-Access%20Management.pdf • *Illinois Bike Transportation Plan (2014),* http://www.idot.illinois.gov/transportation-system/transportation-management/planning/illinois-bike-transportation-plan

State	Relevant Document
Indiana	• *The Indiana Design Manual (2010)*, http://www.in.gov/dot/div/contracts/standards/dm-Archived/10English/index.html • *Indiana State Route Bicycle Suitability Rating Criteria* (unknown), http://www.in.gov/indot/files/LRP_BicycleSuitabilityFinalDraft.pdf • *Indiana State Roadway Bicycle Suitability Map* (2014), http://www.in.gov/indot/files/LRP_BicycleSuitabilityMap.pdf
Iowa	• *Design Manual (2010)*, http://www.iowadot.gov/design/dmanual/manual.html?reload
Kansas	• *2014 Bureau of Design Manual (2014)*, http://kart.ksdot.org/Download/DownloadDetail.aspx?FileID=50 • *Kansas Bicycle and Pedestrian Transportation Plan (1995)*, http://www.ksdot.org/Assets/wwwksdotorg/bureaus/burRail/bike/Documents/bikeplan1995.pdf
Kentucky	• *Highway Design Manual(2006)*, http://transportation.ky.gov/highway-design/pages/highway-design-manual.aspx
Louisiana	• *Road Design Manual (2009)*, http://wwwsp.dotd.la.gov/Inside_LaDOTD/Divisions/Engineering/Road_Design/Pages/Road-Design-Manual.aspx • *Statewide Bicycle and Pedestrian Master Plan (2009)*, http://wwwsp.dotd.la.gov/Inside_LaDOTD/Divisions/Multimodal/Highway_Safety/Bicycle_Ped/Misc%20Documents/BikePed_Final09282009.pdf • *No: II.2.1.14 - Bicycle and Pedestrian Facilities (2000)*, http://wwwsp.dotd.la.gov/Inside_LaDOTD/Divisions/Engineering/EDSM/EDSM/EDSM_II_2_1_14.pdf
Maine	• *MaineDOT Highway Design Guide Volume II: State Standards (2003)*, http://www.maine.gov/mdot/technicalpubs/documents/pdf/hwydg/vol2/hdgstate.pdf
Maryland	• *Maryland Twenty-Year Bicycle & Pedestrian Master Plan (2014)*, http://www.mdot.maryland.gov/Office_of_Planning_and_Capital_Programming/CTP/CTP_14_19/1_Final_CTP_Documents/Final_2014_BikePed_Master_Plan.pdf
Massachusetts	• *Project Development & Design Guide (2006)*, http://www.massdot.state.ma.us/highway/DoingBusinessWithUs/ManualsPublicationsForms/ProjectDevelopmentDesignGuide.aspx • *Massachusetts Pedestrian Transportation Plan (1998)*, http://www.massdot.state.ma.us/Portals/17/docs/pedplan/PEDPLAN.PDF • *Massachusetts Bicycle Transportation Plan (2008)*, http://www.massdot.state.ma.us/portals/0/docs/bike/bikeplan2008.pdf
Michigan	• *Michigan Department of Transportation. Road Design Manual (2011)*, http://mdotcf.state.mi.us/public/design/englishroadmanual/

State	Relevant Document
Minnesota	• *Road Design Manual (2012),* http://roaddesign.dot.state.mn.us/roaddesign.aspx • *Minnesota Statewide Bicycle Planning Study (2013),* http://www.dot.state.mn.us/bike/study/Minnesota%20Statewide%20Bicycle%20Planning%20Study%20March%202013.pdf • *Minnesota Department of Transportation Bikeway Facility Design Manual (2007),* http://www.dot.state.mn.us/bike/pdfs/manual/manual.pdf • *Minnesota's Best Practices for Pedestrian/Bicycle Safety (2013),* http://www.dot.state.mn.us/stateaid/trafficsafety/reference/ped-bike-handbook-09.18.2013-v1.pdf
Mississippi	• *Roadway Design Manual (2001),* http://sp.mdot.ms.gov/RoadwayDesign/Roadway%20Design%20Manual/2001%20Roadway%20Design%20Manual.pdf
Missouri	• *Practical Design Manual (2006),* http://www.modot.org/business/documents/PracticalDesignImplementation.pdf
Montana	• *Road Design Manual (2008),* http://www.mdt.mt.gov/publications/manuals.shtml • *TranPlan 21 (2007),* http://www.mdt.mt.gov/pubinvolve/docs/tp21_summary_report.pdf
Nebraska	• *Roadway Design Manual (2012),* http://www.transportation.nebraska.gov/roadway-design/rw-design-man-chapters.htm
Nevada	• *Road Design Guide (2010),* http://www.nevadadot.com/uploadedFiles/NDOT/About_NDOT/NDOT_Divisions/Engineering/Design/2010_Road_Design_Guide.pdf
New Hampshire	• *New Hampshire Statewide Bicycle And Pedestrian Plan (2000),* http://www.nh.gov/dot/org/projectdevelopment/highwaydesign/detailsheets/index.htm
New Jersey	• *Roadway Design Manual (2011),* http://www.state.nj.us/transportation/eng/documents/RDM/ • *Bikeway Planning and Design Guidelines (unknown),* http://www.state.nj.us/transportation/publicat/pdf/BikeComp/introtofac.pdf • *New Jersey Bicycle and Pedestrian Master Plan (2004),* http://www.nj.gov/transportation/commuter/bike/pdf/bikepedmasterplanphase2.pdf
New Mexico	---
New York	• *Highway Design Manual-Chapter 5 (2011),* https://www.dot.ny.gov/divisions/engineering/design/dqab/hdm • *The New York State Bicycle And Pedestrian Plan (1997),* https://www.dot.ny.gov/display/programs/bicycle/maps/app_repository/bike_and_ped_plan.pdf

State	Relevant Document
North Carolina	• *Roadway Design Manual (2014),* https://connect.ncdot.gov/projects/roadway/pages/roadway-design-manual.aspx • *North Carolina Bicycle Facilities Planning And Design Guidelines (1994),* https://connect.ncdot.gov/projects/BikePed/Documents/Bicycle%20Projects%20Planning%20and%20Design%20Guidelines%20-%20Full%20Version.pdf • *The North Carolina Statewide Pedestrian and Bicycle Plan (2013)* • http://www.ncdot.gov/bikeped/download/WalkBikeNCPlanChapterslowres.pdf
North Dakota	• *Roadway Design Manual (2007),* http://www.dot.nd.gov/manuals/design/designmanual/designmanual.htm, • *North Dakota state bicycle plan (1994),* https://scholarsbank.uoregon.edu/xmlui/bitstream/handle/1794/10261/HE5738_N9N67_1994.pdf?sequence=1
Ohio	• *Location and Design Manual, Volume 1 Roadway Design (2014),* http://www.dot.state.oh.us/Divisions/Engineering/Roadway/DesignStandards/roadway/Pages/locationanddesignmanuals.aspx
Oklahoma	---
Oregon	• *Roadway Design Manual (2012),* http://www.oregon.gov/ODOT/HWY/ENGSERVICES/Pages/hwy_manuals.aspx#2012_English_Manual • *Oregon Bicycle and Pedestrian Design Guide(2011),* ftp://ftp.odot.state.or.us/techserv/roadway/web_drawings/HDM/2011%20HDM%20Rewrite/2012%20Appendix%20L%20Bike%20Ped%20Design%20Guide.pdf
Pennsylvania	• *2007 PennDOT Bicycle And Pedestrian Plan (2007),* ftp://ftp.dot.state.pa.us/public/pdf/BPPlan.pdf
Rhode Island	---
South Carolina	• *Road Design Plan Preparation Guide (unknown),* http://www.scdot.org/doing/road_plan.aspx
South Dakota	• *Road Design Manual (unknown),* http://sddot.com/business/design/forms/roaddesign/Default.aspx • *South Dakota Statewide Long Range Transportation Plan(2010),* http://www.sddot.com/resources/reports/FinalSDLRTP.pdf

State	Relevant Document
Tennessee	• *Roadway Design Guidelines (2014),* http://www.tdot.state.tn.us/chief_engineer/assistant_engineer_design/design/DesGuide.htm • *Tennessee Long-Range Transportation Plan Bicycle and Pedestrian Element (2005),* http://www.tdot.state.tn.us/plango/pdfs/plan/BicyclePed.pdf • *Update of Tennessee's State Bicycle Route Plan (2011),* http://www.tdot.state.tn.us/bikeped/pdfs/TechMemo-1-111211.pdf, http://www.tdot.state.tn.us/bikeped/pdfs/Tech-Memo-2-111211.pdf, http://www.tdot.state.tn.us/bikeped/pdfs/TechMemo-3-111211.pdf, http://www.tdot.state.tn.us/bikeped/pdfs/Tech-Memo-4-111211.pdf
Texas	• *Roadway Design Manual (2014),* http://onlinemanuals.txdot.gov/txdotmanuals/rdw/rdw.pdf • *Guidelines for Bicycle and Pedestrian Facilities in Texas (1997),* http://d2dtl5nnlpfr0r.cloudfront.net/tti.tamu.edu/documents/1449-3F.pdf • AASHTO *Guide for the Development of Bicycle Facilities, 4th edition (2012)*
Utah	• *Roadway Design Manual of Instruction (2011),* http://www.udot.utah.gov/main/f?p=100:pg:0::::V,T:,1498 • *Utah Bicycle & Pedestrian Master Plan Design Guide (unknown),* http://www.choosehealth.utah.gov/documents/pdfs/Utah_Bike_Ped_Guide.pdf
Vermont	• *Vermont State Design Standards (1997),* http://vtransengineering.vermont.gov/sites/aot_program_development/files/documents/publications/VermontStateDesignStandards.pdf • *Vermont Pedestrian and Bicycle Facility Planning and Design Manual (2002),* http://vtransengineering.vermont.gov/sites/aot_program_development/files/documents/ltf/PedestrianandBicycleFacilityDesignManual.pdf • *Vermont Pedestrian and Bicycle Policy Plan(2008),* http://vtransengineering.vermont.gov/sites/aot_program_development/files/documents/ltf/BikePedVTBPPP2-10-08Final.pdf
Virginia	• *Road Design Manual (2005),* http://virginiadot.org/business/locdes/rdmanual-index.asp • *VDOT State Bicycle Policy Plan (unknown),* http://www.virginiadot.org/programs/resources/VDOT_Bicycle_Policy_Plan.pdf
Washington	• *Design Manual (2013),* http://www.wsdot.wa.gov/publications/manuals/fulltext/M22-01/design.pdf • *Washington State Bicycle Facilities and Pedestrian Walkways Plan (2008),* http://www.wsdot.wa.gov/NR/rdonlyres/F061CF6D-7B96-4E61-BF20-50EAF2716997/0/BikePedPlan.pdf
West Virginia	---

State	Relevant Document
Wisconsin	• *Facilities Development Manual (2014),* http://roadwaystandards.dot.wi.gov/standards/fdm/index.htm • *Wisconsin Pedestrian Policy Plan 2020 (2002),* http://www.dot.wisconsin.gov/projects/state/docs/ped2020-plan.pdf • *Wisconsin Bicycle Planning Guidance(2003),* http://www.dot.wisconsin.gov/projects/state/docs/bike-guidance.pdf • *Wisconsin Bicycle Facility Design Handbook(2004),* http://www.dot.wisconsin.gov/projects/state/docs/bike-facility.pdf • *Wisconsin rural Bicycle planning guide(2006),* http://www.dot.wisconsin.gov/projects/state/docs/bicycle-rural-guide.pdf
Wyoming	• *Road Design Manual (2014),* http://www.dot.state.wy.us/home/engineering_technical_programs/manuals_publications/road_design_manual.html • *Wyoming Bicycle & Pedestrian Transportation Plan (2002),* https://www.dot.state.wy.us/files/live/sites/wydot/files/shared/Planning/Wyoming%20Bicycle%20%26%20Pedestrian%20Transportation%20Plan.pdf

APPENDIX B – REVIEW OF SUPPORT VECTOR REGRESSION

Support Vector Machines (SVM) are learning machines executing the structural risk minimization inductive principle to attain good generalization on a limited number of learning patterns. The theory was originally been developed by Vapnik et al. on a basis of a separable bipartition problem at the AT&T Bell Laboratories in 1992. The basic idea of SVM is to map the data *x* into a high-dimensional feature space *F* via a nonlinear mapping and to perform linear regression in this space. The support vector algorithm can also be applied to regression, maintaining all the main features that characterize the maximal margin algorithm; a non-linear function is learned by a linear learning machine in a kernel-induced feature space while the capacity of the system is controlled by a parameter that does not depend on the dimensionality of the space.

SVR is one of the most common application form of SVM. First, consider a training dataset $\{(x_1, y_1)........(x_n, y_n) \subset \aleph \times \Re\}$, where $\aleph$ denotes the space of the input patterns (e.g., $\aleph = \Re^d$). In ε-SV regression, the target is usually to find a function *f(x)* that has at most ε deviation from the actually obtained targets y_i for all of the training dataset. The other target is to make it as flat as possible. So, errors less than ε are acceptable, but no deviations larger than this. The linear function *f(x)* can be described as follows:

$$f(x) = \langle w, x \rangle + b \text{ with } \omega \in \aleph,\ b \in \Re \tag{1}$$

where $\langle ... \rangle$ denotes the dot product in $\aleph$. Flatness in equation (1) means smaller ω. To obtain this, minimize the Euclidean norm $\|\omega\|^2$. Formally, this can be considered as a convex optimization problem by fulfilling the condition minimize $\frac{1}{2}\|\omega\|^2$ subject to:

$$y_i - \langle w, x_i \rangle - b \le \varepsilon \ \ and \ \ \langle w, x_i \rangle + b - y_i \le \varepsilon \tag{2}$$

The convex optimization in equation (2) is feasible in cases where *f* actually exists and approximates all pairs (x_i , y_i) with ε precision. At times, some errors are usually allowed. Introduce slack variables ξ_i, ξ_i^* to handle otherwise infeasible constraints of the optimization problem in equation (2), the formulation will be:

minimize $\frac{1}{2}\|\omega\|^2 + C\sum_{i=1}^{n}(\xi_i + \xi_i^*)$ subject to:

$$\begin{cases} y_i - \langle w, x_i \rangle - b \le \varepsilon + \xi_i \\ \langle w, x_i \rangle + b - y_i \le \varepsilon + \xi_i^* \\ \xi_i, \xi_i^* \ge 0 \end{cases} \tag{3}$$

The constant $C > 0$ defines the tradeoff between the flatness of f and tolerance of deviations larger than ε. The ε -intensive loss function $|\xi|_\varepsilon$ can be described as:

$$|\xi|_\varepsilon = \begin{cases} 0 & if\, |\xi < \varepsilon| \\ |\xi| - \varepsilon & otherwise \end{cases} \tag{4}$$

The dual formulation provides the key for extending SVM to nonlinear functions. The standard dualization method utilizing Lagrange multipliers can be equated as follows:

$$L = \frac{1}{2}\|\omega\|^2 + C\sum_{i=1}^{n}(\xi_i + \xi_i^*) - \sum_{i=1}^{n}(\alpha + \xi_i - y_i + \langle \omega, x_i \rangle + b) - \sum_{i=1}^{n}\alpha_i^*(\varepsilon + \xi_i^* + y_i - \langle \omega, x_i \rangle - b) - \\ - \sum_{i=1}^{n}(n_i\xi_i + n_i^*\xi_i^*) \tag{5}$$

The dual variables in equation (5) is needed to satisfy positivity constraints (i.e., $\alpha_i, \alpha_i^*, \eta_i, \eta_i^* \ge 0$). It follows from saddle point condition that the partial derivatives of L with respect to the primal variables $(\omega, b, \xi_i, \xi_i^*)$ have to vanish for optimality condition:

$$\frac{\partial N}{\partial \xi_i^*} = C - \alpha_i^{(*)} - \eta_i^{(*)} = 0 \tag{6}$$

The dual optimization problem can be found by maximizing:

$$-\frac{1}{2}\sum_{i,j=1}(\alpha_i - \alpha_i^*)(\alpha_j - \alpha_j^*)\langle x_i, x_j \rangle - \varepsilon\sum_{i=1}^{n}(\alpha_i + \alpha_i^*) + \sum_{i=1}^{n} y_i(\alpha_i - \alpha_i^*) \tag{7}$$

The equation (7) subjects to $\sum_{i=1}^{n}(\alpha_i - \alpha_i^*) = 0, \quad and \quad \alpha_i, \alpha_i^* \in [0, C]$

Equation (7) can be rewritten as follows:

$$\omega = \sum_{i=1}^{n} (\alpha_i^* - \alpha_i) x_i \Rightarrow f(x) = \sum_{i=1}^{n} (\alpha_i - \alpha_i^*) \langle x_i, x \rangle + b \tag{8}$$

This is known as the support vector expansion (i.e., ω can be completely described as a linear combination of the training patterns x_i). Even for evaluating *f(x)*, it is not needed to compute ω explicitly (although this may be computationally more efficient in the linear setting). Computation of *b* is done by exploiting Karush-Kuhn-Tucker conditions, which state that at the optimal solution the product between dual variables and constraints has to vanish, as follows:

$$\begin{aligned} \alpha_i(\varepsilon + \xi_i - y_i + \langle \omega, x_i \rangle + b) = 0 \\ \alpha_i^*(\varepsilon + \xi_i^* + y_i - \langle \omega, x_i \rangle - b) = 0 \end{aligned} \tag{9}$$

$$\begin{aligned} (C - \alpha_i)\xi_i = 0 \\ (C - \alpha_i^*)\xi_i^* = 0 \end{aligned} \tag{10}$$

The following conclusions can be made: a) only samples (x_i , y_i) with corresponding $\alpha_i^* = C$ lie outside the ε- insensitive tube around *f*, b) α_i, α_i^* (i.e., there can never be a set of dual variables that are both simultaneously nonzero as this would require nonzero slacks in both of the directions). At last, for $\alpha_i^* \in (0, C), \xi_i^* = 0$ and moreover the second factor in equation (11) has to vanish. So, *b* can be computed as follows:

$$\begin{aligned} b = y_i - \langle \omega, x_i \rangle - \varepsilon \quad & for\ \alpha_i \in (0, C) \\ b = y_i - \langle \omega, x_i \rangle + \varepsilon \quad & for\ \alpha_i \in (0, C) \end{aligned} \tag{11}$$

From equation (11), it follows that only for $| f(x_i) - y_i | \geq \varepsilon$ the Lagrange multipliers may be nonzero. For all samples inside the ε -tube, the $\alpha_i^* = C$ vanish: for the second factor in equation (11) is nonzero, hence α_i, α_i^* has to be zero such that the Karush-Kuhn-Tucker conditions are satisfied. A sparse expansion of ω exists in terms of x_i (i.e., all x_i are not needed to describe ω). The examples that come with non-vanishing coefficients are called support vectors.

SV algorithm can be turned into nonlinear by simply preprocessing the training patterns x_i, by a map $\phi : X \rightarrow \zeta$, into some feature space ζ and then applying the standard SV regression algorithm. The expansion in equation (10) will be:

$$\omega = \sum_{i=1}^{n} (\alpha_i - \alpha_i^*) \phi(x_i) \text{ and}$$

$$f(x) = \sum_{i=1}^{n} (\alpha_i - \alpha_i^*) k(x_i, x) + b \tag{12}$$

The difference with the linear case is that ω is no longer explicitly given. In the nonlinear setting, the optimization problem corresponds to finding the flattest function in feature space, not in input space. The standard SVR to solve approximation problem is:

$$f(x) = \sum_{i=1}^{N} (\alpha^*{}_i - \alpha_i) k(x_i, x) + b \tag{13}$$

where, α_i, and α_i^* are Lagrange multipliers.

APPENDIX C – STRATEGIC CORRIDOR DEVELOPMENT PLAN

As land development expands into rural areas, pedestrian and bicycle activity increases. It is unlikely that these increased volumes of pedestrians and bicycles were anticipated when many of the highways were originally designed. The shoulders along these rural corridors may not be of suitable quality or widths to safely accommodate this growing activity. One option at these locations is for the pedestrians and bicycles to share the roadway travel lanes; however, this shared use of the travel lane introduces substantial speed differentials between motor vehicles and the pedestrians of bicyclists. There is a need to systematically establish priorities for improving the safety of all road users, with particular attention to the more vulnerable pedestrians and bicyclists. One way to accomplish this objective is for a transportation agency to perform cost-effective shoulder improvements along lower volume, higher speed highways located in close proximity to urbanized areas. This plan introduces a strategic ranking process for identifying key candidate improvement locations.

SECTION 1 – RANKING PROCESS FOR TXDOT SHOULDER IMPROVEMENT PROJECTS

Rural roadways near developments or attractions are transitioning. In many locations pedestrians or bicyclists must share the road with higher speed motor vehicles. When exclusive facilities such as shared use paths or sidewalks are not available, these users often travel on the roadway shoulder. For this reason, shoulders often require improvements to make them suitable location for these roadway users. Basic suitability requires paved, well maintained shoulders that can easily accommodate bicycles or pedestrians. Locations where longitudinal rumble strips are present should provide additional lateral separation on the shoulder. Rumble strips should also provide gaps to permit bicycles to safely enter and exit the shoulder region. As the risk to non-motorized users increases due to high speeds or volumes, the shoulder widths should increase to offset the effect of these higher speeds.

Many factors should be considered when evaluating if a shoulder along a rural highway is suitable for bicycle and pedestrian use. In many cases, this information can be readily accessed; however, several factors must be estimated or predicted. This plan includes suitable shoulder width recommendations and other roadway characteristics necessary to improve bicycle and pedestrian operations and safety along rural roadways.

Table 42 depicts shoulder suitability criteria for bicycle and pedestrian use. The use of rumble strips on rural highways generally poses additional navigational challenges to bicyclists, so an additional 1 ft (minimum) of shoulder width is recommended at these locations.

Table 42. Recommended Shoulder Suitability Criteria.

<table>
<tr><th>Description</th><th>Speed Limit (mph)</th><th>Rural Two-Lane Roadway*</th><th>Rural Multilane Roadway*</th></tr>
<tr><td rowspan="4">Shoulder Width (No Rumble Strips Present) (ft)</td><td>≤ 55</td><td>6</td><td>8</td></tr>
<tr><td>60</td><td>8</td><td>9</td></tr>
<tr><td>65</td><td>10</td><td>10</td></tr>
<tr><td>≥ 70</td><td>11</td><td>11</td></tr>
<tr><td rowspan="4">Shoulder Width (Rumble Strips Present and/or Vertical Grades ≥ 5%) (ft)</td><td>≤ 55</td><td rowspan="4">Avoid where possible, but add at least 1' at locations with these features</td><td>9</td></tr>
<tr><td>60</td><td>10</td></tr>
<tr><td>65</td><td>11</td></tr>
<tr><td>≥ 70</td><td>12</td></tr>
<tr><td>Adjacent Motor Vehicle Travel Lane (ft)</td><td>All</td><td>12</td><td>12</td></tr>
<tr><td>Rumble Strip Configuration</td><td>All</td><td colspan="2">Where present, rumble strips should have 12' periodic gaps at intervals of 40 to 60'</td></tr>
<tr><td>Shoulder Surface Type and Quality</td><td>All</td><td colspan="2">Fully paved with surface similar to that of adjacent motor vehicle lane</td></tr>
<tr><td>Pavement Maintenance</td><td>All</td><td colspan="2">Routine maintenance required to maintain debris free riding surface</td></tr>
<tr><td colspan="4">*Add an additional 1' shoulder width at locations where roadside obstacles such as guardrails or barrier are present.</td></tr>
</table>

The task of prioritizing bicycle and pedestrian shoulder improvement projects can be complex. Important ranking criteria include site location, user demand, connectivity, and suitability of existing conditions. The following six-step procedure demonstrates one approach to selecting and prioritizing these projects.

Step 1

Select the type of road and study area of interest. For the study regions, determine the household population density or future expected land use density. Census data can be used for this purpose if the population density per square mile is not known. Insert the population density value into the graphic shown in Figure 20 to directly predict the number of non-motorized trips per week for each candidate rural location.

Example Application to Predict the Number of Non-Motorized Trips

For a rural two-lane road with a population density of 12,000 people per square mile, the predicted number of non-motorized trips per week is 20 (as shown in Figure 20).

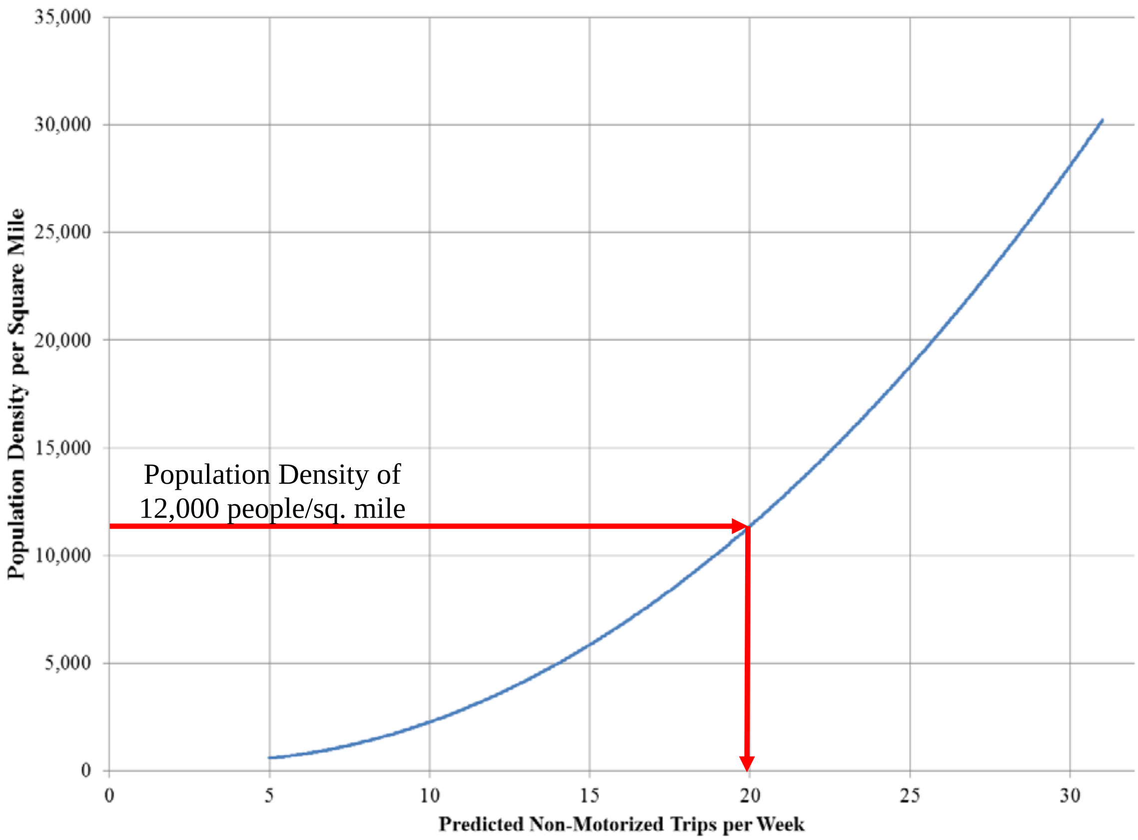

Figure 20. Predicted Number of Non-Motorized Trips per Week for Rural Texas Locations.

Step 2

Determine the existing lane width, shoulder width, and shoulder pavement type. This information is available in the RHiNo file. Maps for each TxDOT district, depicting the shoulder width and pedestrian or bicycle crashes, are included in Section 2.

Step 3

Narrow down the list to candidate corridors that have paved shoulder widths that are less than the recommended widths shown in Table 42. *Note that rumble strip and barrier information may not be known at this stage.* Table 43 (rural two-lane roadways) and Table 44 (rural multilane roadways) demonstrate the existing versus proposed comparison of potential improvement corridors identified during Step 1 and Step 2 for Texas facilities.

Step 4

Sort the corridors identified in Step 3 based on total number of non-motorized trips. Note that the Table 43 and Table 44 corridors are listed in a ranked order that is based on the number of non-motorized trips per week. When the trips are similar for two candidate locations, additional ranking should be based on 1) corridors with higher ADT values, and 2) locations with higher speed limits. Figure 21 (two-lane roadways) and Figure 22 (multilane roadways) depict the geographic location of these sites in Texas.

Step 5

Examine and prioritize the candidate corridors by performing a detailed examination of the individual locations identified during the Step 4 ranking process. This should include determining locations with rumble strips, guardrail or barrier, and steep vertical grades. This information will be used to identify the final recommended shoulder width. Also, examine locations for continuity gaps where shoulders do not meet the criteria for only a portion of the road. This connectivity evaluation should also include short connections between communities of up to 3 miles.

Step 6

Perform a final ranking of the resulting corridors based on additional information obtained during the Step 5 site-specific detailed evaluations.

Table 43. Ranked Two-Lane Sites.

Rank	Speed Limit (mph)	Primary Street	Existing Shld. Width (ft)	Proposed Shld. Width (ft)	Beginning Latitude & Longitude	Ending Latitude & Longitude	Predicted Ped/Bike Trips per week	Current ADT (vpd)
1	70	FM 665	4	10	27.72993601, -98.04257622	27.729878, -98.065102	20	10,079
2	55	TX 274	2	6	32.27985945, -96.18004904	32.2604, -96.162924	19	4675
3	55	FM 2367	2	6	28.51562624, -99.8790587	28.509715, -99.874374	11	1355
4	60	FM 1303	2	8	29.2059849, -98.33483764	29.217695, -98.362072	8	2292
5	55	FM 429	1	6	32.67471535, -96.18850638	32.679462, -96.194172	8	2203
6	55	FM 149	1	6	30.26009042, -95.7062409	30.280681, -95.713237	7	8263
7	55	FM 1485	2	6	30.14516628, -95.12680457	30.145599, -95.117524	7	6987
8	65	FM 2004	3	10	29.27689025, -95.1390837	29.293513, -95.122212	7	5939
9	70	FM 60	1	10	30.48803884, -96.48200309	30.469151, -96.502687	7	5669
10	75	TX 317	6	10	31.21640244, -97.39792962	31.202198, -97.40271	7	5504
11	60	FM 344	3	8	32.14848126, -95.40169426	32.143079, -95.353749	7	4349
12	70	US HWY 83	6	10	26.71221708, -99.11144018	26.686313, -99.108091	7	4201
13	75	US HWY 281	6	10	32.64638788, -98.09606524	32.690984, -98.110422	7	3525
14	55	FM 803	2	6	26.11993915, -97.51919149	26.09938, -97.521936	7	3270
15	60	FM 20	2	8	29.99394058, -97.43588255	29.963951, -97.448822	7	3078
16	60	FM 521	1	8	28.95490956, -95.70644855	28.985178, -95.667862	7	2613
17	70	FM 3013	5	10	29.74179673, -96.15561352	29.708791, -96.192189	7	2299
18	65	FM 534	1	10	28.02336873, -97.94024283	28.070047, -97.953804	7	2112
19	60	FM 2657	2	8	30.89582061, -97.90617815	30.924833, -97.899515	7	1692
20	55	FM 1725	2	6	30.51673253, -95.30410123	30.998127, -97.445349	7	1539
21	70	FM 3088	1	10	27.94299373, -97.825731	27.921747, -97.804918	7	1365
22	55	FM 406	2	6	33.79644736, -96.6171204	33.797521, -96.640707	6	2939
23	60	TX 146	4	8	30.44058835, -94.76639544	30.438559, -94.693599	6	2646
24	60	FM 279	2	8	32.36530767, -95.45147453	32.356317, -95.483158	6	2262

Table 43. Ranked Two-Lane Sites (Continued).

Rank	Speed Limit (mph)	Primary Street	Current Shld. Width (ft)	Proposed Shld. Width (ft)	Beginning Latitude & Longitude	Ending Latitude & Longitude	Predicted Ped/Bike Trips per week	Current ADT (vpd)
25	75	FM 1061	2	10	35.47517234, -102.1729913	35.482141, -102.134449	6	1881
26	60	FM 155	2	8	29.84680073, -96.83818683	29.864919, -96.849982	6	1389
27	60	FM 507	2	8	26.271257, -97.66169277	26.335254, -97.668645	6	1190
28	55	FM 2791	2	6	33.14507597, -94.18948175	33.144665, -94.172392	6	1083

Table 44. Ranked Multilane Sites.

Rank	Speed Limit (mph)	Primary Street	Current Shld. Width (ft)	Proposed Shld. Width (ft)	Beginning Latitude & Longitude	Ending Latitude & Longitude	Predicted Ped/Bike Trips per week	Current ADT (vpd)
1	55	TX 29	2	8	30.65857, -97.8902	30.66778, -97.9109	7	22,955
2	65	TX 29	2	10	30.69649, -97.9852	30.68194, -97.9579	7	10,453
3	65	TX 16	2	10	29.71921, -98.9104	29.71552, -98.8965	7	8261
4	70	TX 31	4	10	32.37245, -95.0467	32.36812, -95.0827	7	6781
5	75	TX 21	2	10	30.27331, -96.9636	30.28088, -96.9612	7	6564
6	70	TX 49	9	10	33.13073, -94.8934	33.13741, -94.9174	7	6345
7	70	US HWY 67	4	10	32.18207, -97.8824	32.18702, -97.8653	7	4796
8	75	TX 7	7	10	31.63045, -94.4538	31.63764, -94.426	7	4479
9	60	US HWY 83	2	9	26.39004, -98.9135	26.38299, -98.8983	6	19,125
10	75	TX 71	3	10	30.49159, -98.2309	30.47904, -98.1933	6	8264
11	75	TX 19	4	10	31.39177, -95.476	31.41565, -95.4746	6	5576
12	55	US HWY 290	6	8	30.07944, -96.021	30.07421, -95.9989	6	5293
13	75	US HWY 84	2	10	32.20252, -99.751	32.17419, -99.7512	6	4142

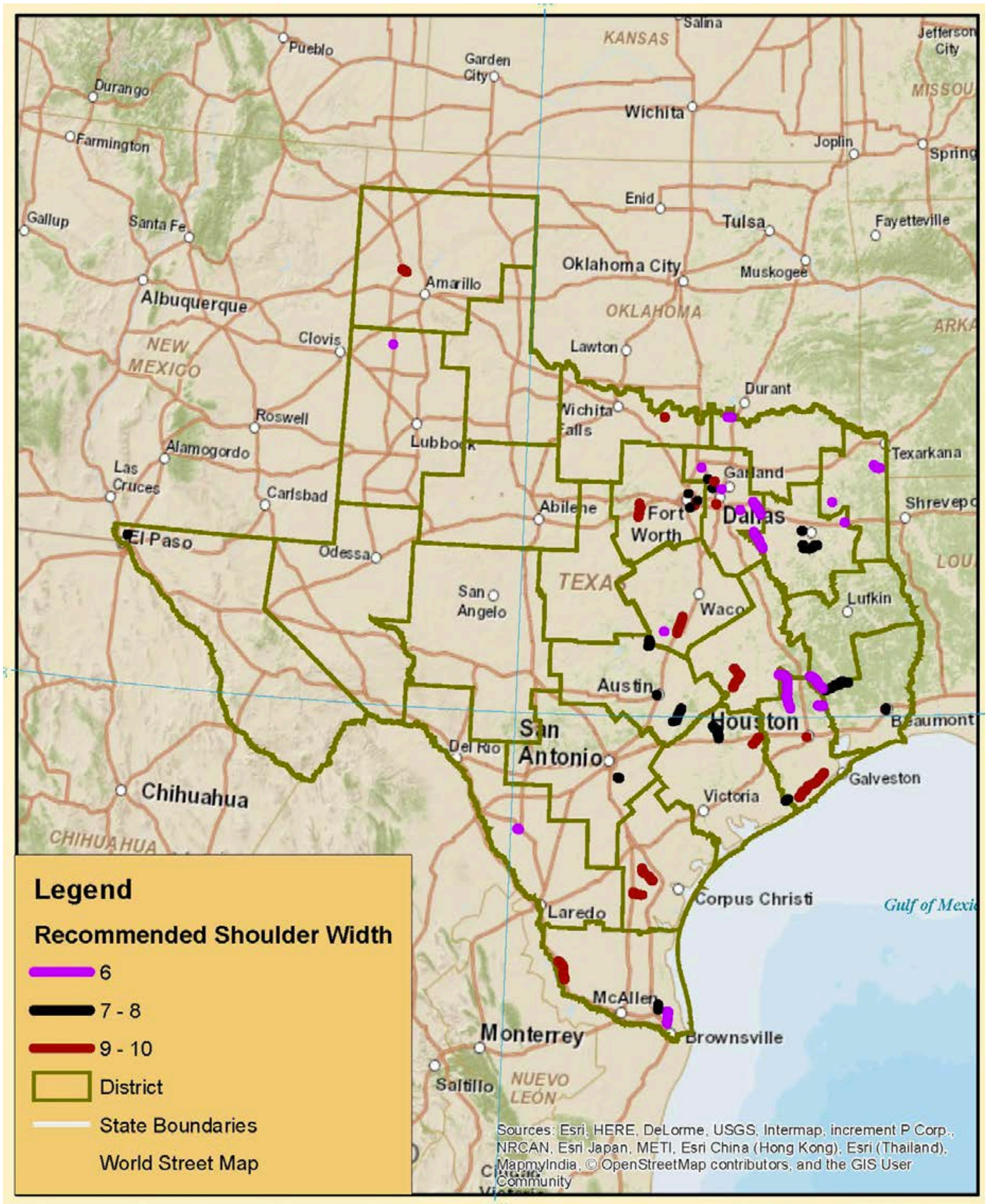

Figure 21. Candidate Improvement Corridors for Two-Lane Facilities.

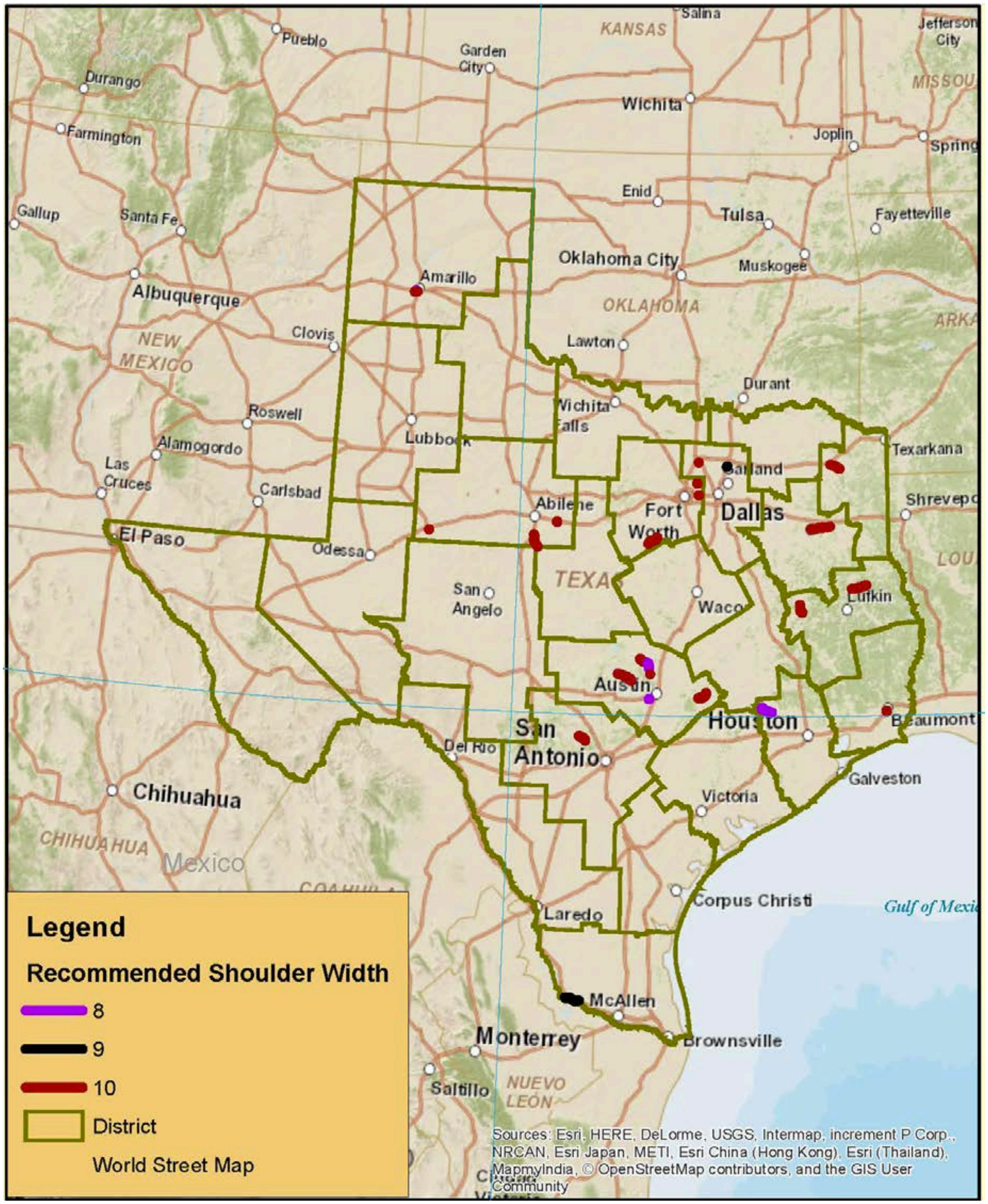

Figure 22. Candidate Improvement Corridors for Multilane Facilities.

Section 1 of this Strategic Corridor Development Plan provided a six-step process to systematically identify locations where there is a need to improve mobility for pedestrians and bicyclists. The focus of this process includes predicting the number of non-motorized trips, identifying locations where the shoulder conditions cannot comfortably accommodate these non-motorized trips, determining a ranking for prioritizing these projects, and then confirming additional site conditions that warrant additional attention and that may then further influence the prioritization of future shoulder improvement projects.

SECTION 2 – TXDOT DISTRICT SHOULDER MAPS

Section 2 of this plan provides an overview of the shoulder width conditions for the individual TxDOT districts. These maps can then be used as part of the Step 2 analysis effort to identify potential corridors that would benefit from shoulder improvement projects.

Summary of TxDOT District Maps

- Rural Two-lane Paved Shoulders with Pedestrian and Bicycle Crashes
  - TxDOT District 01
  - TxDOT District 02
  - TxDOT District 03
  - TxDOT District 04
  - TxDOT District 05
  - TxDOT District 06
  - TxDOT District 07
  - TxDOT District 08
  - TxDOT District 09
  - TxDOT District 10
  - TxDOT District 11
  - TxDOT District 12
  - TxDOT District 13
  - TxDOT District 14
  - TxDOT District 15
  - TxDOT District 16
  - TxDOT District 17
  - TxDOT District 18
  - TxDOT District 19
  - TxDOT District 20

- TxDOT District 21
- TxDOT District 22
- TxDOT District 23
- TxDOT District 24
- TxDOT District 25

- Rural Multilane Paved Shoulders with Pedestrian and Bicycle Crashes
  - TxDOT District 01
  - TxDOT District 02
  - TxDOT District 03
  - TxDOT District 04
  - TxDOT District 05
  - TxDOT District 06
  - TxDOT District 07
  - TxDOT District 08
  - TxDOT District 09
  - TxDOT District 10
  - TxDOT District 11
  - TxDOT District 12
  - TxDOT District 13
  - TxDOT District 14
  - TxDOT District 15
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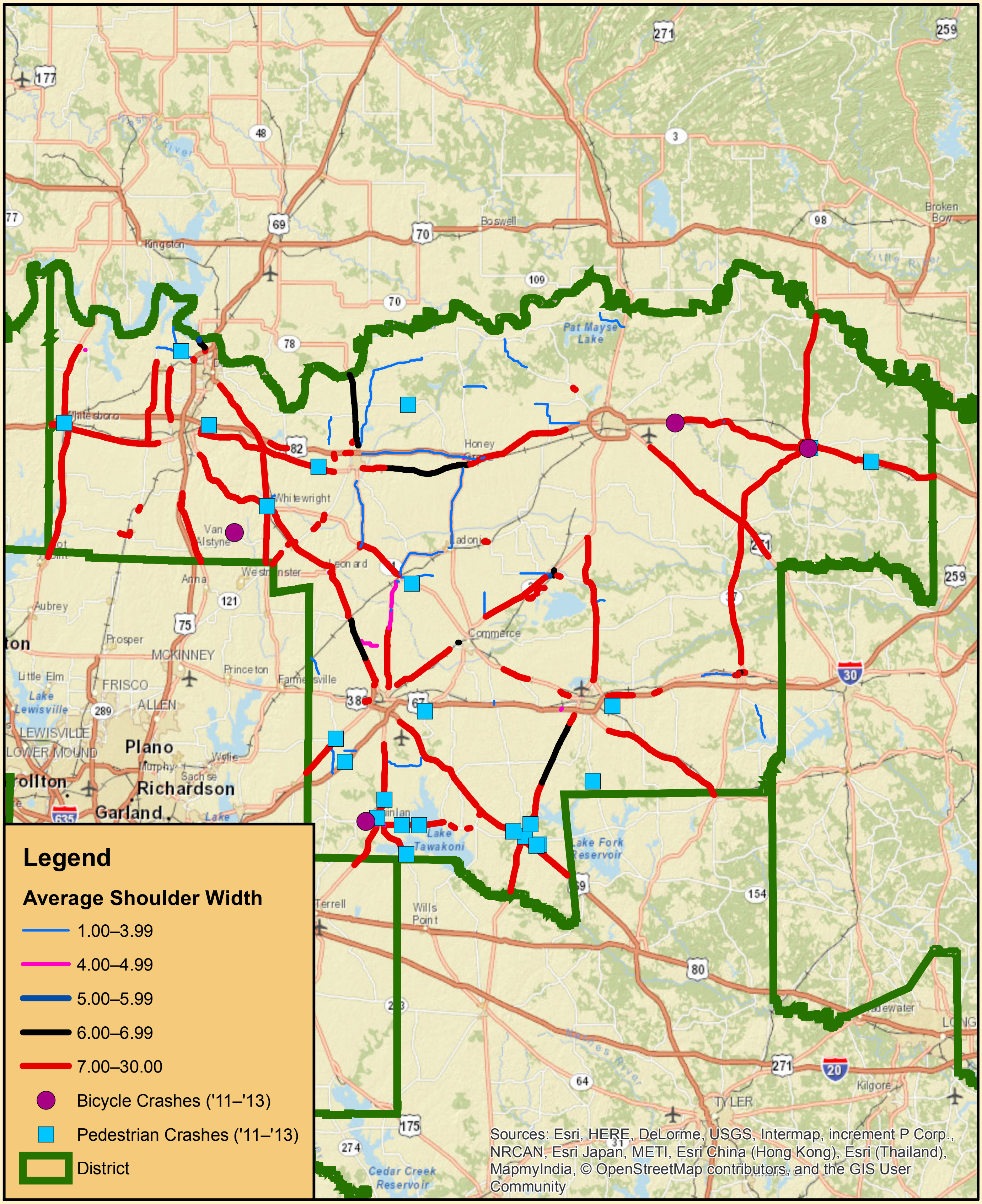
  - TxDOT District 22
  - TxDOT District 23
  - TxDOT District 24
  - TxDOT District 25



Criteria

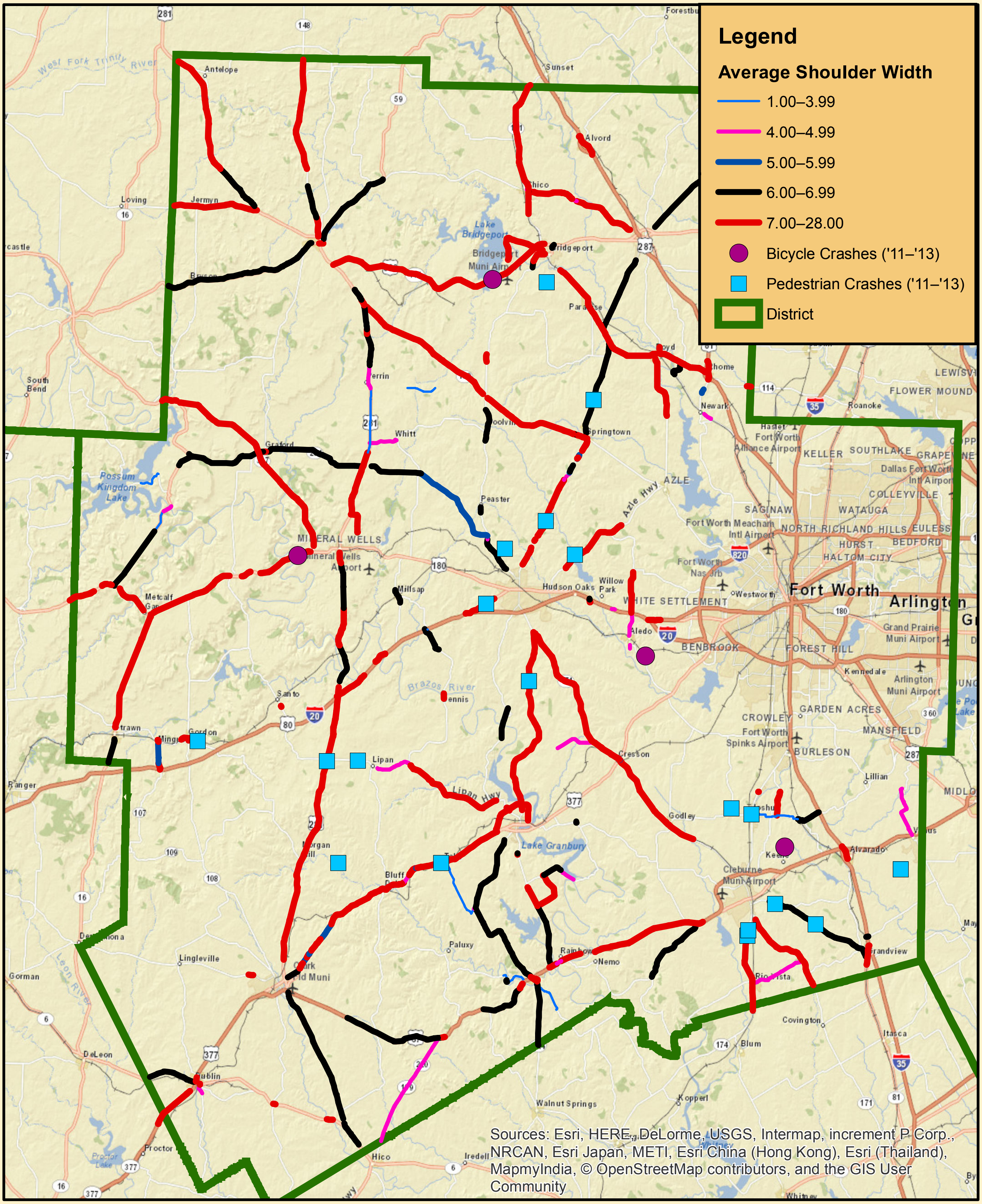
Speed > 35 mph
AADT > 400 vpd

TxDOT District 01

Rural Two-lane Paved Shoulders with Pedestrian and Bicycle Crashes

0 4.5 9 18 27 36 Miles

Coordinate System: Albers
Central Meridian: 96°0'0"W
1st Std Parallel: 20°0'0"N
2nd Std Parallel: 60°0'0"N
Latitude of Origin: 40°0'0"N



Criteria

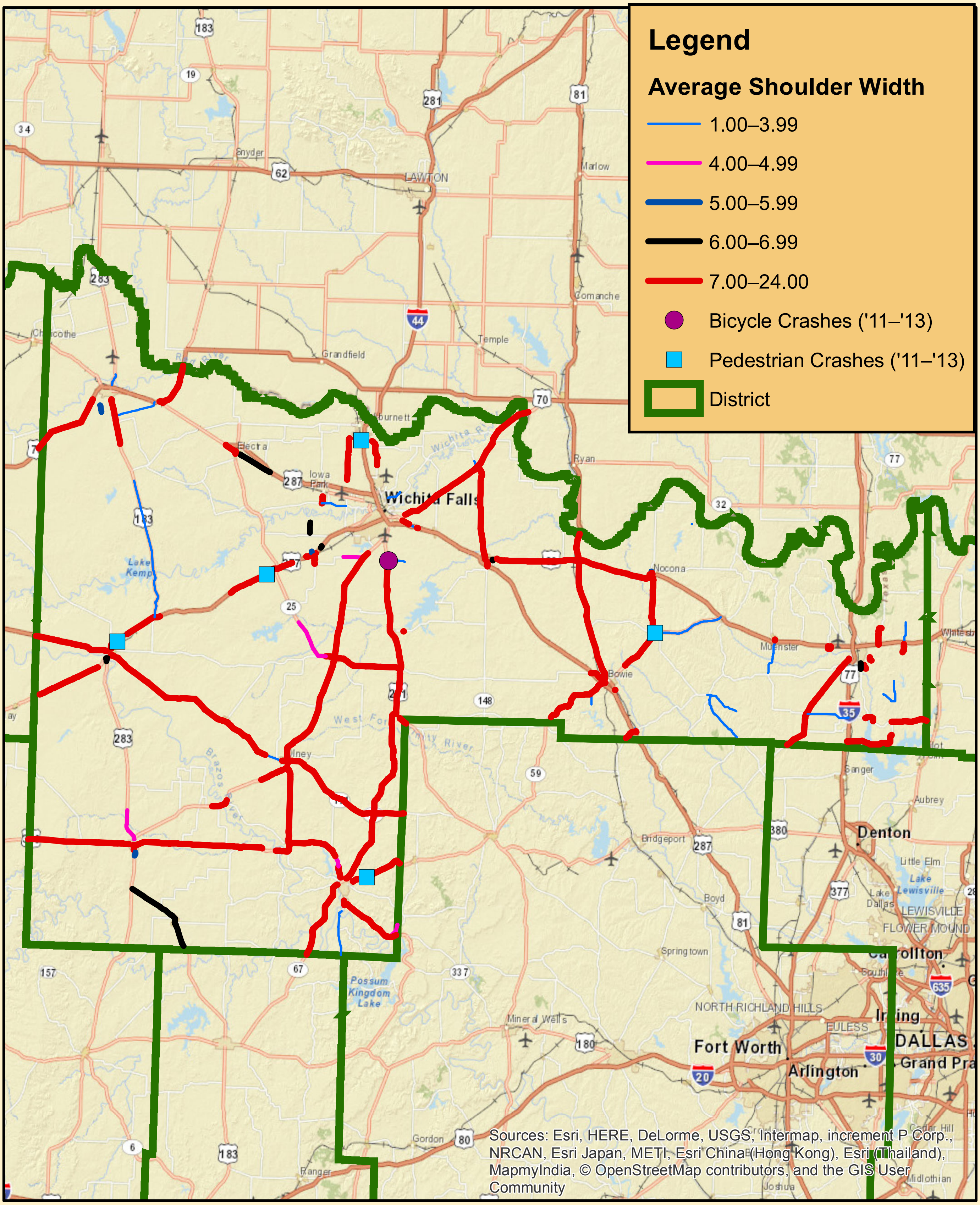
Speed > 35 mph
AADT > 400 vpd

TxDOT District 02

Rural Two-lane Paved Shoulders with Pedestrian and Bicycle Crashes

0 3.25 6.5 13 19.5 26 Miles

Coordinate System: Albers
Central Meridian: 96°0'0"W
1st Std Parallel: 20°0'0"N
2nd Std Parallel: 60°0'0"N
Latitude of Origin: 40°0'0"N



Criteria

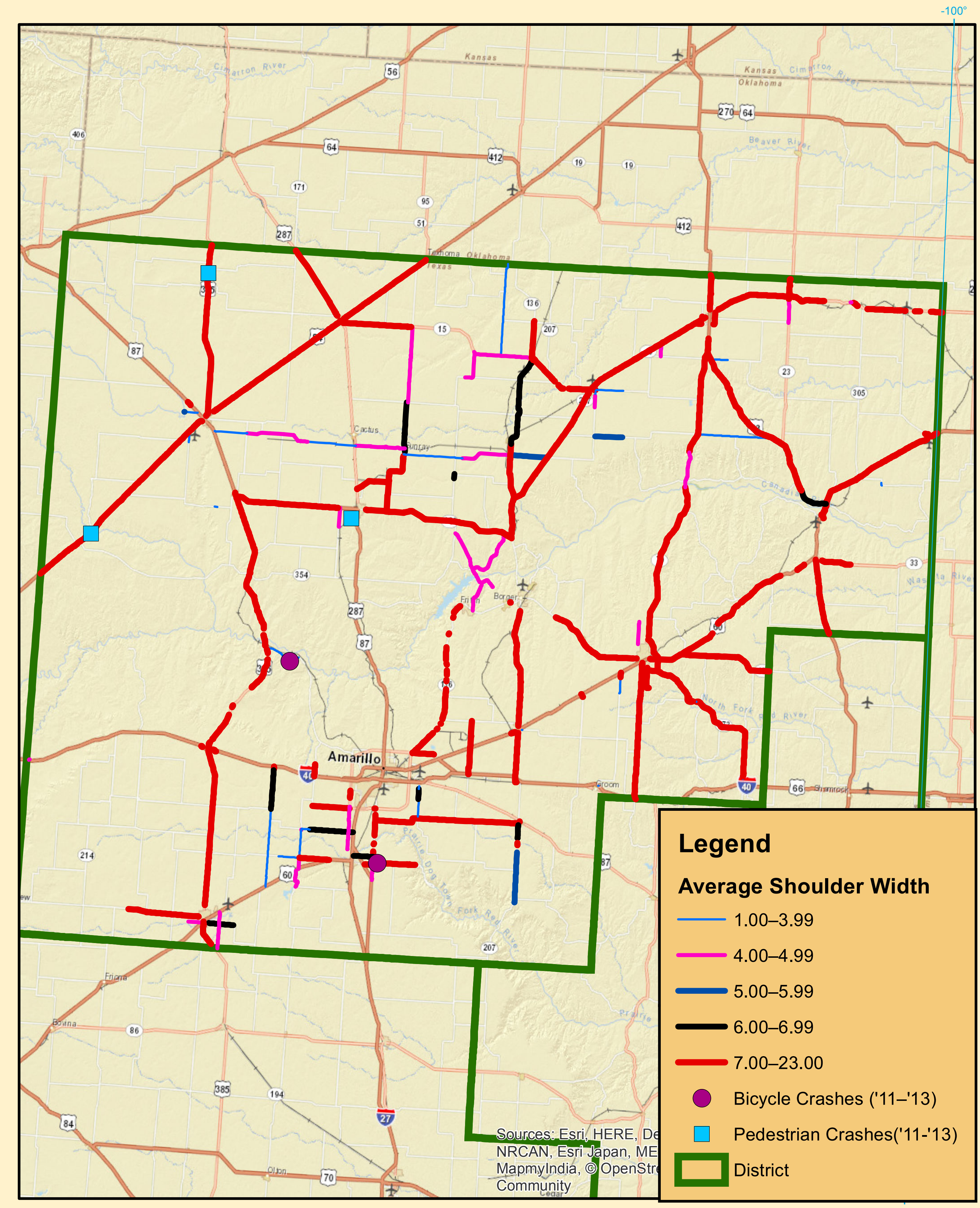
Speed > 35 mph
AADT > 400 vpd

TxDOT District 03

Rural Two-lane Paved Shoulders with Pedestrian and Bicycle Crashes

0 5 10 20 30 40 Miles

Coordinate System: Albers
Central Meridian: 96°0'0"W
1st Std Parallel: 20°0'0"N
2nd Std Parallel: 60°0'0"N
Latitude of Origin: 40°0'0"N



Criteria

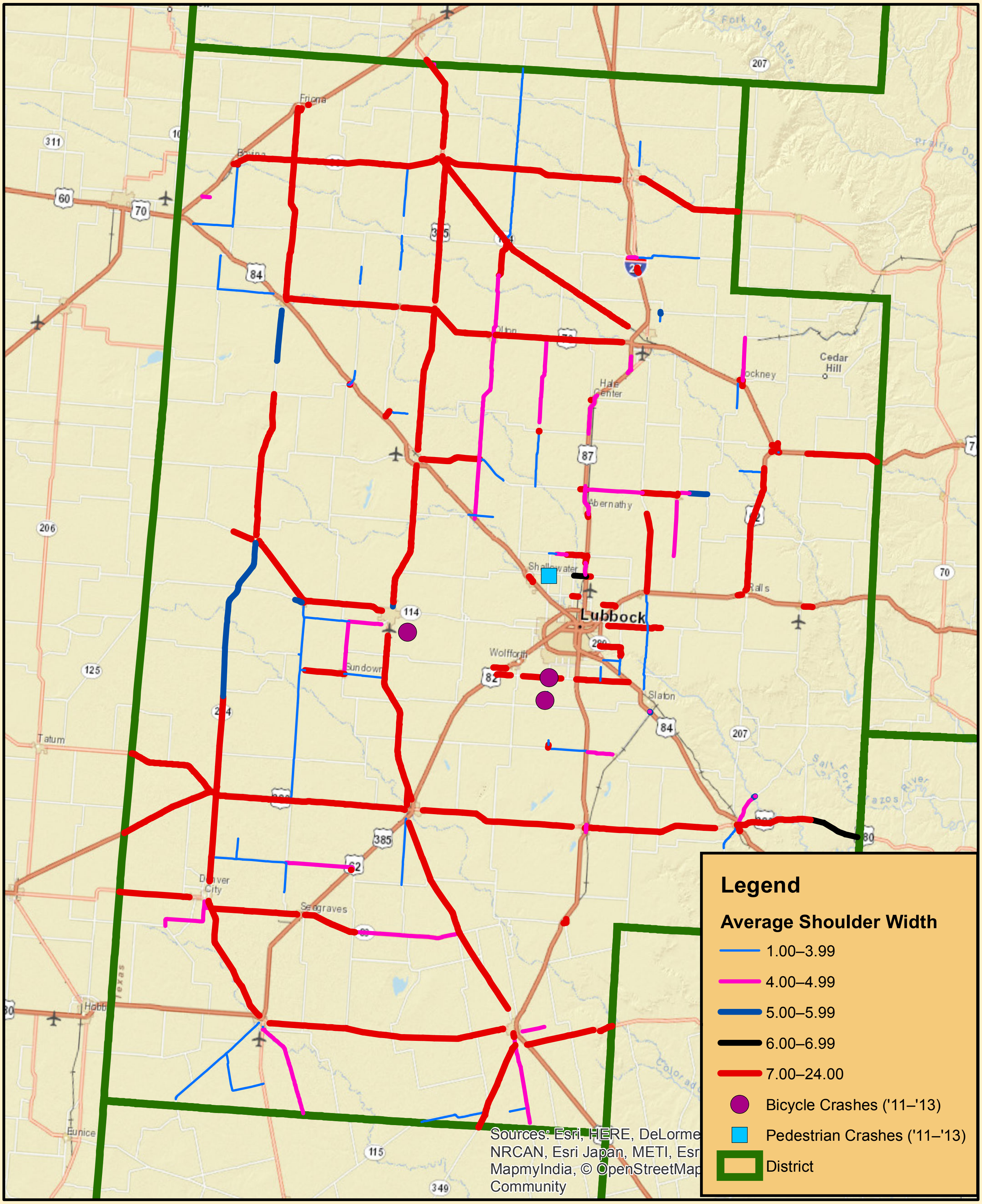
Speed > 35 mph
AADT > 400 vpd

TxDOT District 04

Rural Two-lane Paved Shoulders with Pedestrian and Bicycle Crashes

0 5 10 20 30 40 Miles

Coordinate System: Albers
Central Meridian: 96°0'0"W
1st Std Parallel: 20°0'0"N
2nd Std Parallel: 60°0'0"N
Latitude of Origin: 40°0'0"N



Criteria

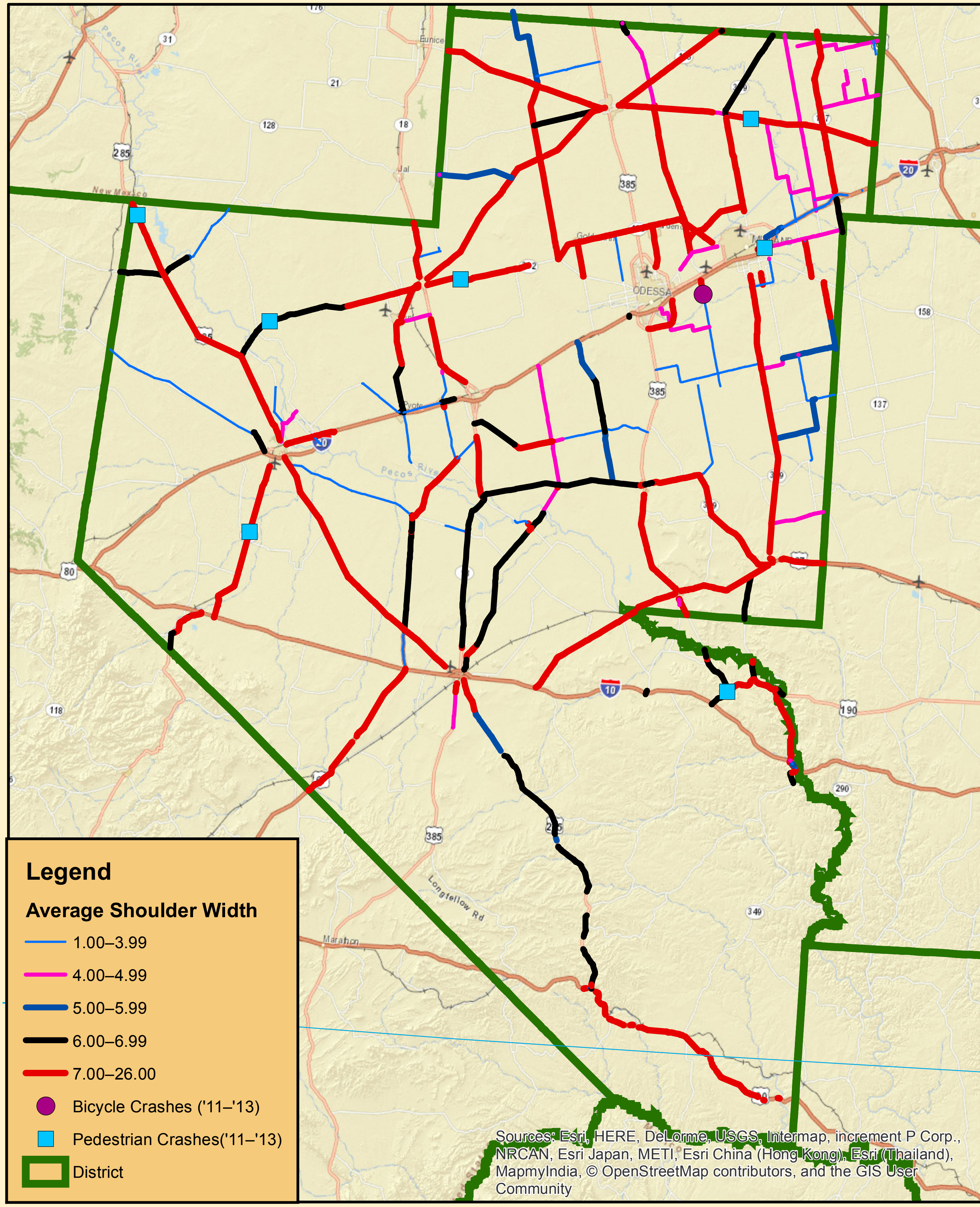
Speed > 35 mph
AADT > 400 vpd

TxDOT District 05

Rural Two-lane Paved Shoulders with Pedestrian and Bicycle Crashes

0 5 10 20 30 40 Miles

Coordinate System: Albers
Central Meridian: 96°0'0"W
1st Std Parallel: 20°0'0"N
2nd Std Parallel: 60°0'0"N
Latitude of Origin: 40°0'0"N



Criteria

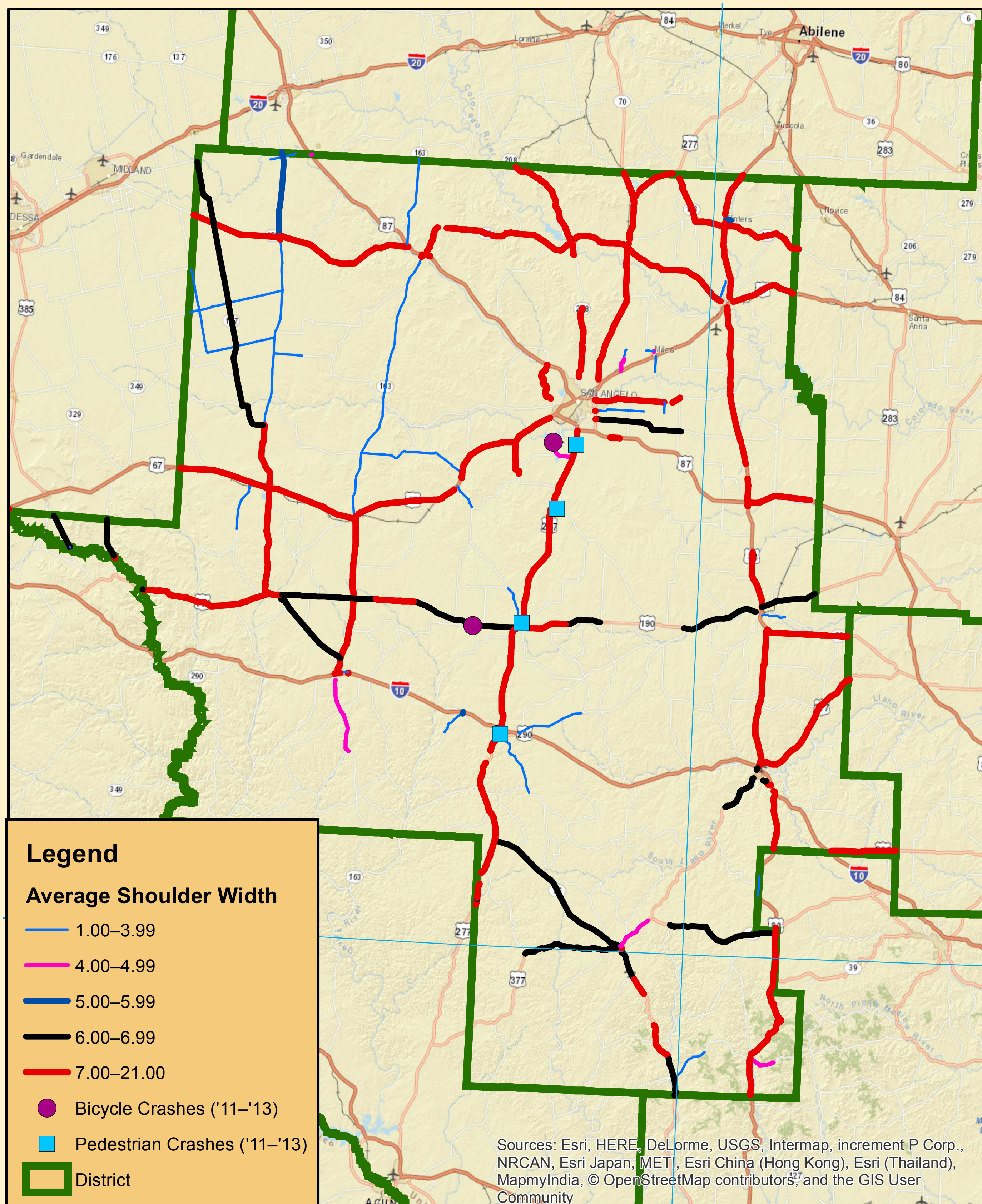
Speed > 35 mph
AADT > 400 vpd

TxDOT District 06

Rural Two-lane Paved Shoulders with Pedestrian and Bicycle Crashes

0 5 10 20 30 40 Miles

Coordinate System: Albers
Central Meridian: 96°0'0"W
1st Std Parallel: 20°0'0"N
2nd Std Parallel: 60°0'0"N
Latitude of Origin: 40°0'0"N



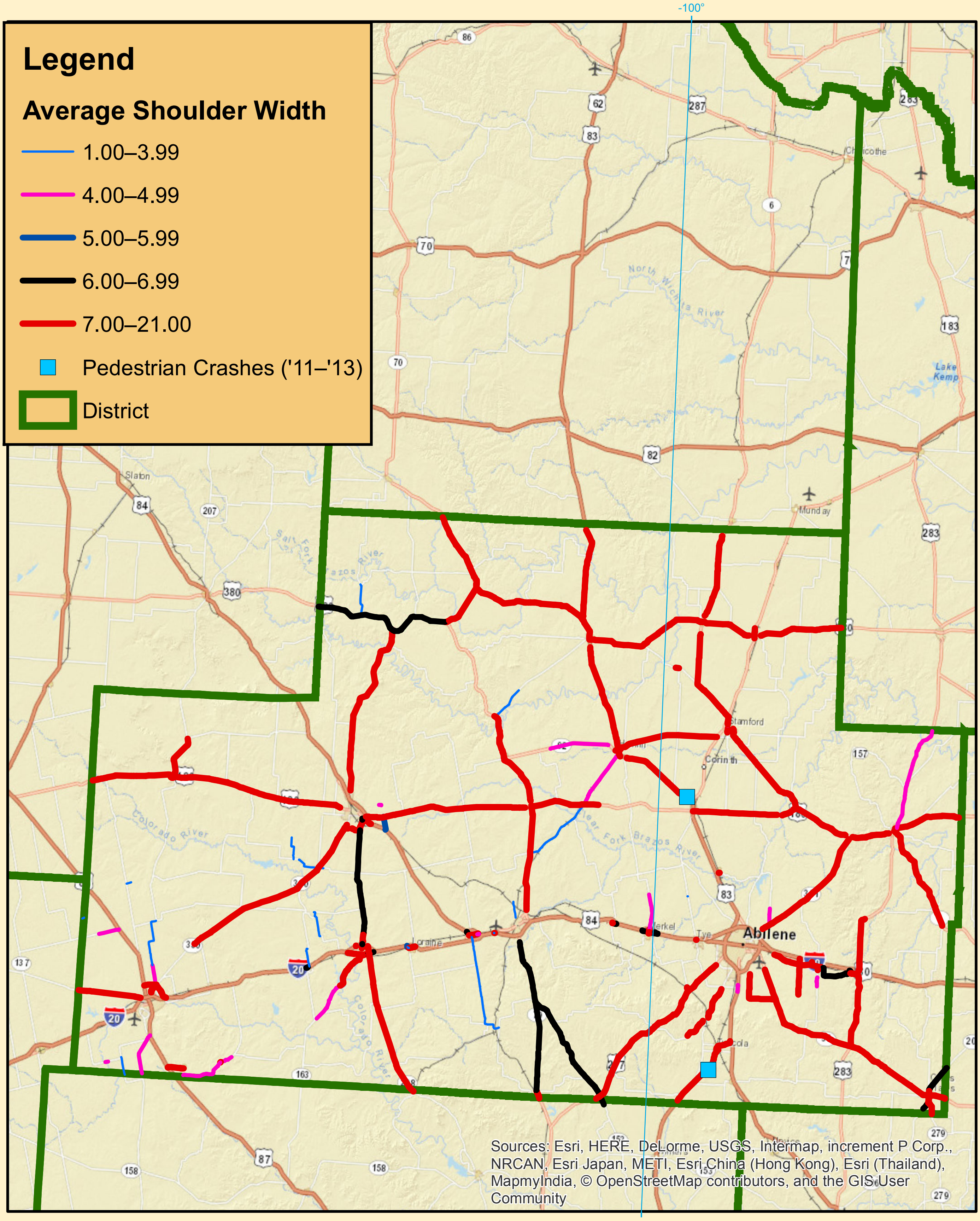
Criteria

Speed > 35 mph
AADT > 400 vpd

TxDOT District 07

Rural Two-lane Paved Shoulders with Pedestrian and Bicycle Crashes

Coordinate System: Albers
Central Meridian: 96°0'0"W
1st Std Parallel: 20°0'0"N
2nd Std Parallel: 60°0'0"N
Latitude of Origin: 40°0'0"N



Criteria

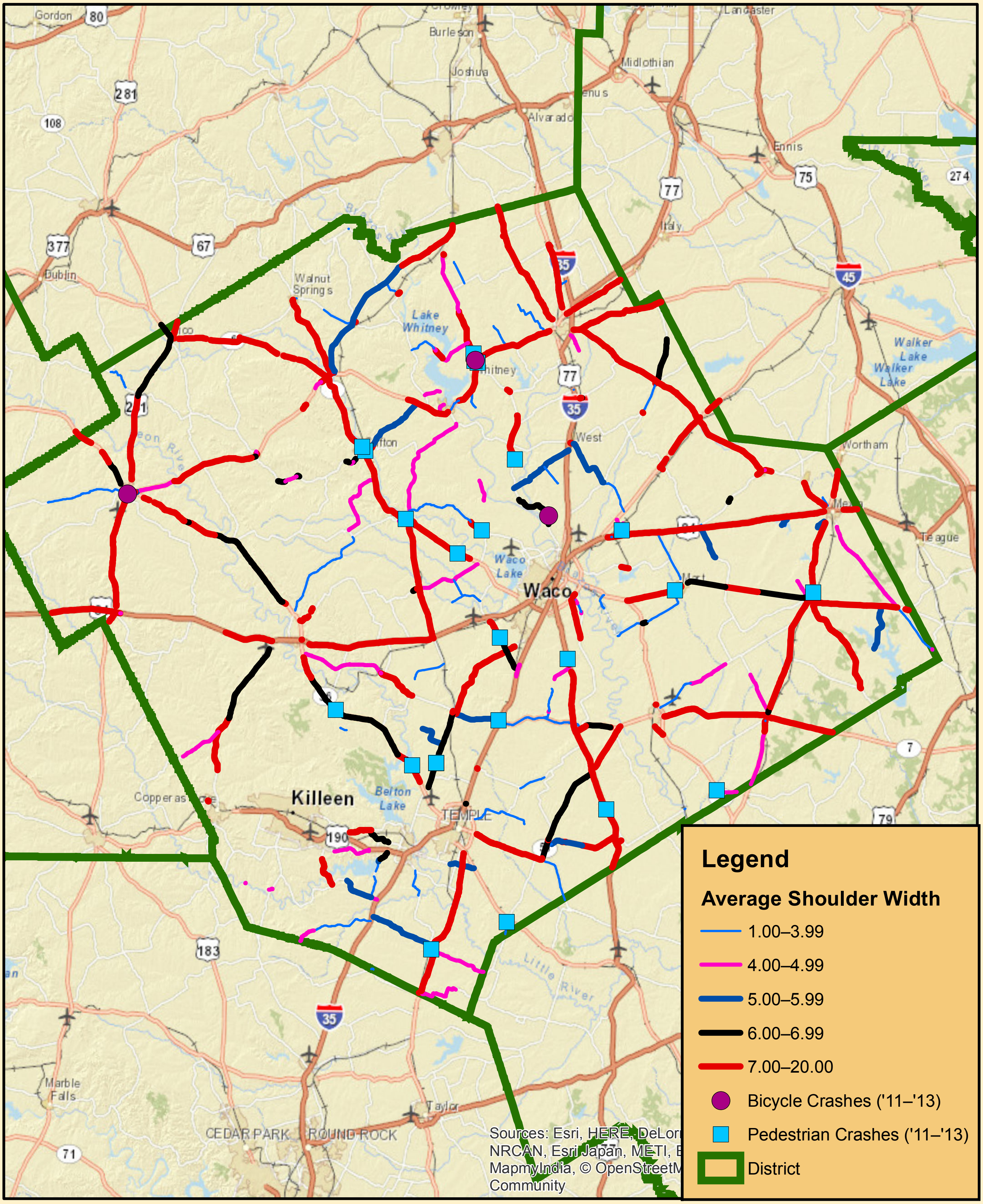
Speed > 35 mph
AADT > 400 vpd

TxDOT District 08

Rural Two-lane Paved Shoulders with Pedestrian Crashes

0 5 10 20 30 40 Miles

Coordinate System: Albers
Central Meridian: 96°0'0"W
1st Std Parallel: 20°0'0"N
2nd Std Parallel: 60°0'0"N
Latitude of Origin: 40°0'0"N



Criteria

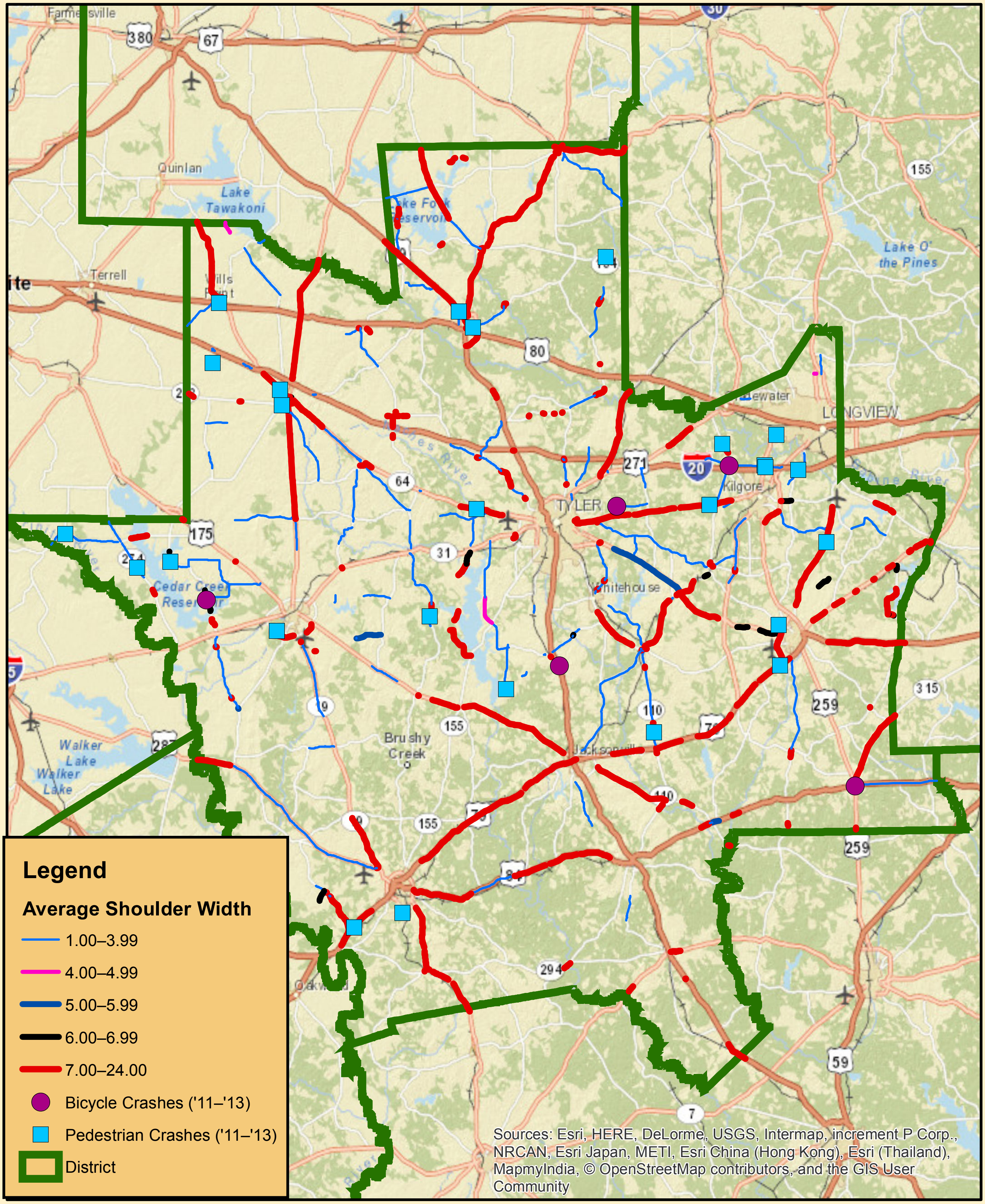
Speed > 35 mph
AADT > 400 vpd

TxDOT District 09

Rural Two-lane Paved Shoulders with Pedestrian and Bicycle Crashes

0 4.5 9 18 27 36 Miles

Coordinate System: Albers
Central Meridian: 96°0'0"W
1st Std Parallel: 20°0'0"N
2nd Std Parallel: 60°0'0"N
Latitude of Origin: 40°0'0"N



Criteria

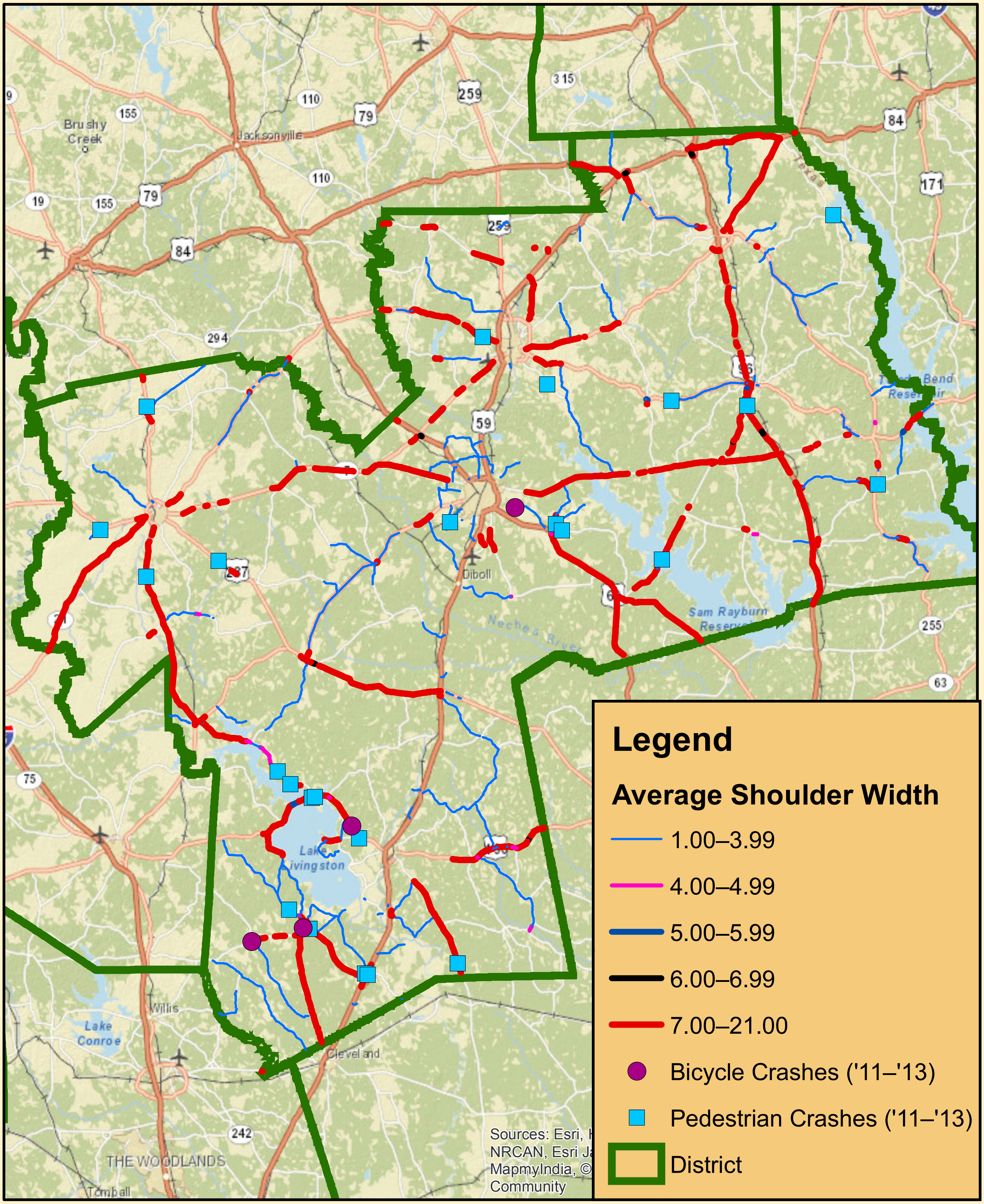
Speed > 35 mph
AADT > 400 vpd

TxDOT District 10

Rural Two-lane Paved Shoulders with Pedestrian and Bicycle Crashes

0 4 8 16 24 32 Miles

Coordinate System: Albers
Central Meridian: 96°0'0"W
1st Std Parallel: 20°0'0"N
2nd Std Parallel: 60°0'0"N
Latitude of Origin: 40°0'0"N



Criteria

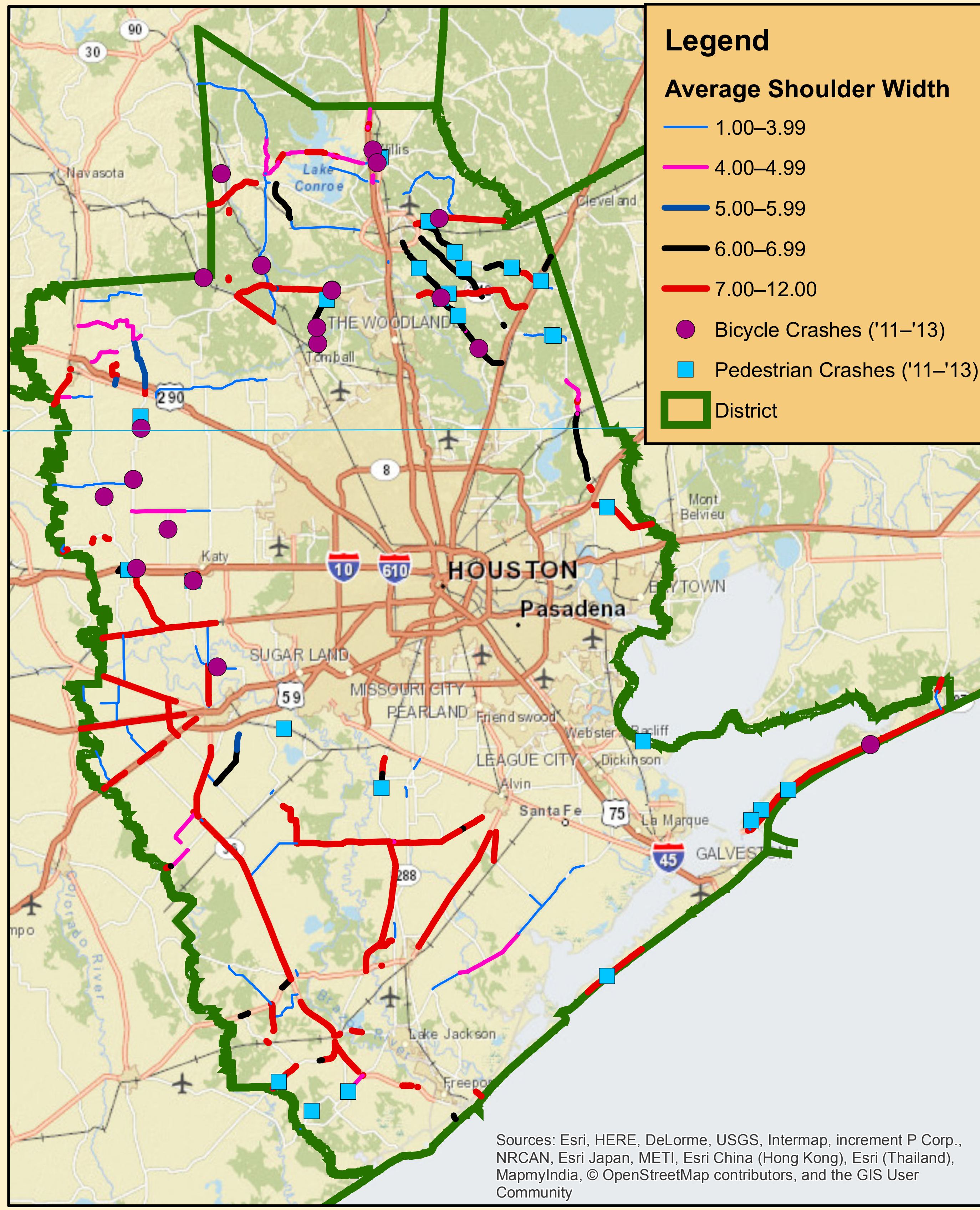
Speed > 35 mph
AADT > 400 vpd

TxDOT District 11

Rural Two-lane Paved Shoulders with Pedestrian and Bicycle Crashes

0 4.25 8.5 17 25.5 34 Miles

Coordinate System: Albers
Central Meridian: 96°0'0"W
1st Std Parallel: 20°0'0"N
2nd Std Parallel: 60°0'0"N
Latitude of Origin: 40°0'0"N



Criteria

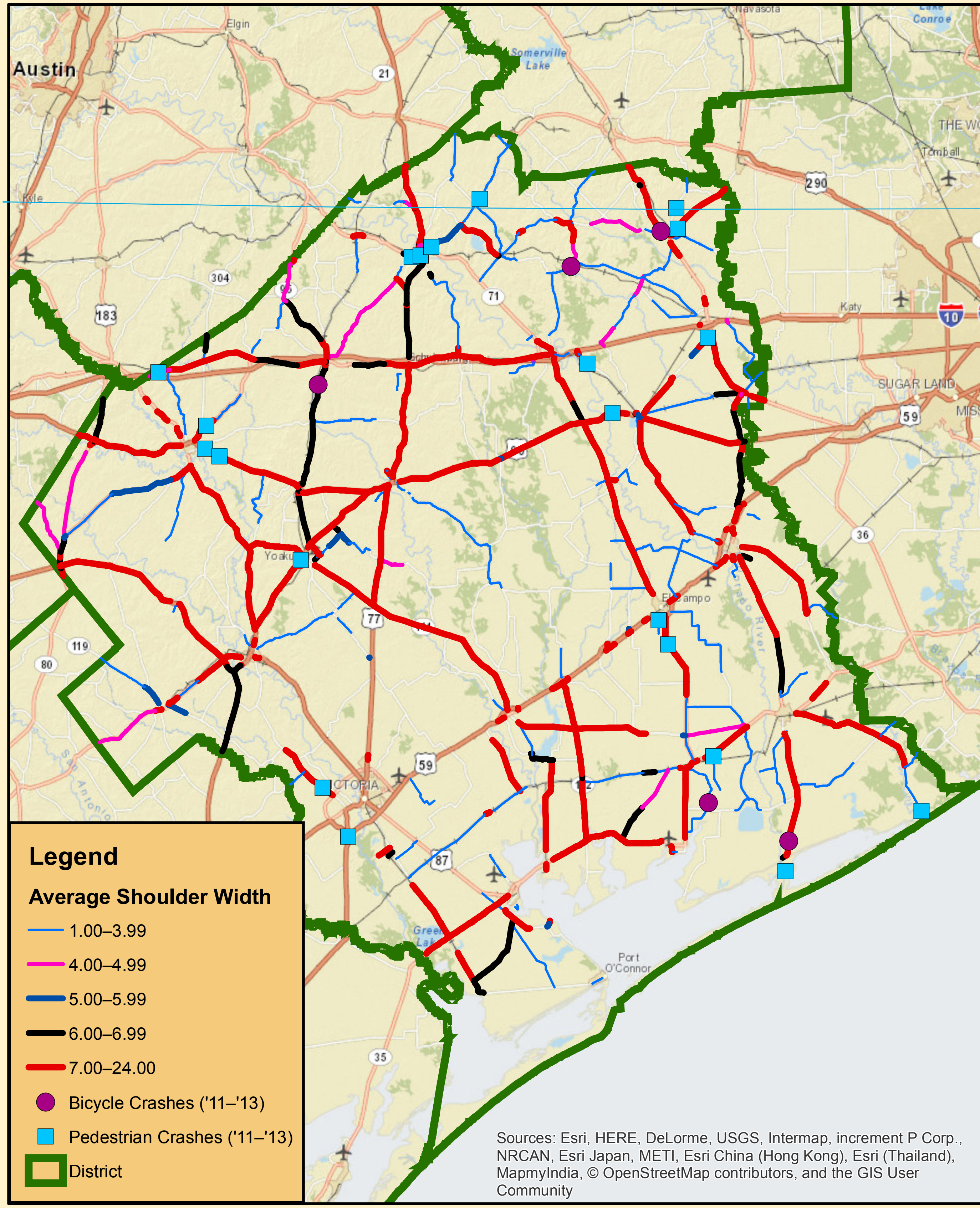
Speed > 35 mph
AADT > 400 vpd

TxDOT District 12

Rural Two-lane Paved Shoulders with Pedestrian and Bicycle Crashes

0 3.75 7.5 15 22.5 30 Miles

Coordinate System: Albers
Central Meridian: 96°0'0"W
1st Std Parallel: 20°0'0"N
2nd Std Parallel: 60°0'0"N
Latitude of Origin: 40°0'0"N



Criteria

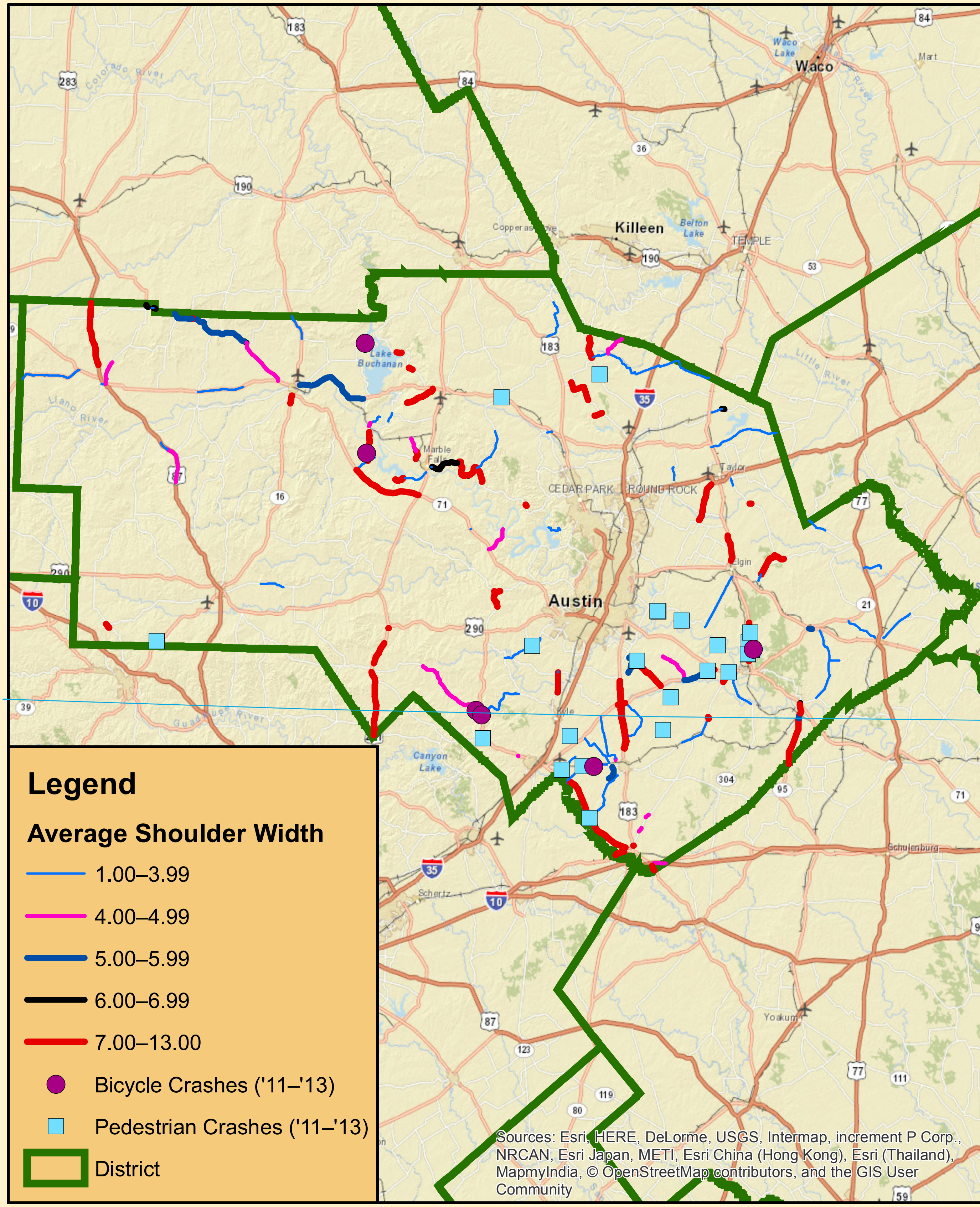
Speed > 35 mph
AADT > 400 vpd

TxDOT District 13

Rural Two-lane Paved Shoulders with Pedestrian and Bicycle Crashes

0 5 10 20 30 40 Miles

Coordinate System: Albers
Central Meridian: 96°0'0"W
1st Std Parallel: 20°0'0"N
2nd Std Parallel: 60°0'0"N
Latitude of Origin: 40°0'0"N



Criteria

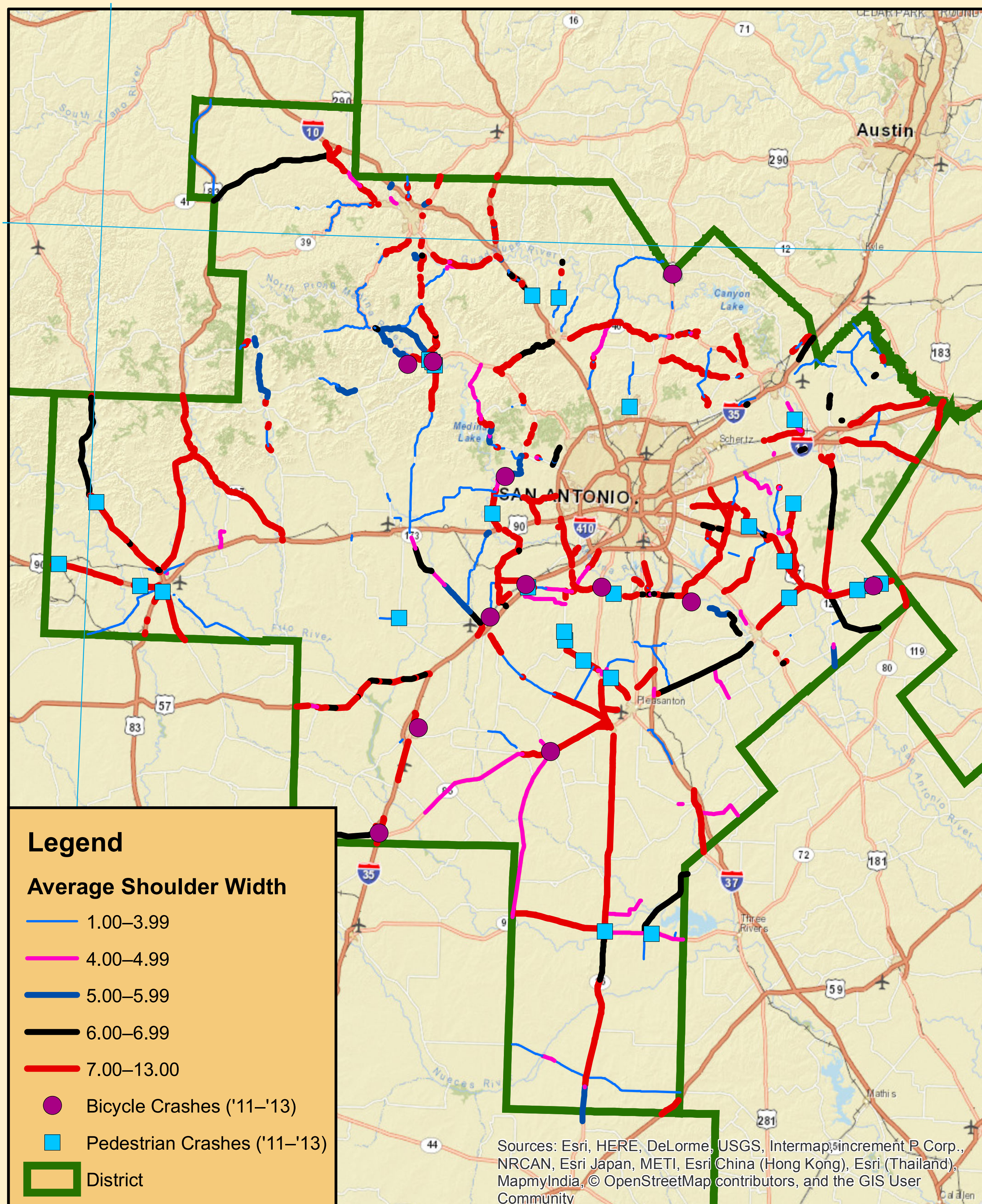
Speed > 35 mph
AADT > 400 vpd

TxDOT District 14

Rural Two-lane Paved Shoulders with Pedestrian and Bicycle Crashes

0 5 10 20 30 40 Miles

Coordinate System: Albers
Central Meridian: 96°0'0"W
1st Std Parallel: 20°0'0"N
2nd Std Parallel: 60°0'0"N
Latitude of Origin: 40°0'0"N



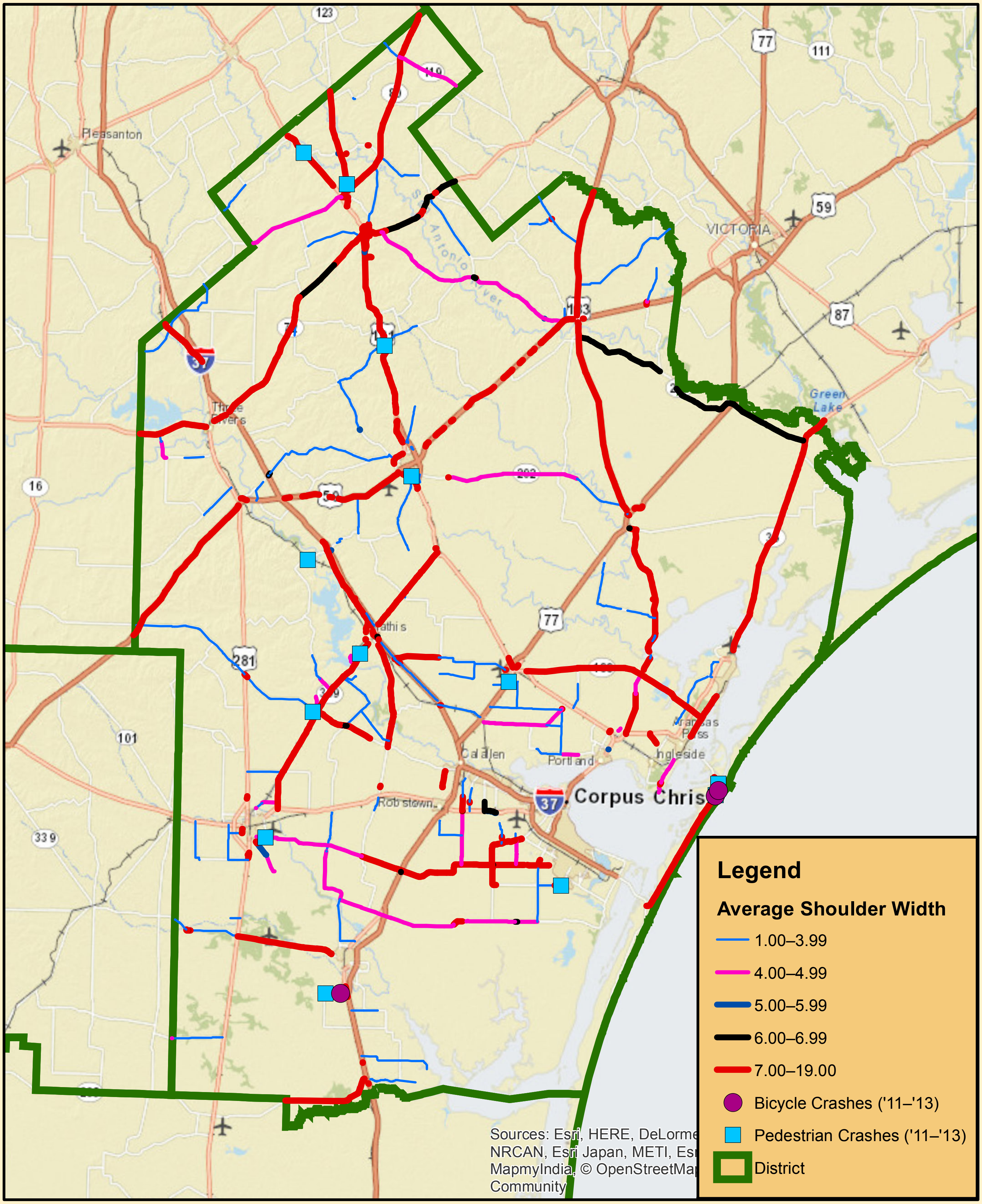
Criteria

Speed > 35 mph
AADT > 400 vpd

TxDOT District 15

Rural Two-lane Paved Shoulders with Pedestrian and Bicycle Crashes

Coordinate System: Albers
Central Meridian: 96°0'0"W
1st Std Parallel: 20°0'0"N
2nd Std Parallel: 60°0'0"N
Latitude of Origin: 40°0'0"N



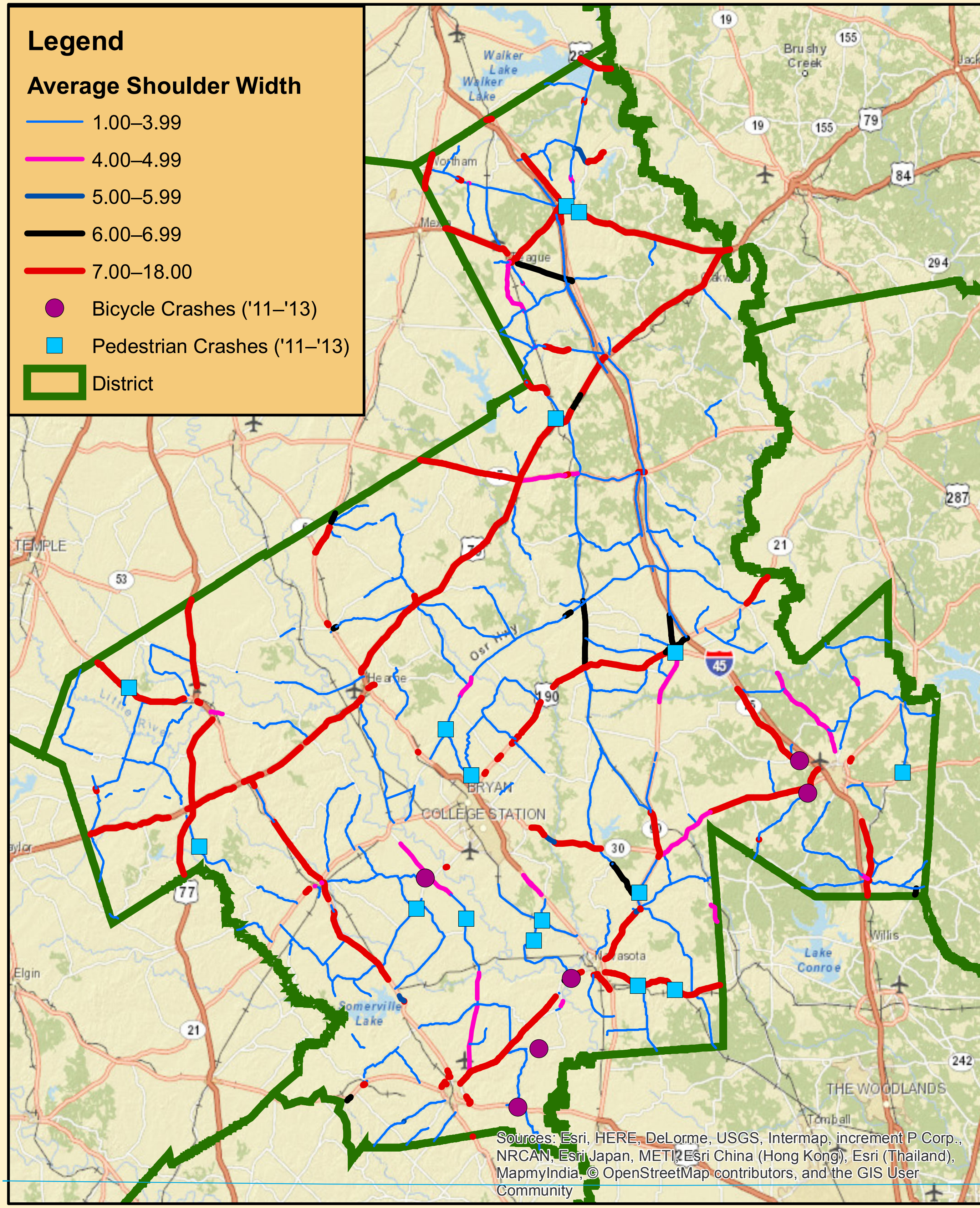
Criteria

Speed > 35 mph
AADT > 400 vpd

TxDOT District 16

Rural Two-lane Paved Shoulders with Pedestrian and Bicycle Crashes

Coordinate System: Albers
Central Meridian: 96°0'0"W
1st Std Parallel: 20°0'0"N
2nd Std Parallel: 60°0'0"N
Latitude of Origin: 40°0'0"N



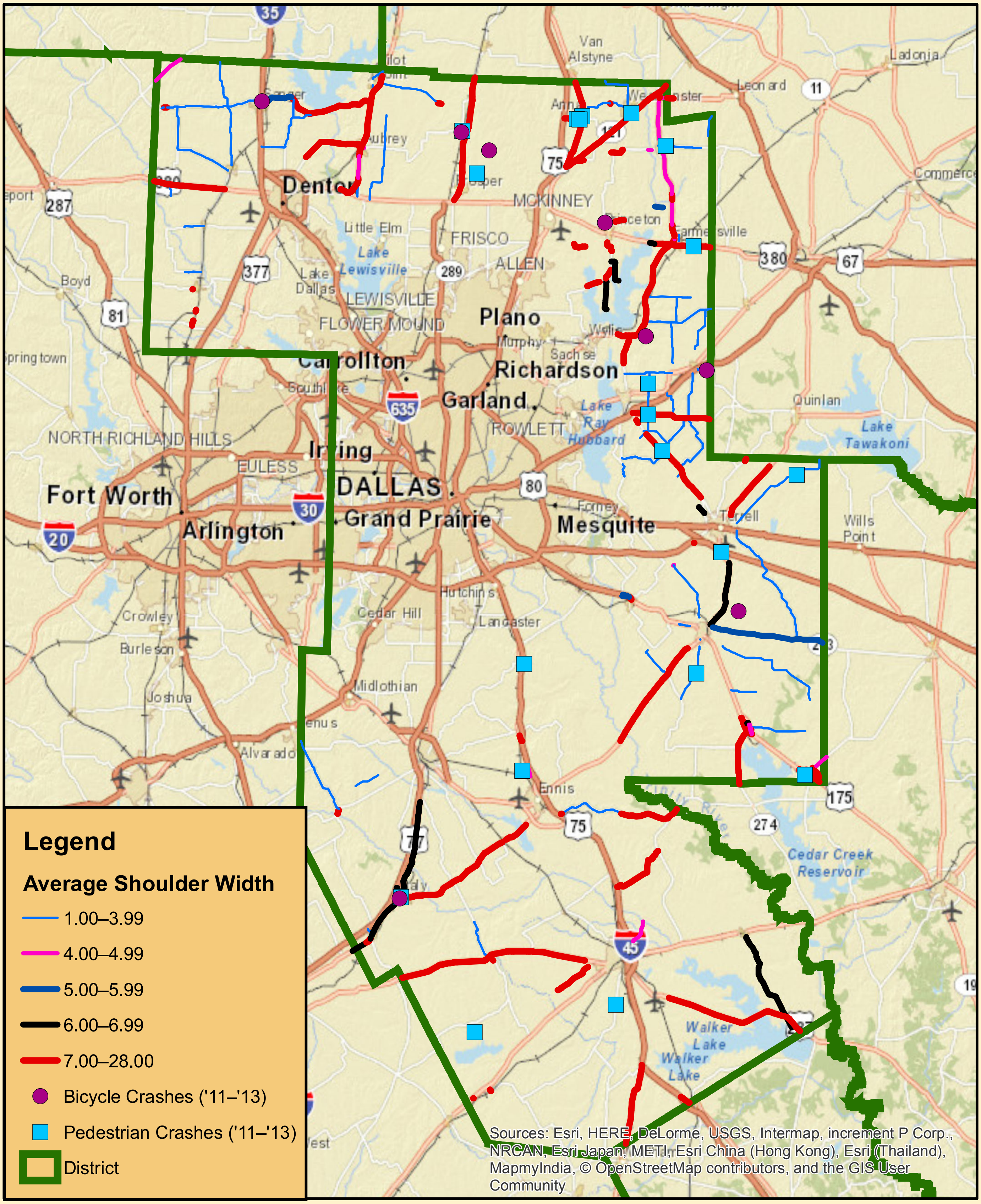
Criteria

Speed > 35 mph
AADT > 400 vpd

TxDOT District 17

Rural Two-lane Paved Shoulders with Pedestrian and Bicycle Crashes

Coordinate System: Albers
Central Meridian: 96°0'0"W
1st Std Parallel: 20°0'0"N
2nd Std Parallel: 60°0'0"N
Latitude of Origin: 40°0'0"N



Criteria

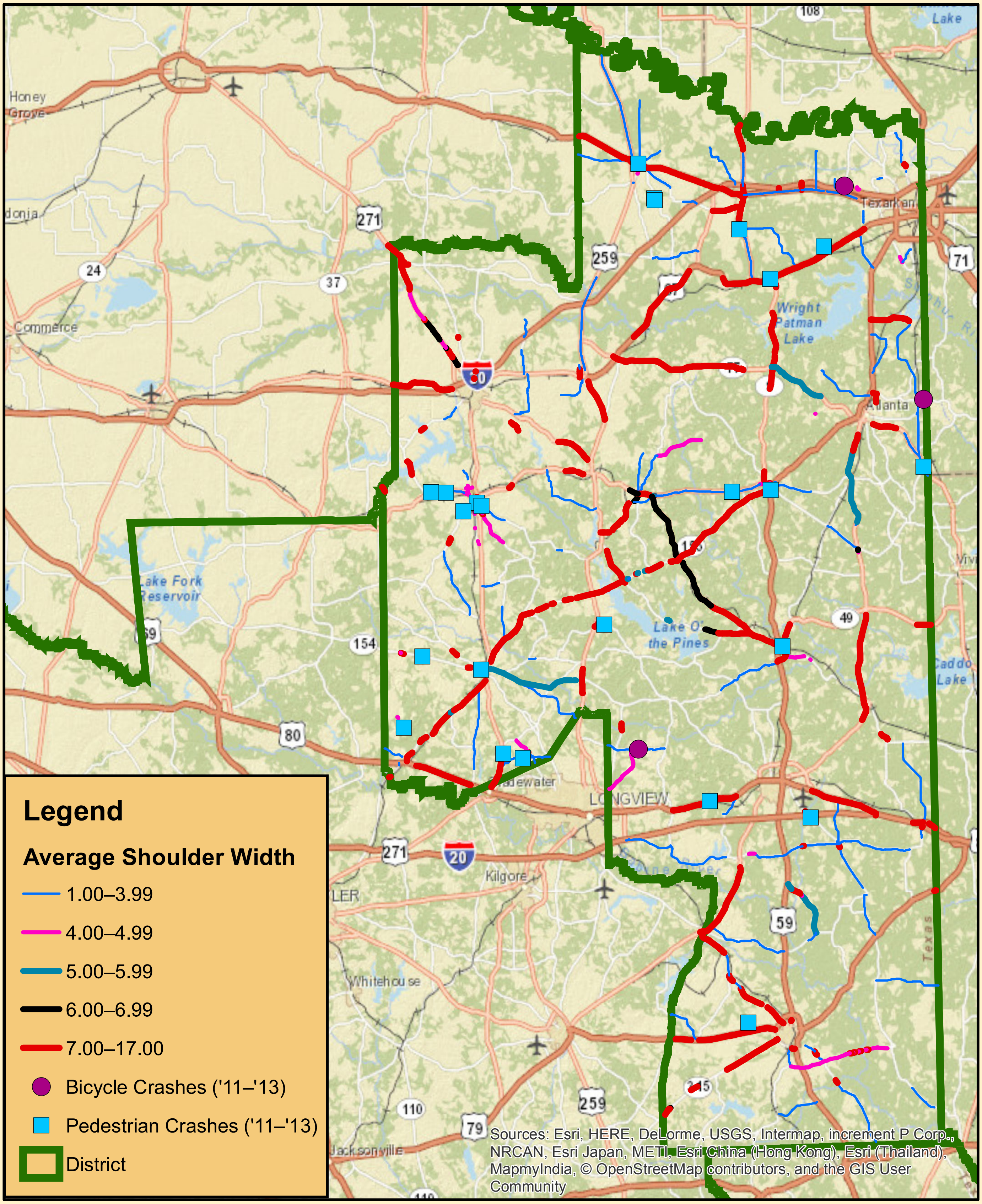
Speed > 35 mph
AADT > 400 vpd

TxDOT District 18

Rural Two-lane Paved Shoulders with Pedestrian and Bicycle Crashes

0 3.5 7 14 21 28 Miles

Coordinate System: Albers
Central Meridian: 96°0'0"W
1st Std Parallel: 20°0'0"N
2nd Std Parallel: 60°0'0"N
Latitude of Origin: 40°0'0"N



Criteria

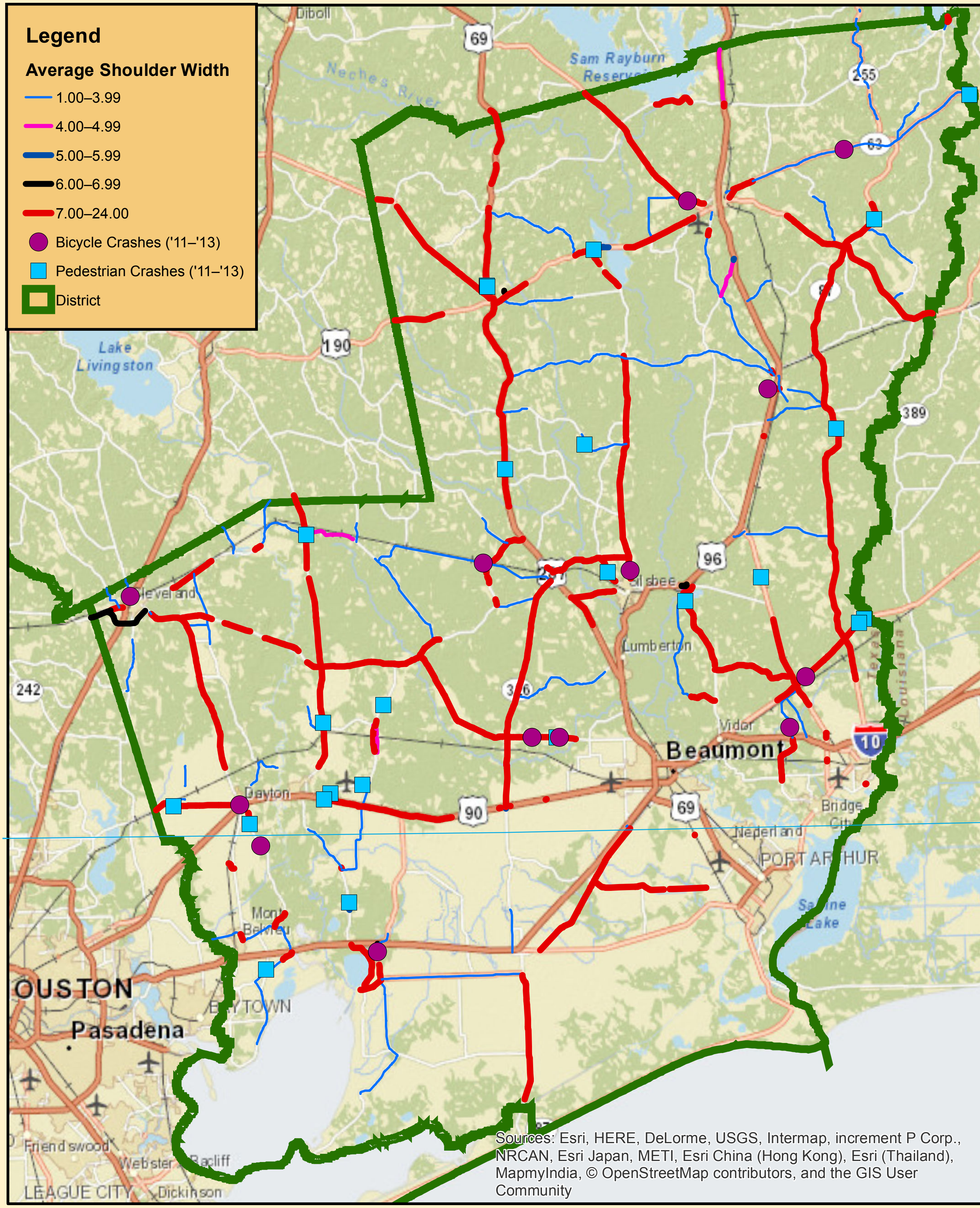
Speed > 35 mph
AADT > 400 vpd

TxDOT District 19

Rural Two-lane Paved Shoulders with Pedestrian and Bicycle Crashes

0 3.75 7.5 15 22.5 30 Miles

Coordinate System: Albers
Central Meridian: 96°0'0"W
1st Std Parallel: 20°0'0"N
2nd Std Parallel: 60°0'0"N
Latitude of Origin: 40°0'0"N



Criteria

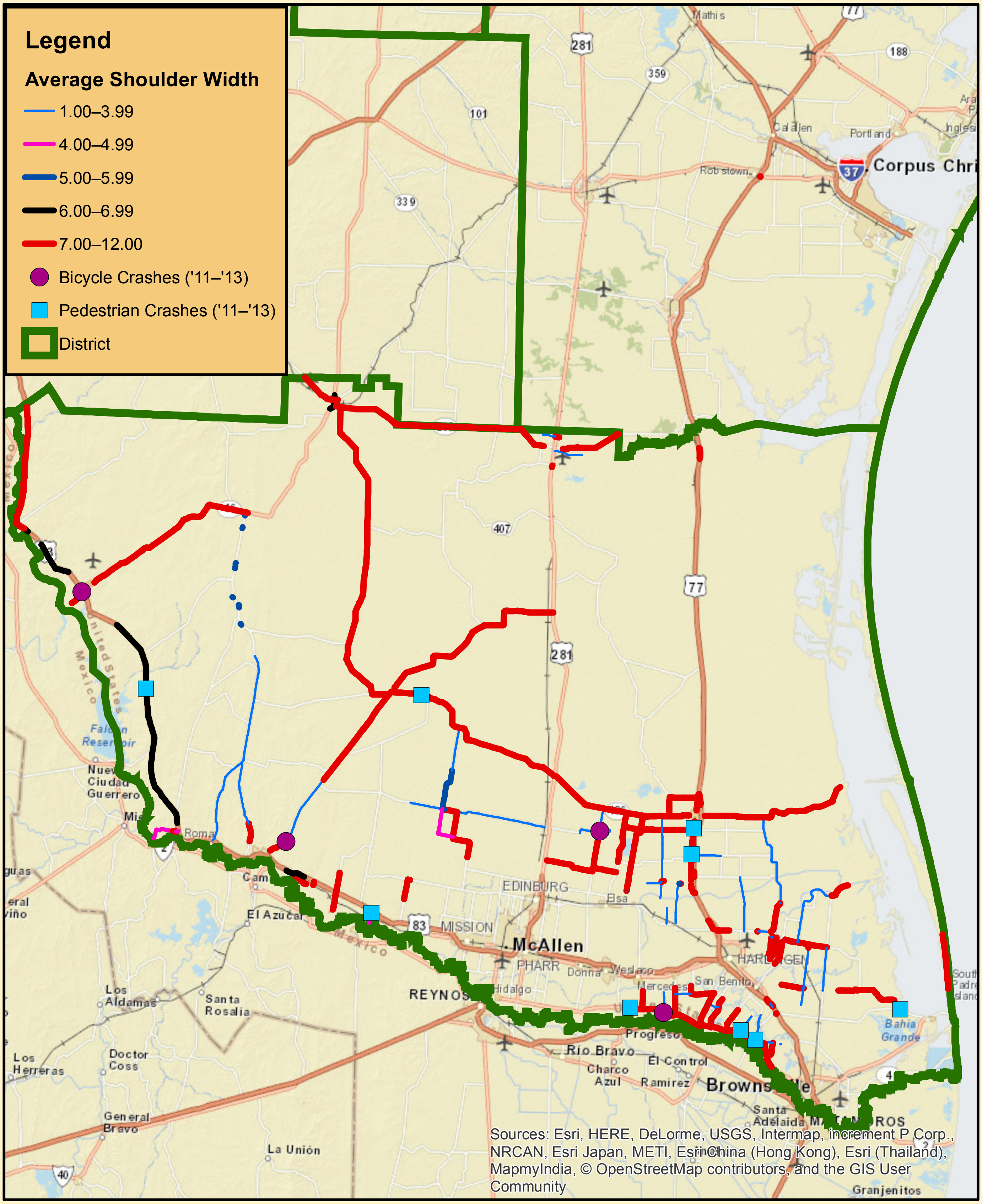
Speed > 35 mph
AADT > 400 vpd

TxDOT District 20

Rural Two-lane Paved Shoulders with Pedestrian and Bicycle Crashes

0 3.5 7 14 21 28 Miles

Coordinate System: Albers
Central Meridian: 96°0'0"W
1st Std Parallel: 20°0'0"N
2nd Std Parallel: 60°0'0"N
Latitude of Origin: 40°0'0"N



Criteria

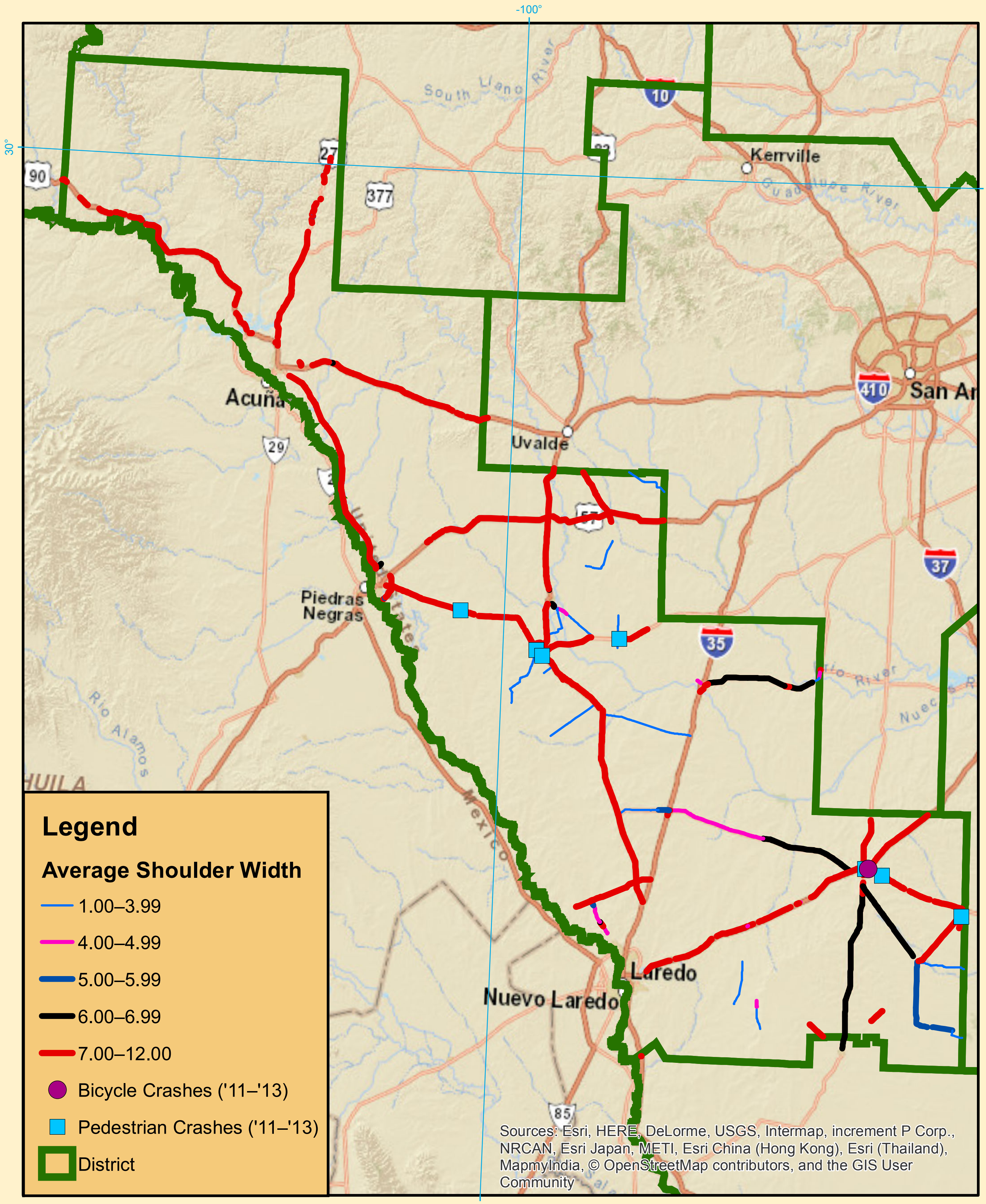
Speed > 35 mph
AADT > 400 vpd

TxDOT District 21

Rural Two-lane Paved Shoulders with Pedestrian and Bicycle Crashes

0 5 10 20 30 40 Miles

Coordinate System: Albers
Central Meridian: 96°0'0"W
1st Std Parallel: 20°0'0"N
2nd Std Parallel: 60°0'0"N
Latitude of Origin: 40°0'0"N



Criteria

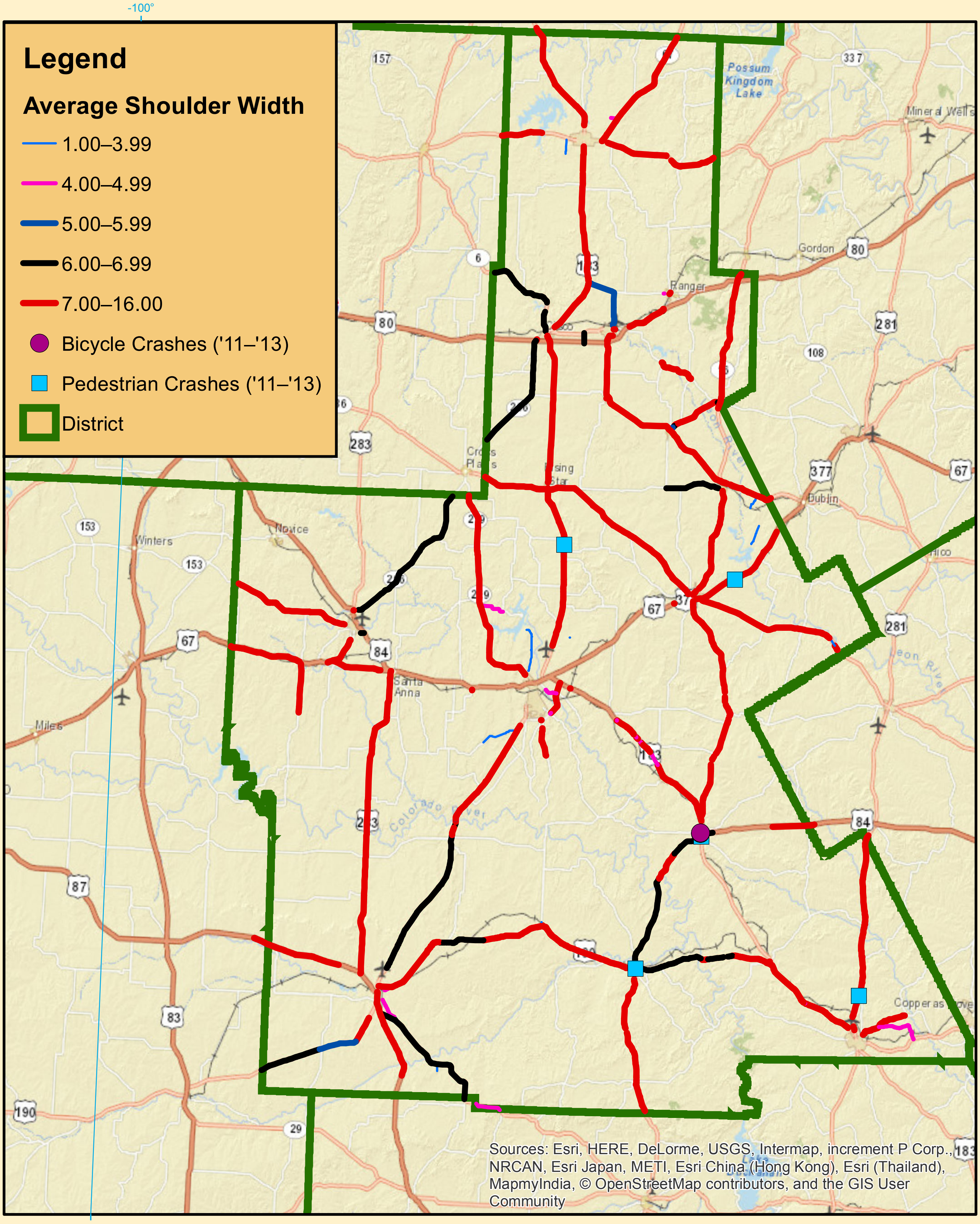
Speed > 35 mph
AADT > 400 vpd

TxDOT District 22

Rural Two-lane Paved Shoulders with Pedestrian and Bicycle Crashes

0 5 10 20 30 40 Miles

Coordinate System: Albers
Central Meridian: 96°0'0"W
1st Std Parallel: 20°0'0"N
2nd Std Parallel: 60°0'0"N
Latitude of Origin: 40°0'0"N



Criteria

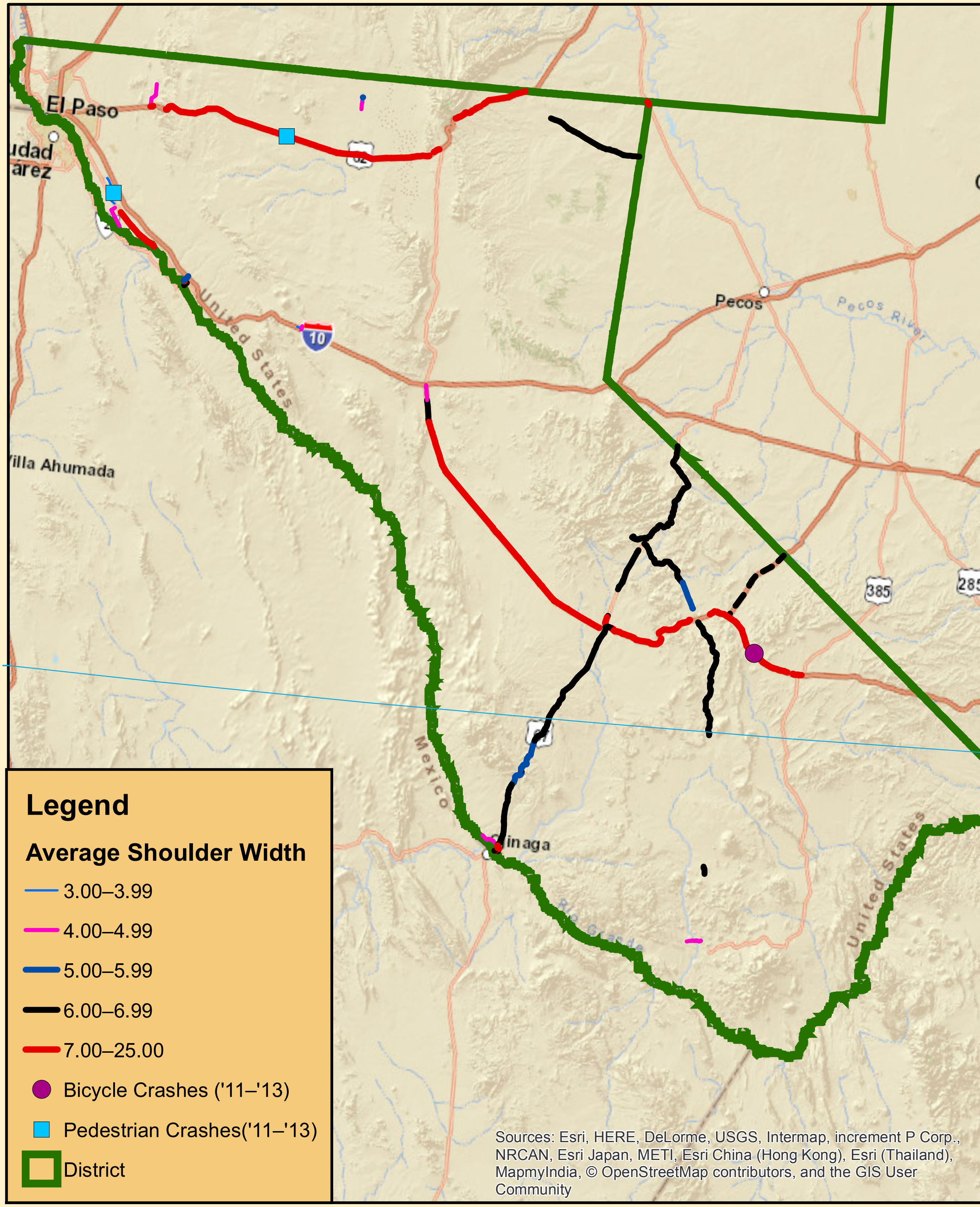
Speed > 35 mph
AADT > 400 vpd

TxDOT District 23

Rural Two-lane Paved Shoulders with Pedestrian and Bicycle Crashes

0 4.5 9 18 27 36 Miles

Coordinate System: Albers
Central Meridian: 96°0'0"W
1st Std Parallel: 20°0'0"N
2nd Std Parallel: 60°0'0"N
Latitude of Origin: 40°0'0"N



Criteria

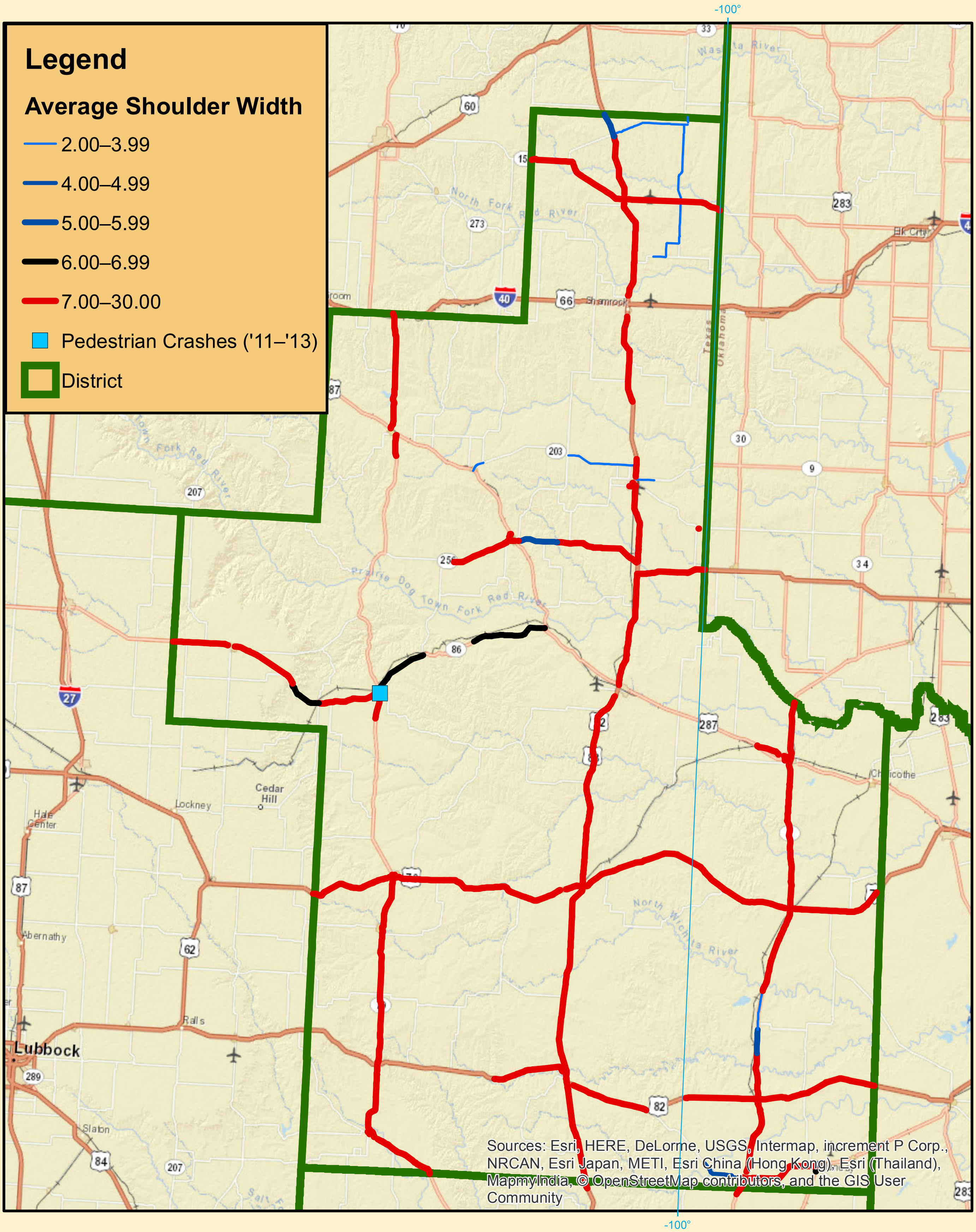
Speed > 35 mph
AADT > 400 vpd

TxDOT District 24

Rural Two-lane Paved Shoulders with Pedestrian and Bicycle Crashes

0 5 10 20 30 40 Miles

Coordinate System: Albers
Central Meridian: 96°0'0"W
1st Std Parallel: 20°0'0"N
2nd Std Parallel: 60°0'0"N
Latitude of Origin: 40°0'0"N



Criteria

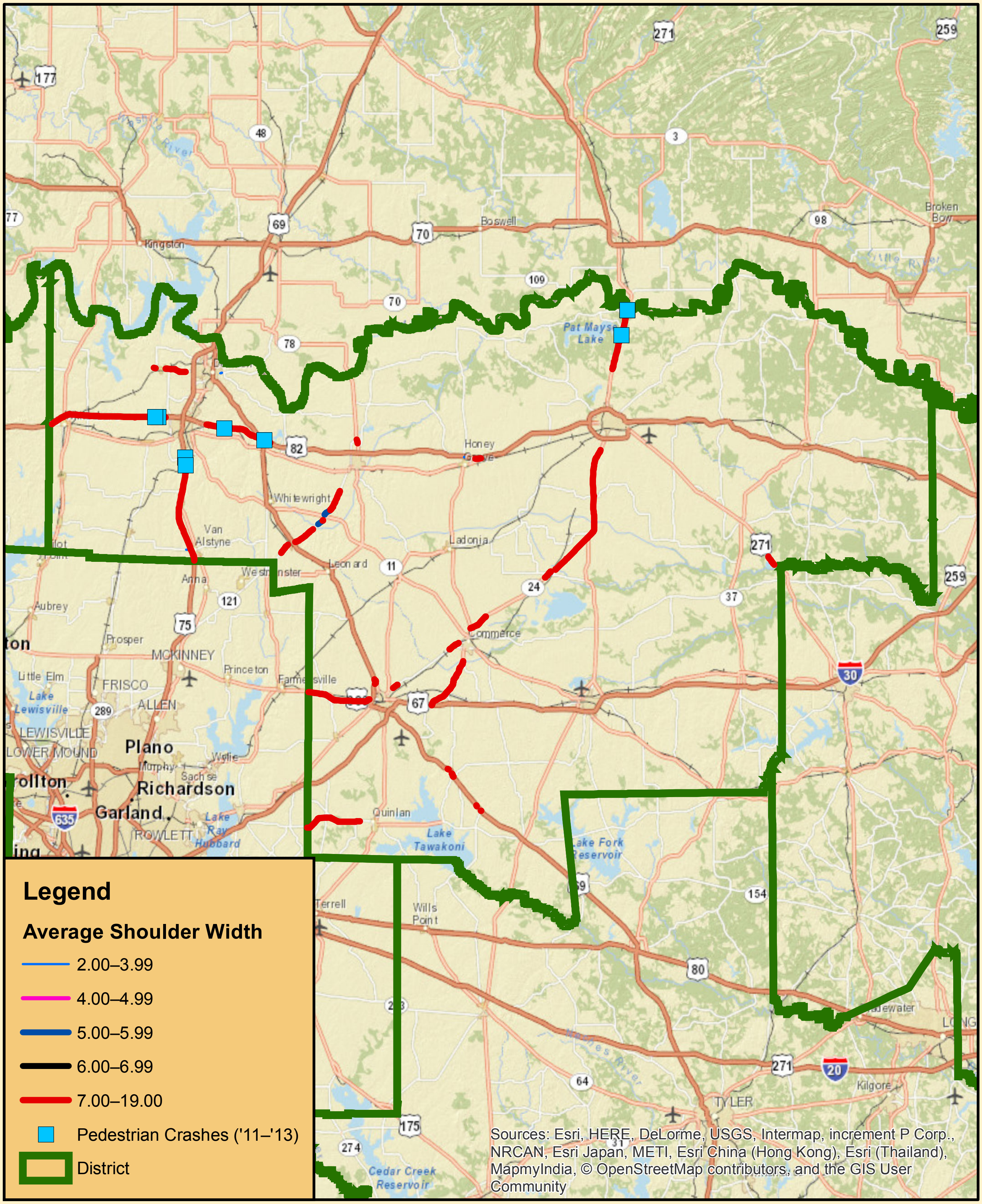
Speed > 35 mph
AADT > 400 vpd

TxDOT District 25

Rural Two-lane Paved Shoulders with Pedestrian Crashes

0 5 10 20 30 40 Miles

Coordinate System: Albers
Central Meridian: 96°0'0"W
1st Std Parallel: 20°0'0"N
2nd Std Parallel: 60°0'0"N
Latitude of Origin: 40°0'0"N



Criteria

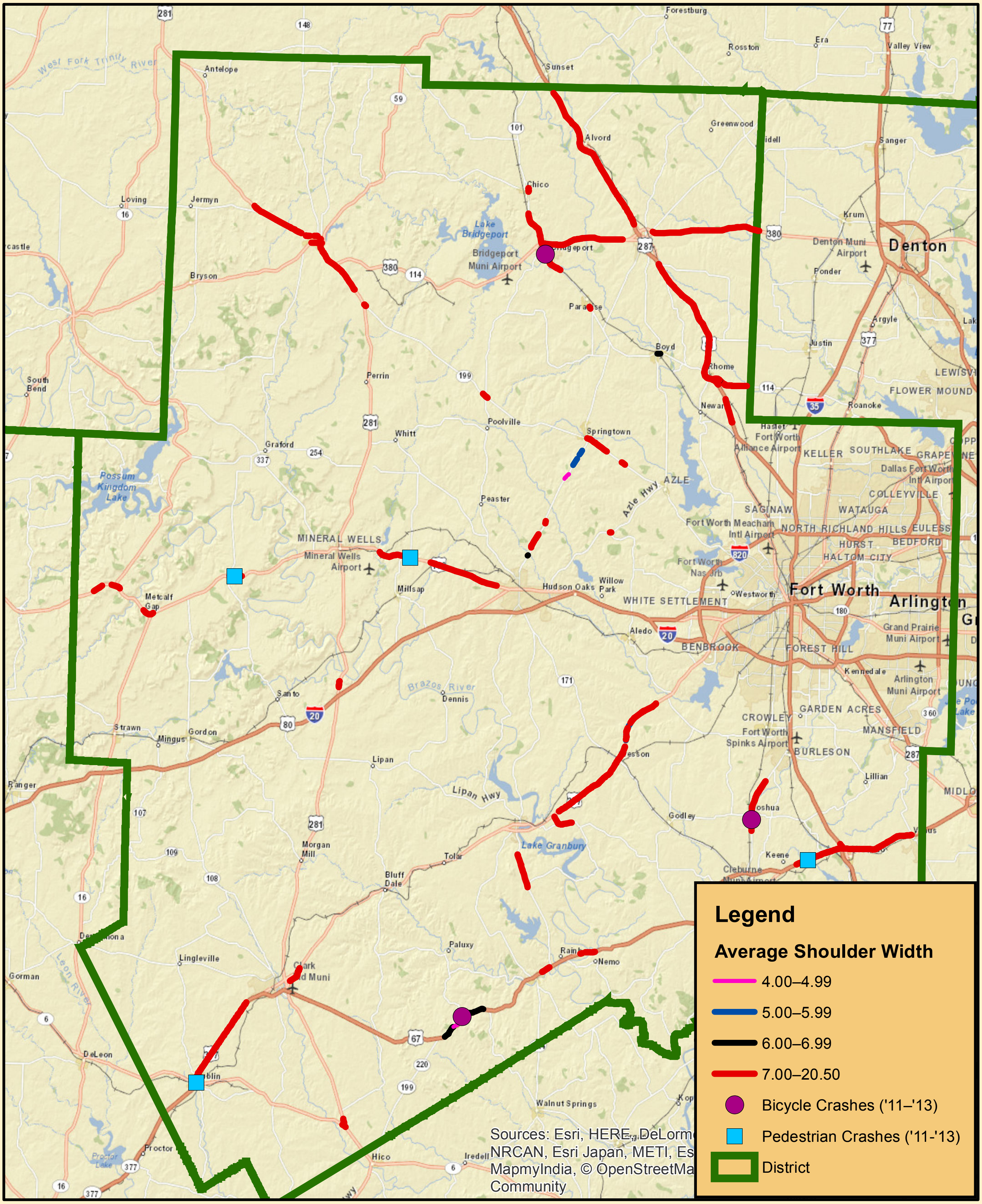
Speed > 35 mph
AADT > 400 vpd

TxDOT District 01

Rural Multilane Paved Shoulders with Pedestrian Crashes

0 4.5 9 18 27 36 Miles

Coordinate System: Albers
Central Meridian: 96°0'0"W
1st Std Parallel: 20°0'0"N
2nd Std Parallel: 60°0'0"N
Latitude of Origin: 40°0'0"N



Criteria

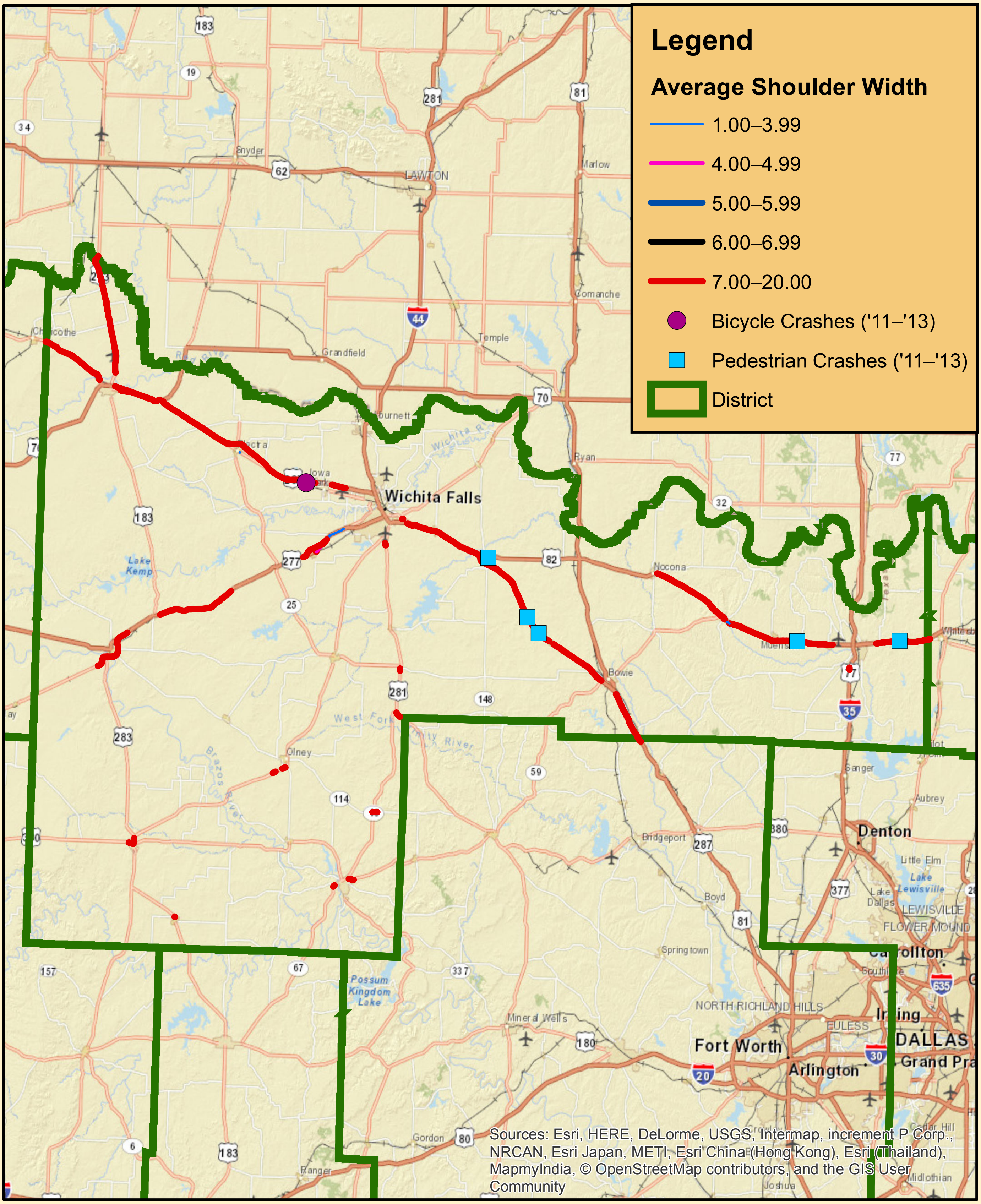
Speed > 35 mph
AADT > 400 vpd

TxDOT District 02

Rural Multilane Paved Shoulders with Pedestrian and Bicycle Crashes

0 3.25 6.5 13 19.5 26 Miles

Coordinate System: Albers
Central Meridian: 96°0'0"W
1st Std Parallel: 20°0'0"N
2nd Std Parallel: 60°0'0"N
Latitude of Origin: 40°0'0"N



Criteria

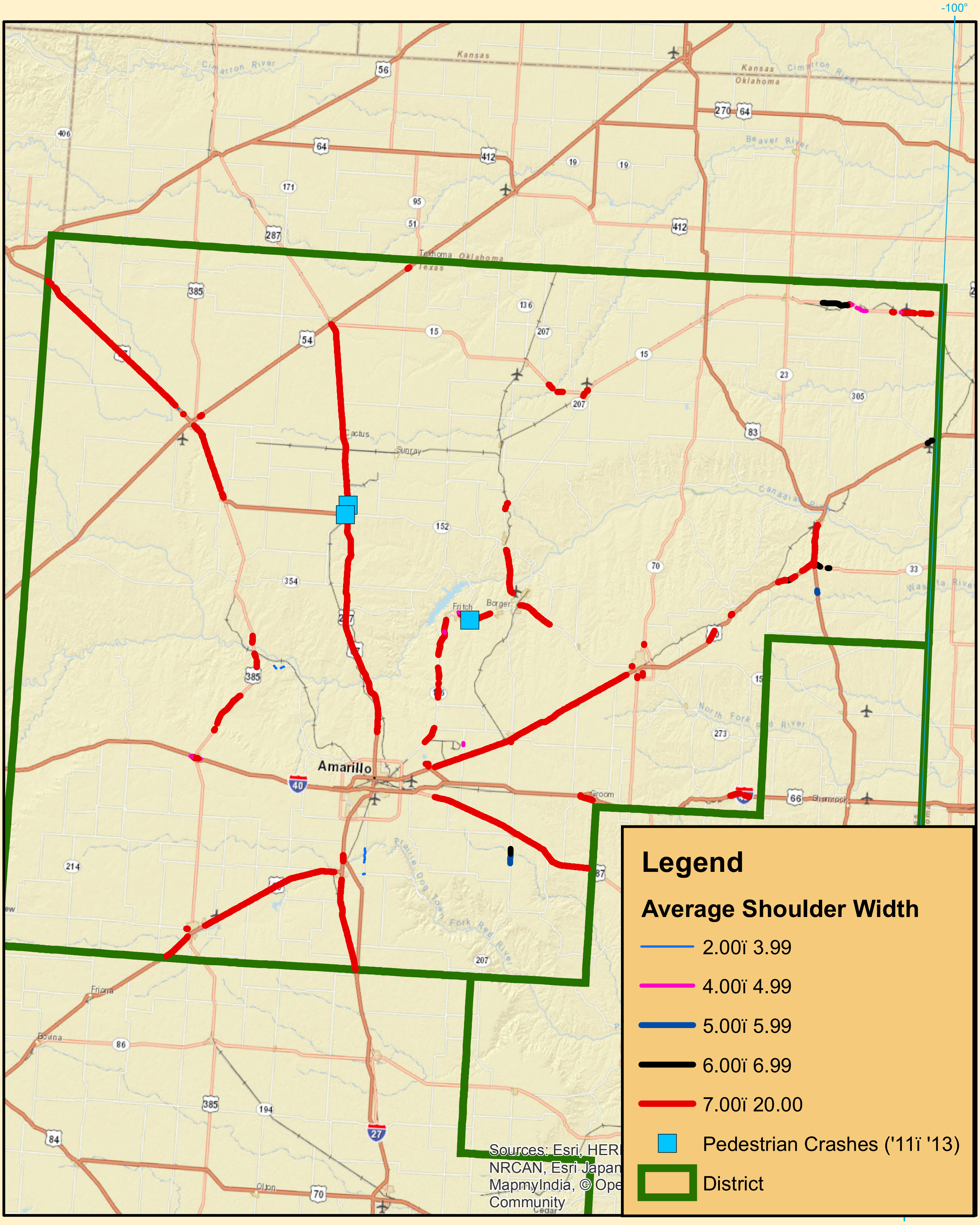
Speed > 35 mph
AADT > 400 vpd

TxDOT District 03

Rural Multilane Paved Shoulders with Pedestrian and Bicycle Crashes

0 5 10 20 30 40 Miles

Coordinate System: Albers
Central Meridian: 96°0'0"W
1st Std Parallel: 20°0'0"N
2nd Std Parallel: 60°0'0"N
Latitude of Origin: 40°0'0"N



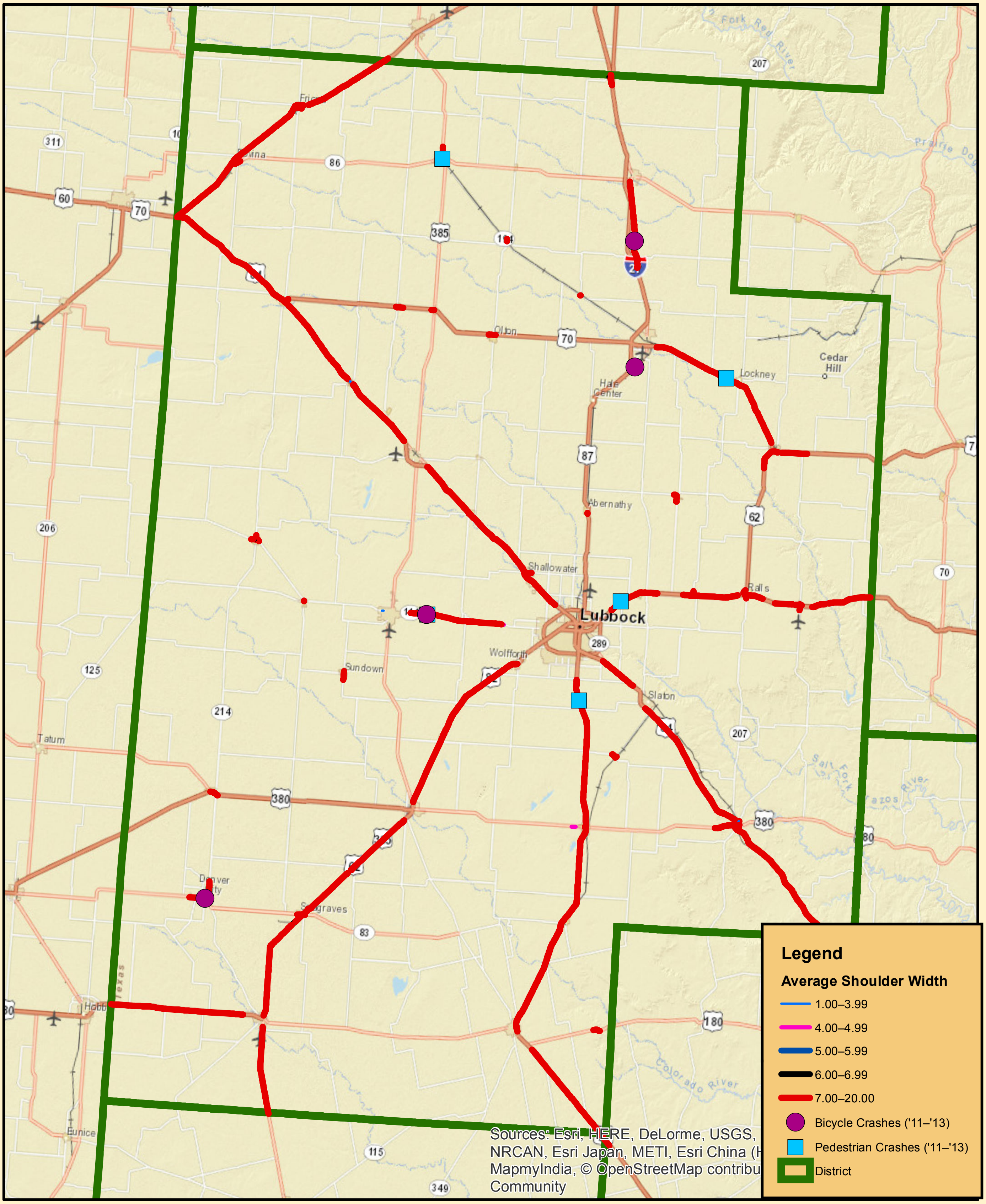
Criteria
Speed > 35 mph
AADT > 400 vpd

TxDOT District 04

Rural Multilane Paved Shoulders with Pedestrian Crashes

0 5 10 20 30 40 Miles

Coordinate System: Albers
Central Meridian: 96°0'0"W
1st Std Parallel: 20°0'0"N
2nd Std Parallel: 60°0'0"N
Latitude of Origin: 40°0'0"N



Criteria

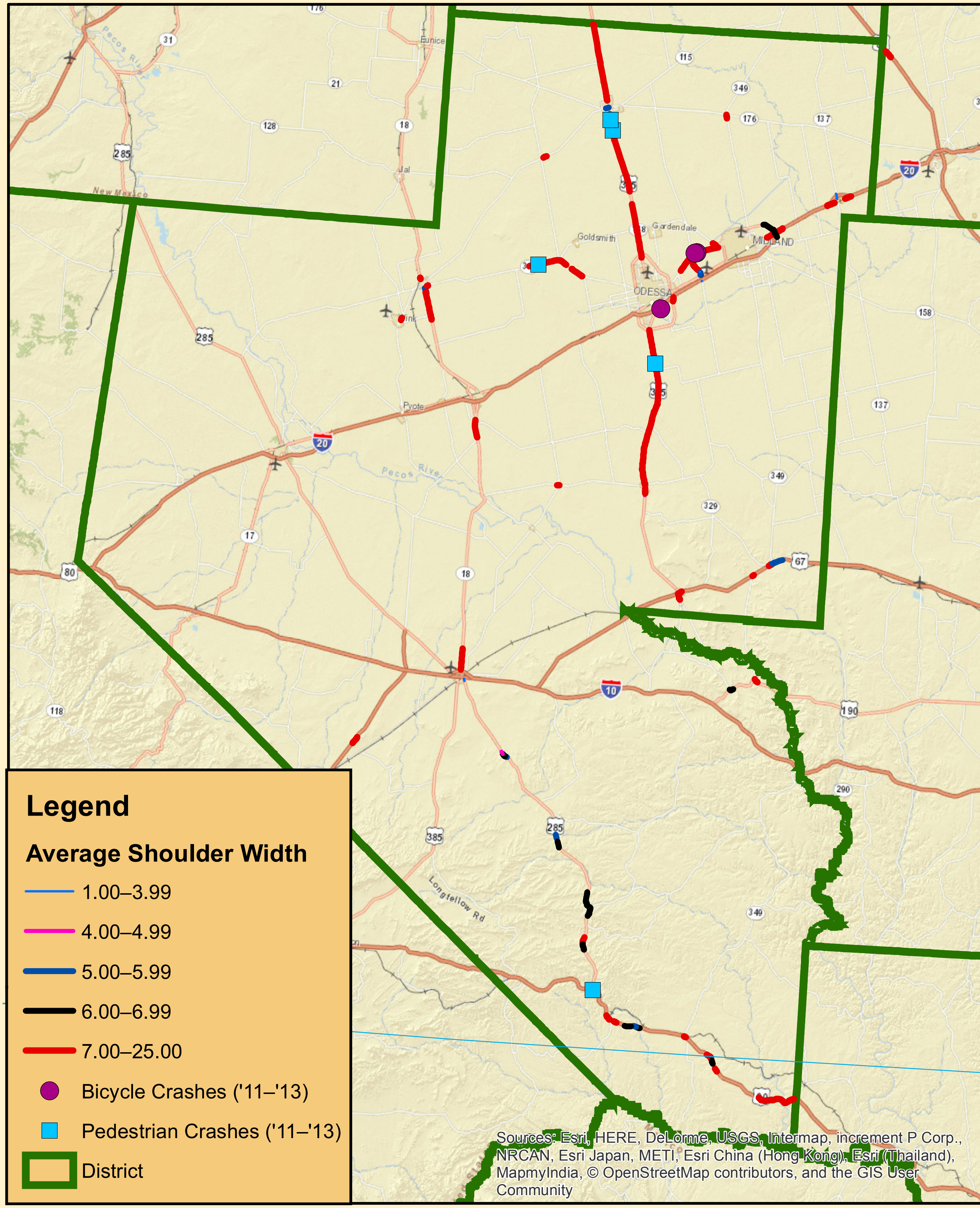
Speed > 35 mph
AADT > 400 vpd

TxDOT District 05

Rural Multilane Paved Shoulders with Pedestrian and Bicycle Crashes

0 5 10 20 30 40 Miles

Coordinate System: Albers
Central Meridian: 96°0'0"W
1st Std Parallel: 20°0'0"N
2nd Std Parallel: 60°0'0"N
Latitude of Origin: 40°0'0"N



Criteria

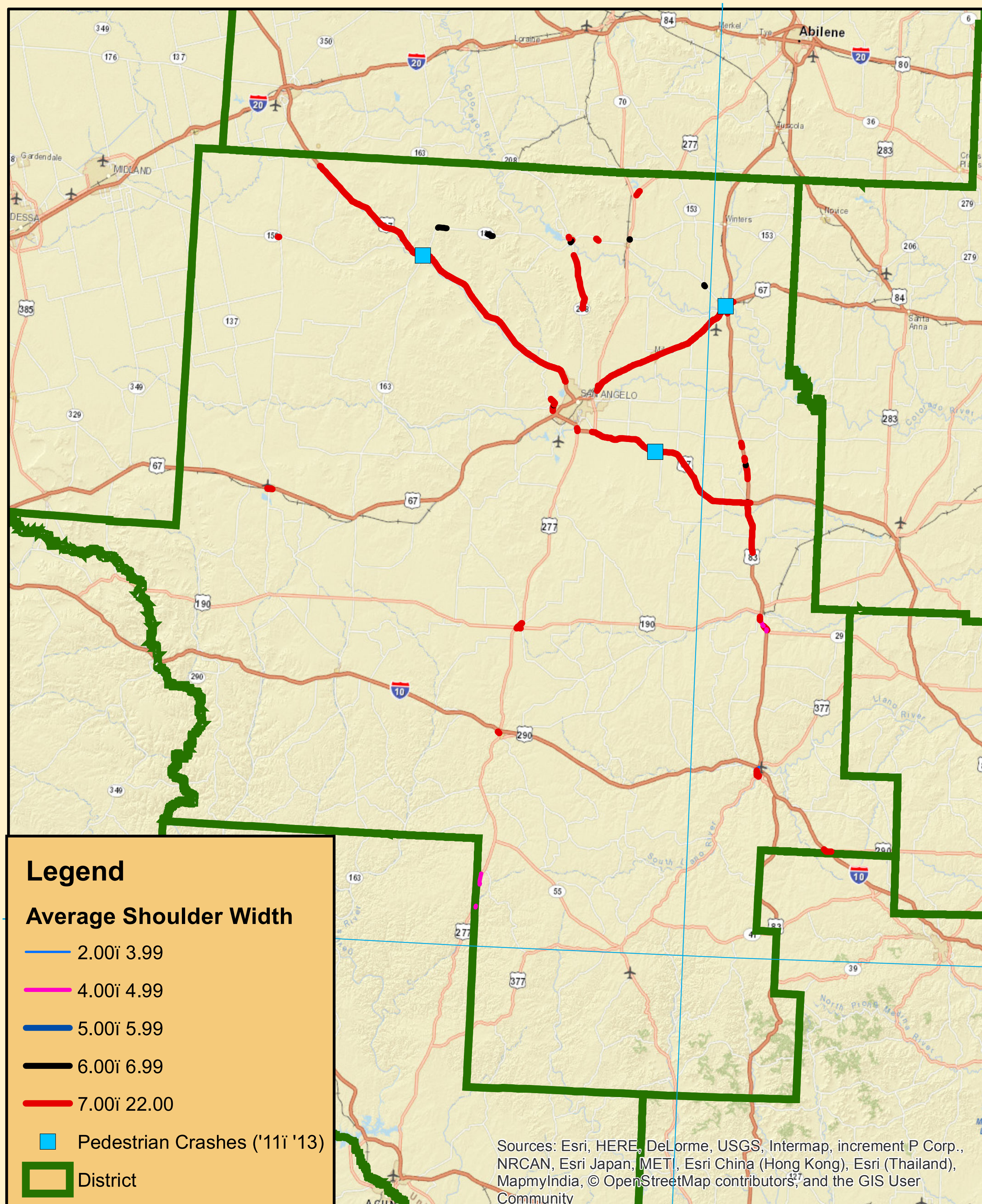
Speed > 35 mph
AADT > 400 vpd

TxDOT District 06

Rural Multilane Paved Shoulders with Pedestrian and Bicycle Crashes

0 5 10 20 30 40 Miles

Coordinate System: Albers
Central Meridian: 96°0'0"W
1st Std Parallel: 20°0'0"N
2nd Std Parallel: 60°0'0"N
Latitude of Origin: 40°0'0"N



Criteria

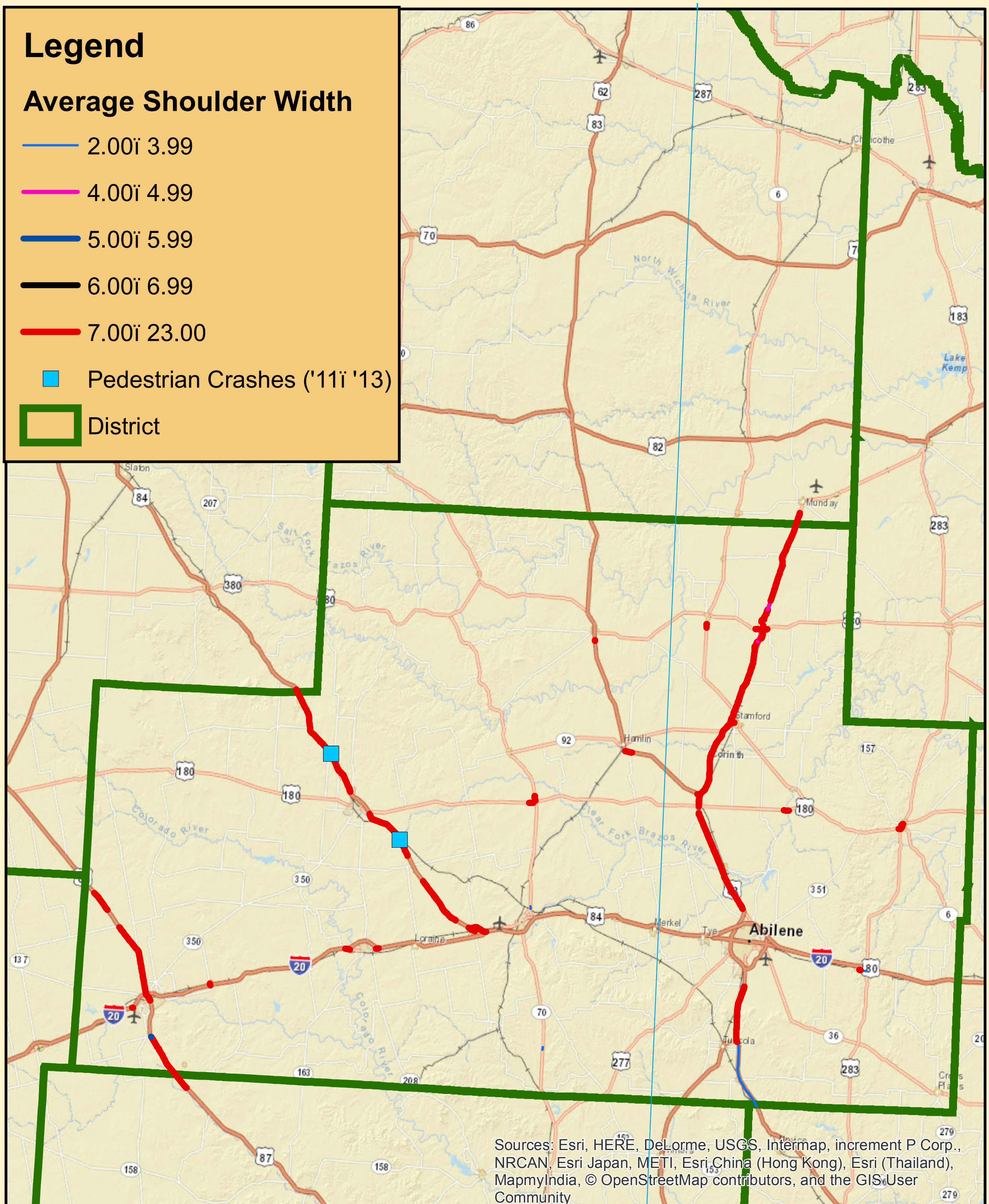
Speed > 35 mph
AADT > 400 vpd

TxDOT District 07

Rural Multilane Paved Shoulders
with Pedestrian Crashes

0 5 10 20 30 40 Miles

Coordinate System: Albers
Central Meridian: 96°0'0"W
1st Std Parallel: 20°0'0"N
2nd Std Parallel: 60°0'0"N
Latitude of Origin: 40°0'0"N



Criteria

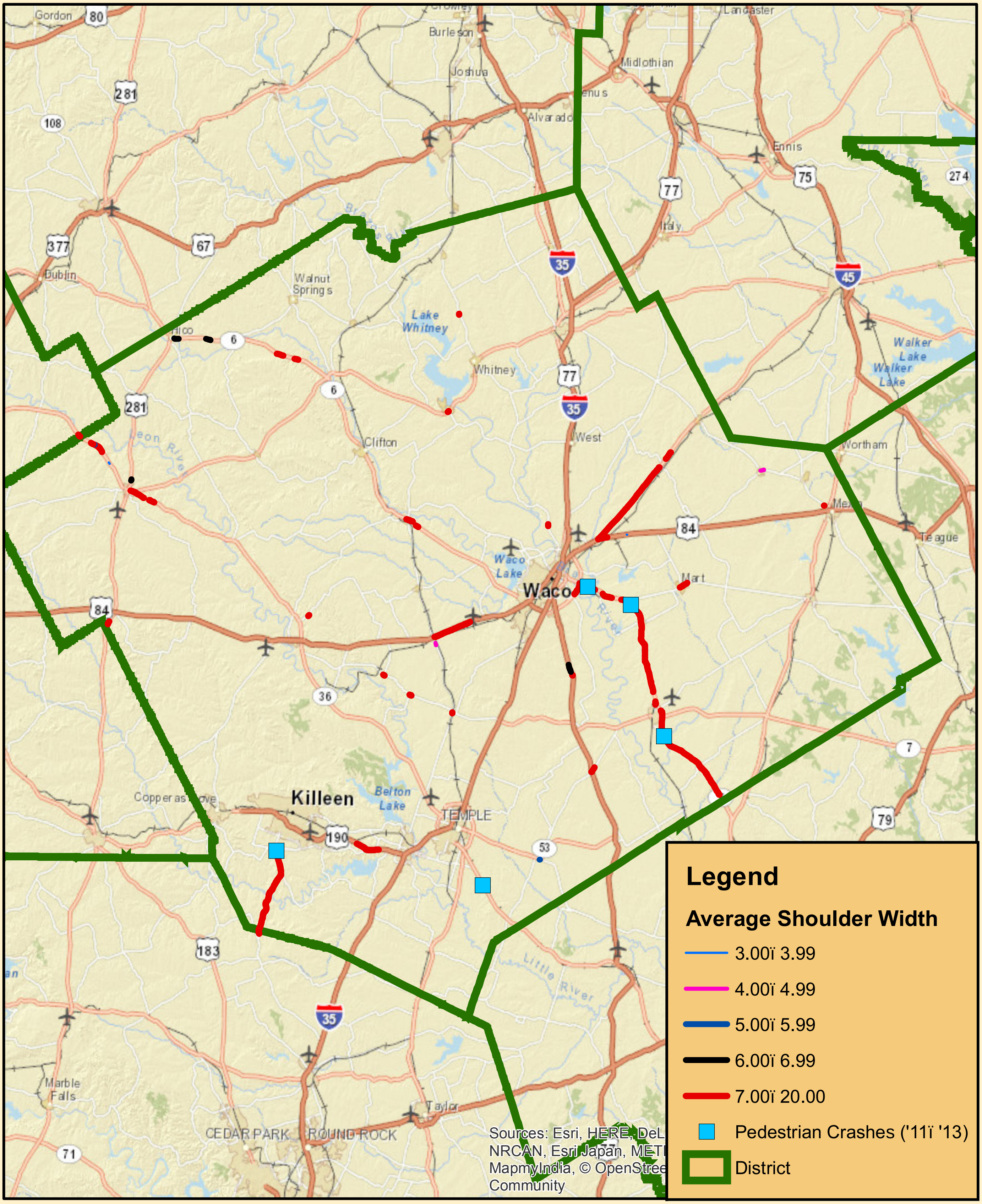
Speed > 35 mph
AADT > 400 vpd

TxDOT District 08

Rural Multilane Paved Shoulders with Pedestrian Crashes

0 5 10 20 30 40 Miles

Coordinate System: Albers
Central Meridian: 96°0'0"W
1st Std Parallel: 20°0'0"N
2nd Std Parallel: 60°0'0"N
Latitude of Origin: 40°0'0"N



Criteria

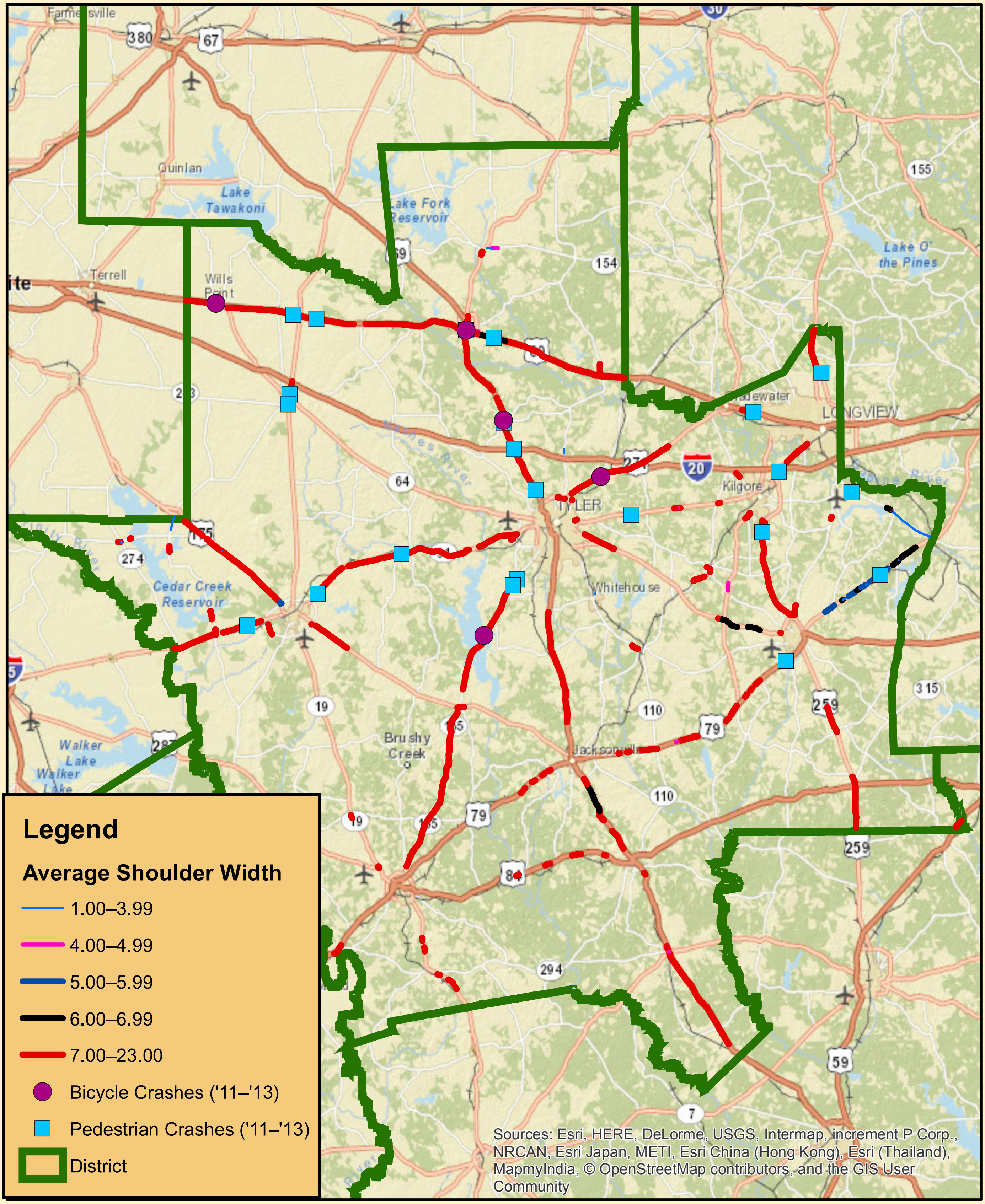
Speed > 35 mph
AADT > 400 vpd

TxDOT District 09

Rural Multilane Paved Shoulders with Pedestrian Crashes

0 4.5 9 18 27 36 Miles

Coordinate System: Albers
Central Meridian: 96°0'0"W
1st Std Parallel: 20°0'0"N
2nd Std Parallel: 60°0'0"N
Latitude of Origin: 40°0'0"N



Criteria

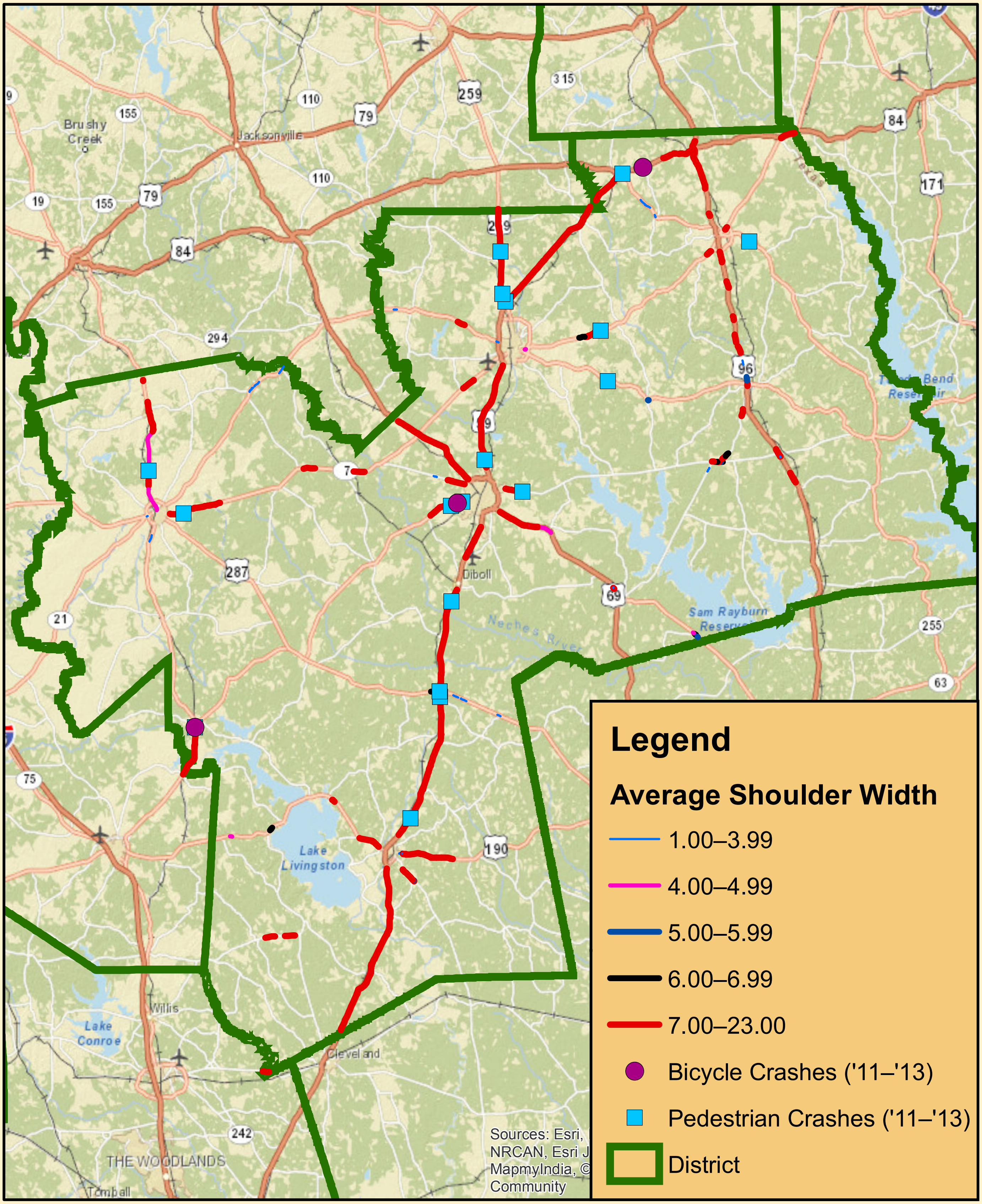
Speed > 35 mph
AADT > 400 vpd

TxDOT District 10

Rural Multilane Paved Shoulders with Pedestrian and Bicycle Crashes

0 4 8 16 24 32 Miles

Coordinate System: Albers
Central Meridian: 96°0'0"W
1st Std Parallel: 20°0'0"N
2nd Std Parallel: 60°0'0"N
Latitude of Origin: 40°0'0"N



Criteria

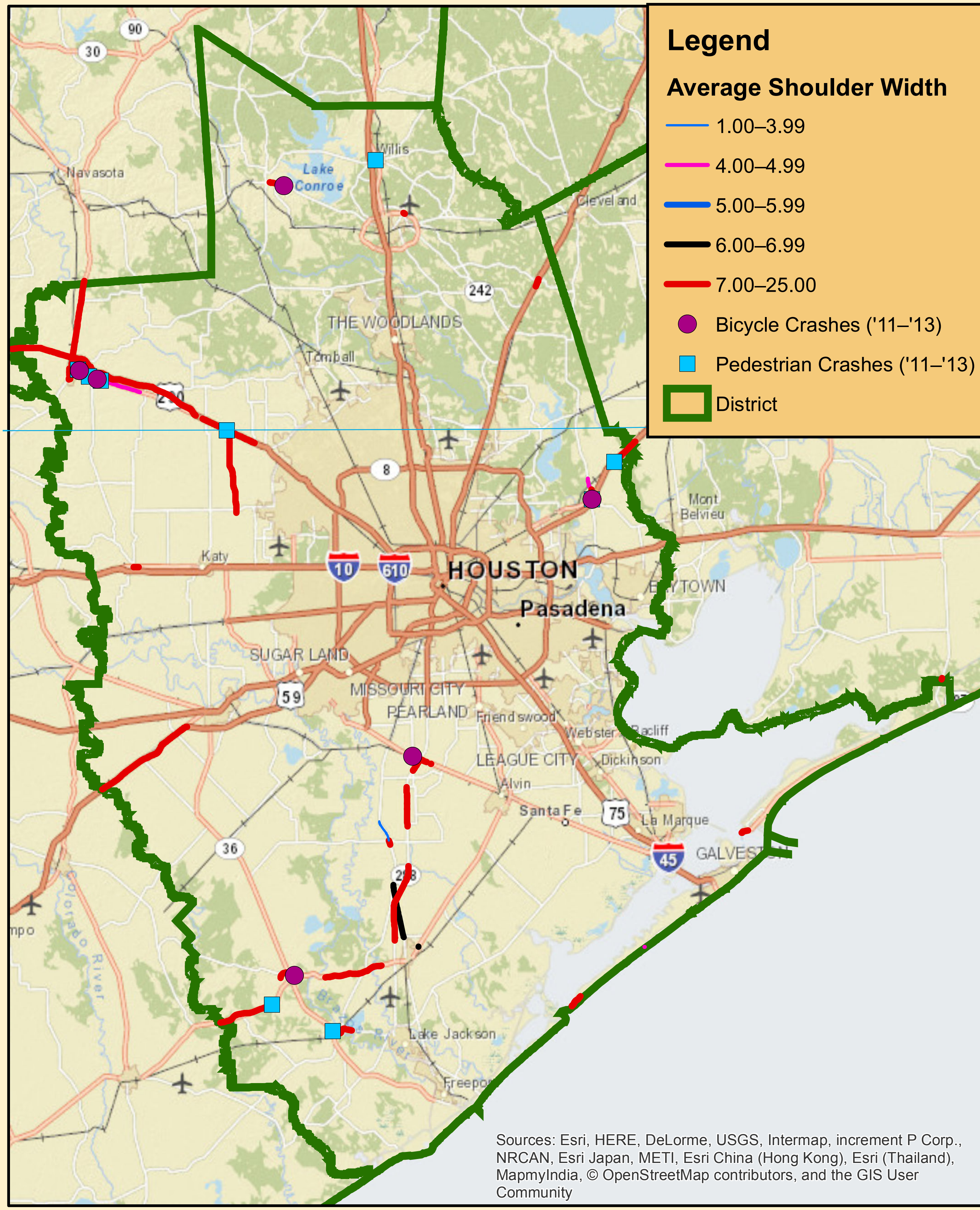
Speed > 35 mph
AADT > 400 vpd

TxDOT District 11

Rural Multilane Paved Shoulders with Pedestrian and Bicycle Crashes

0 4.25 8.5 17 25.5 34 Miles

Coordinate System: Albers
Central Meridian: 96°0'0"W
1st Std Parallel: 20°0'0"N
2nd Std Parallel: 60°0'0"N
Latitude of Origin: 40°0'0"N



Criteria

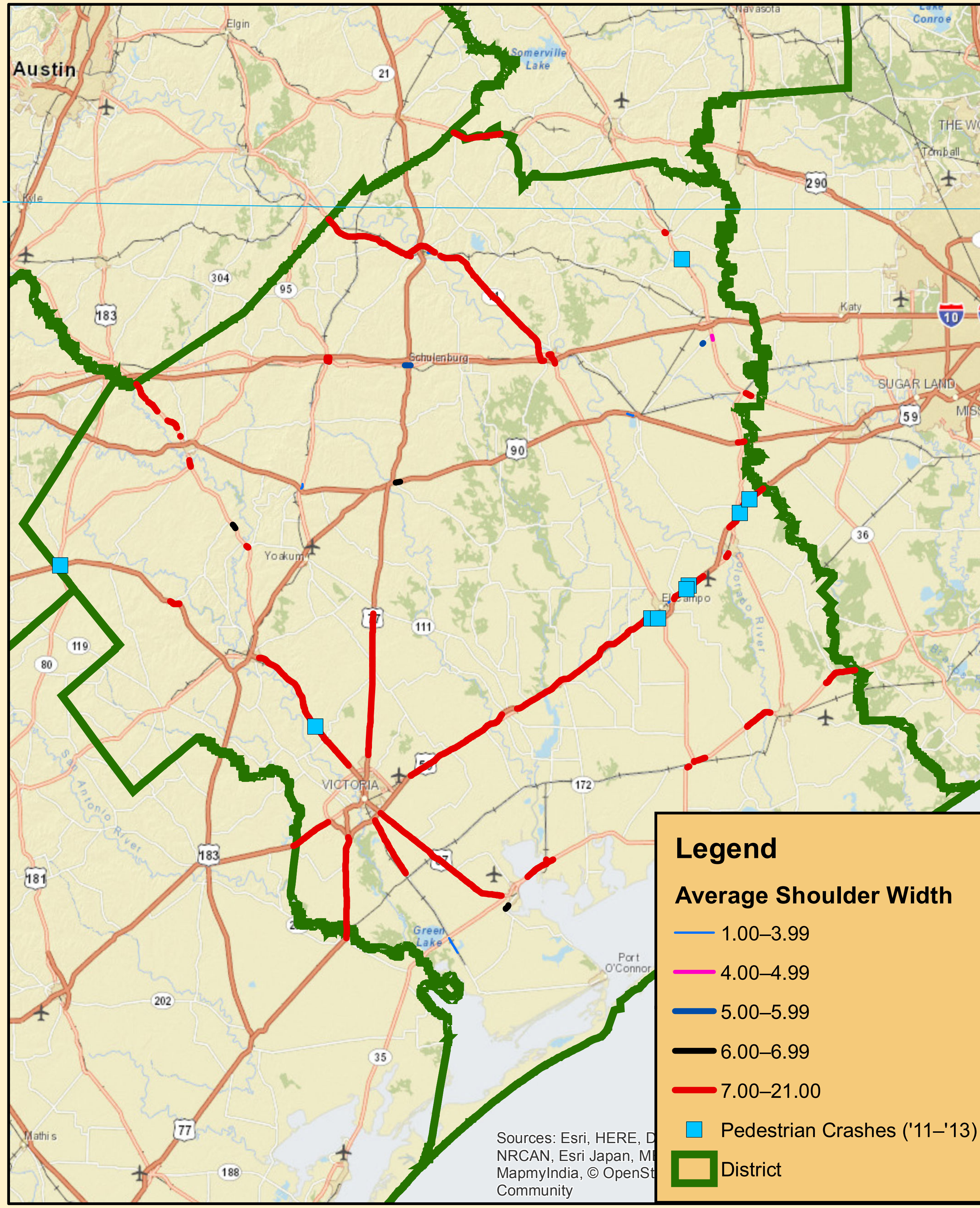
Speed > 35 mph
AADT > 400 vpd

TxDOT District 12

Rural Multilane Paved Shoulders with Pedestrian and Bicycle Crashes

0 3.75 7.5 15 22.5 30 Miles

Coordinate System: Albers
Central Meridian: 96°0'0"W
1st Std Parallel: 20°0'0"N
2nd Std Parallel: 60°0'0"N
Latitude of Origin: 40°0'0"N



Criteria

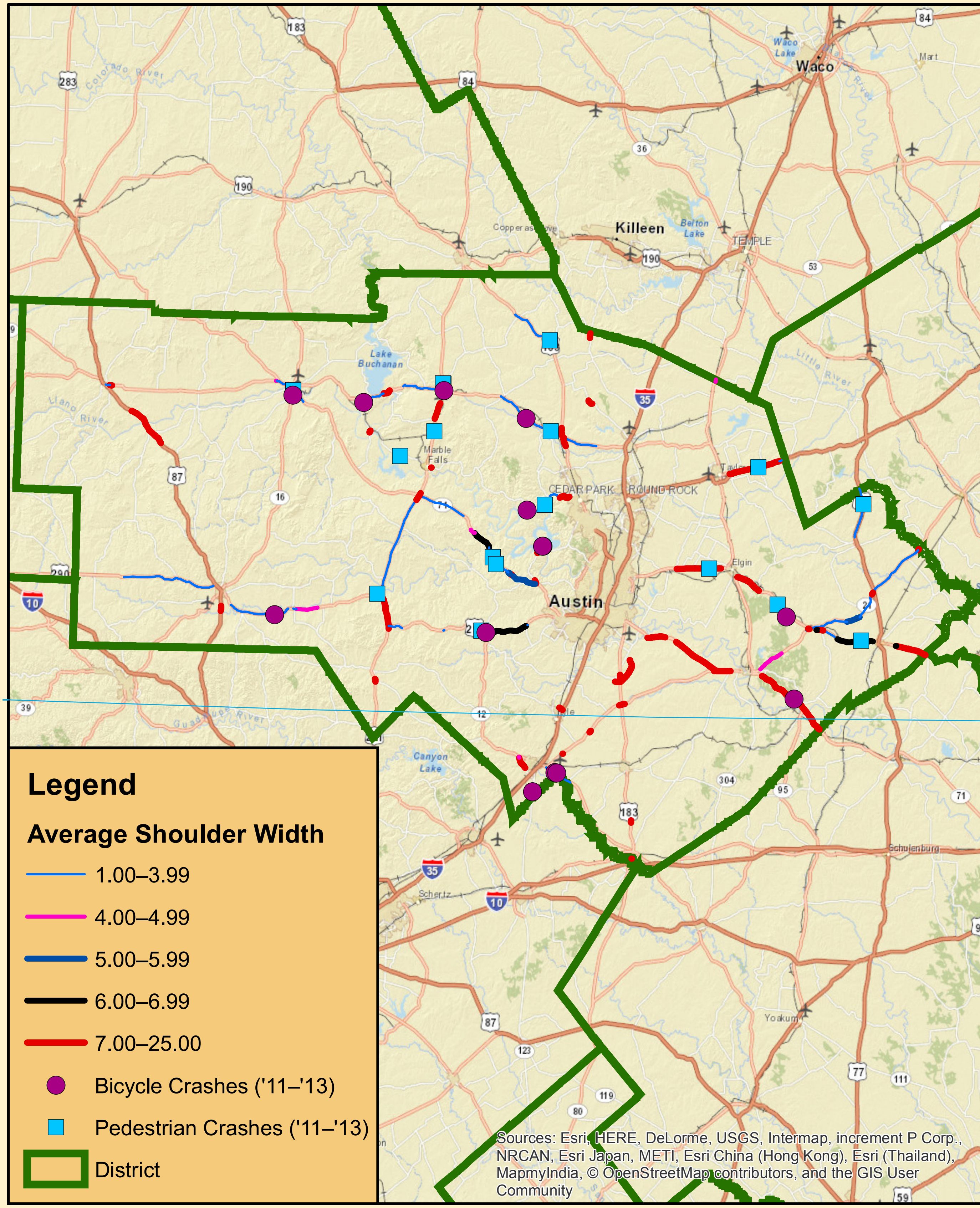
Speed > 35 mph
AADT > 400 vpd

TxDOT District 13

Rural Multilane Paved Shoulders with Pedestrian Crashes

0 5 10 20 30 40 Miles

Coordinate System: Albers
Central Meridian: 96°0'0"W
1st Std Parallel: 20°0'0"N
2nd Std Parallel: 60°0'0"N
Latitude of Origin: 40°0'0"N



Criteria

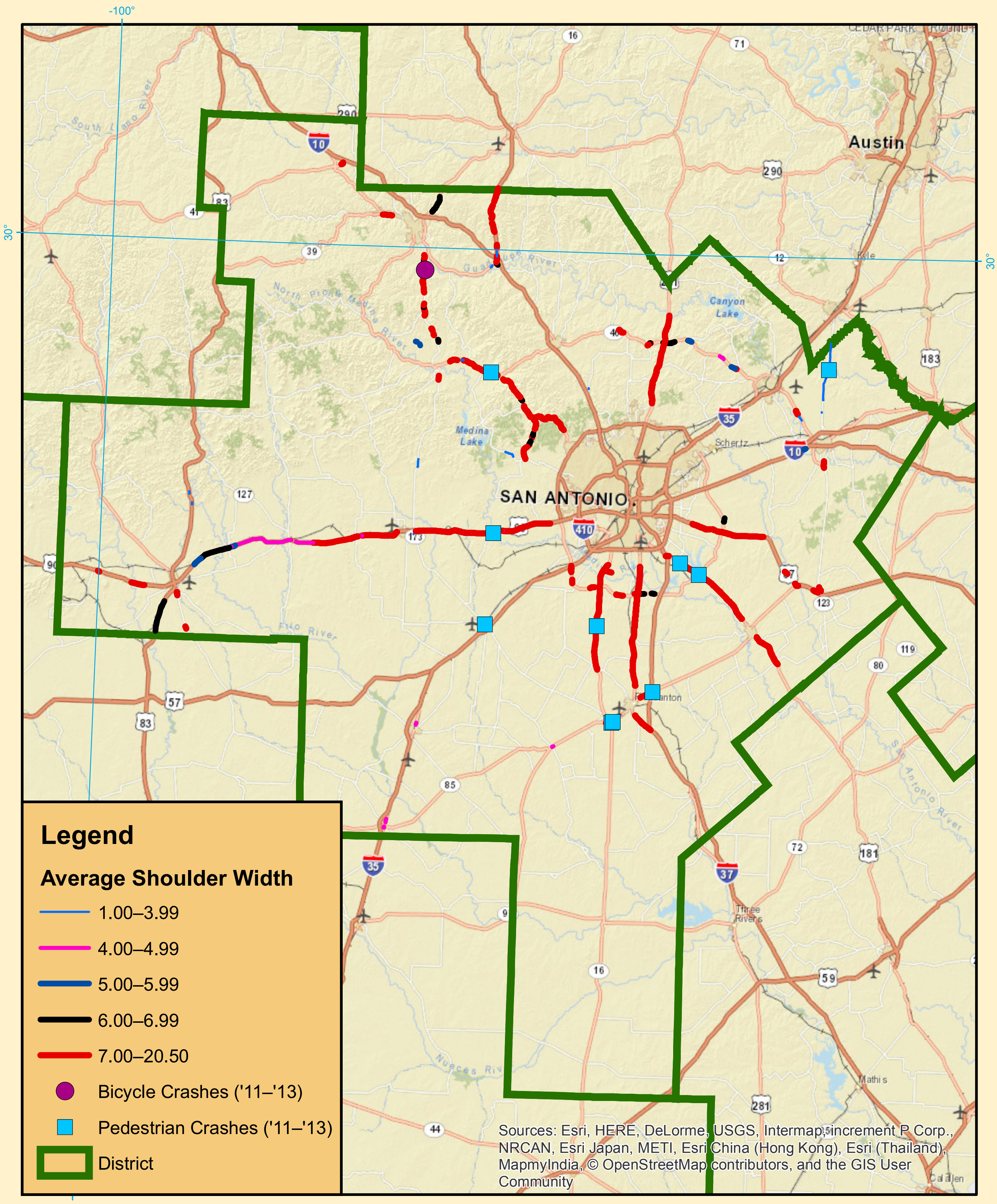
Speed > 35 mph
AADT > 400 vpd

TxDOT District 14

Rural Multilane Paved Shoulders with Pedestrian and Bicycle Crashes

0 5 10 20 30 40 Miles

Coordinate System: Albers
Central Meridian: 96°0'0"W
1st Std Parallel: 20°0'0"N
2nd Std Parallel: 60°0'0"N
Latitude of Origin: 40°0'0"N



Criteria

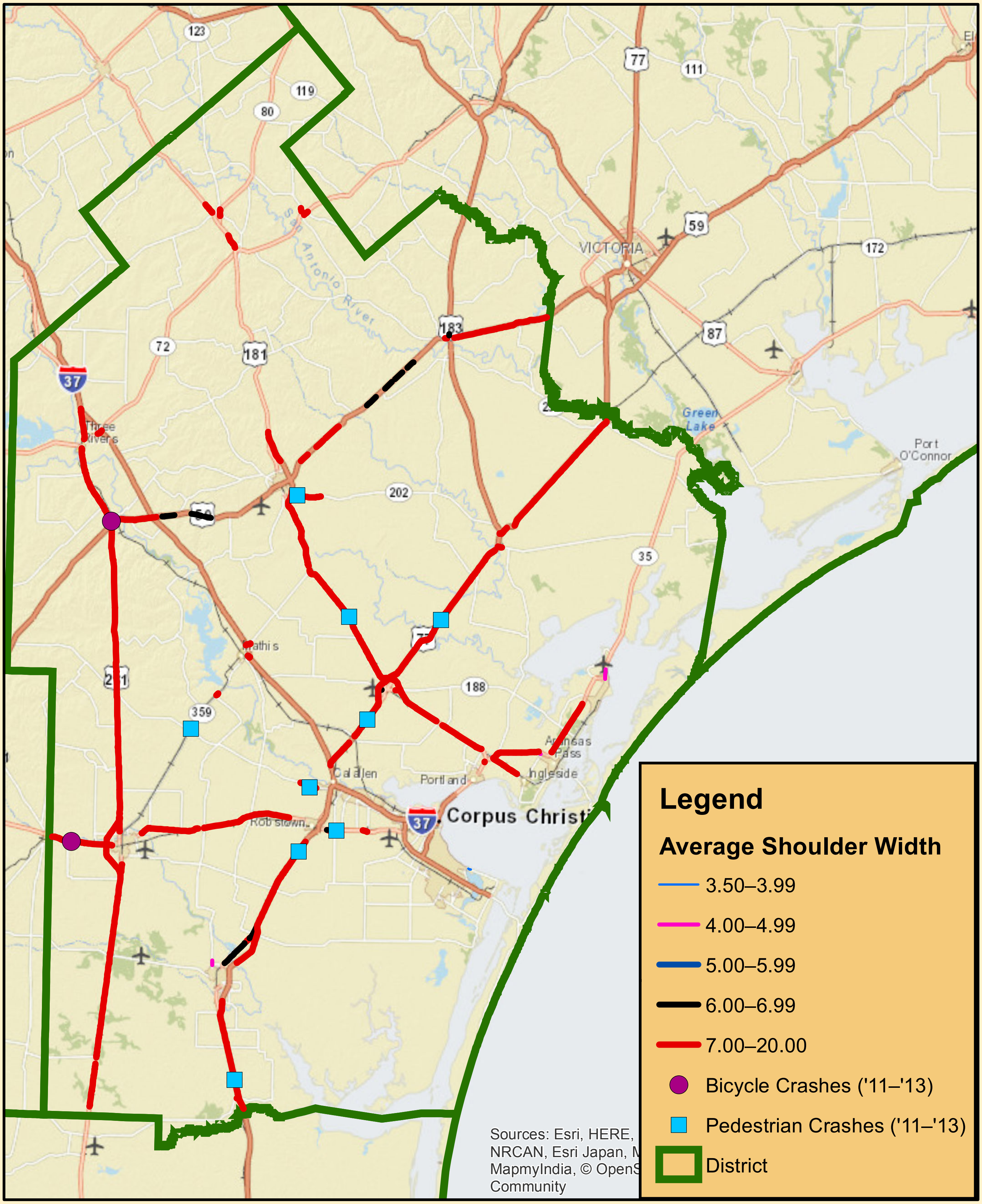
Speed > 35 mph
AADT > 400 vpd

TxDOT District 15

Rural Multilane Paved Shoulders with Pedestrian and Bicycle Crashes

0 5 10 20 30 40 Miles

Coordinate System: Albers
Central Meridian: 96°0'0"W
1st Std Parallel: 20°0'0"N
2nd Std Parallel: 60°0'0"N
Latitude of Origin: 40°0'0"N



Criteria

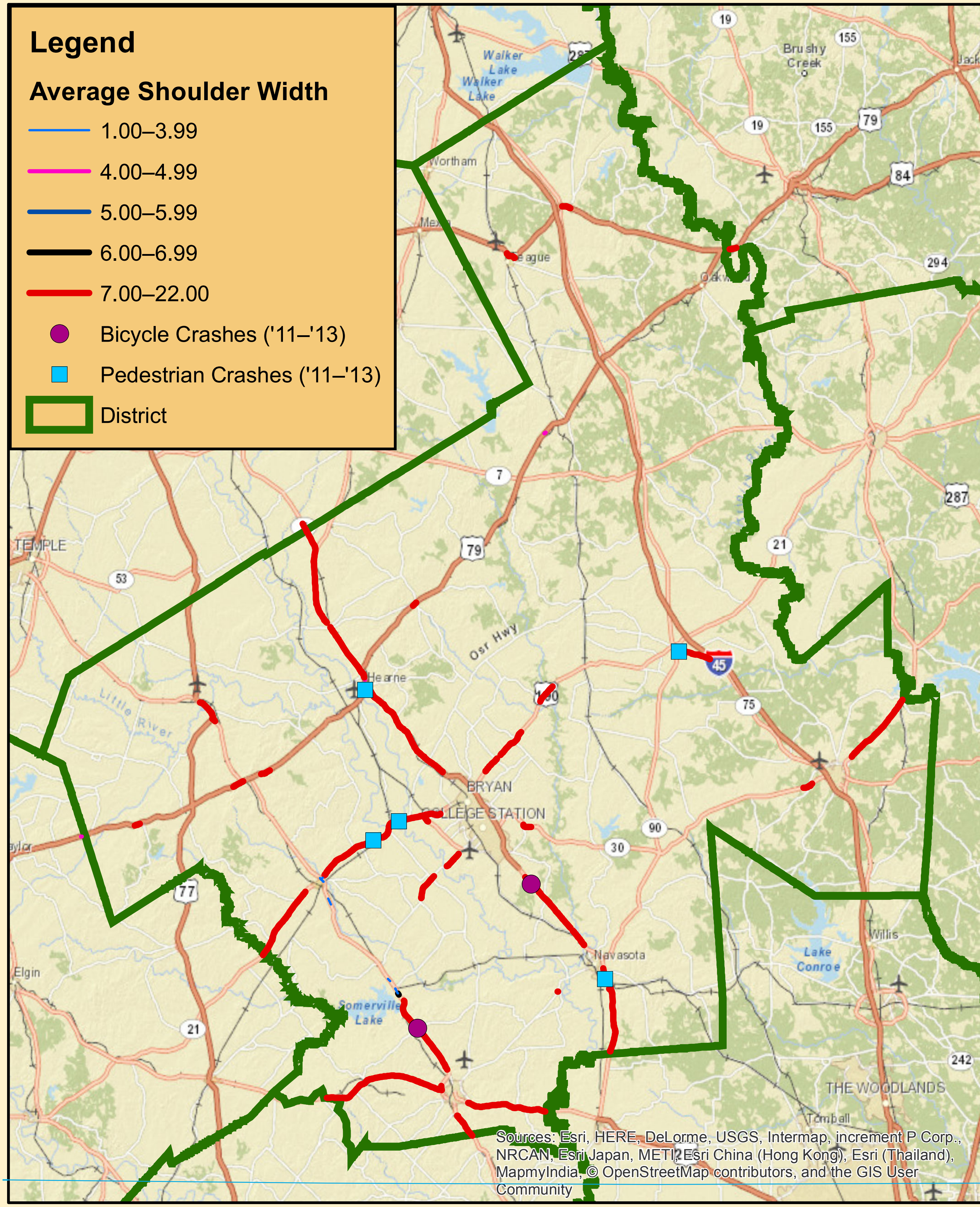
Speed > 35 mph
AADT > 400 vpd

TxDOT District 16

Rural Multilane Paved Shoulders with Pedestrian and Bicycle Crashes

0 4.25 8.5 17 25.5 34 Miles

Coordinate System: Albers
Central Meridian: 96°0'0"W
1st Std Parallel: 20°0'0"N
2nd Std Parallel: 60°0'0"N
Latitude of Origin: 40°0'0"N



Criteria

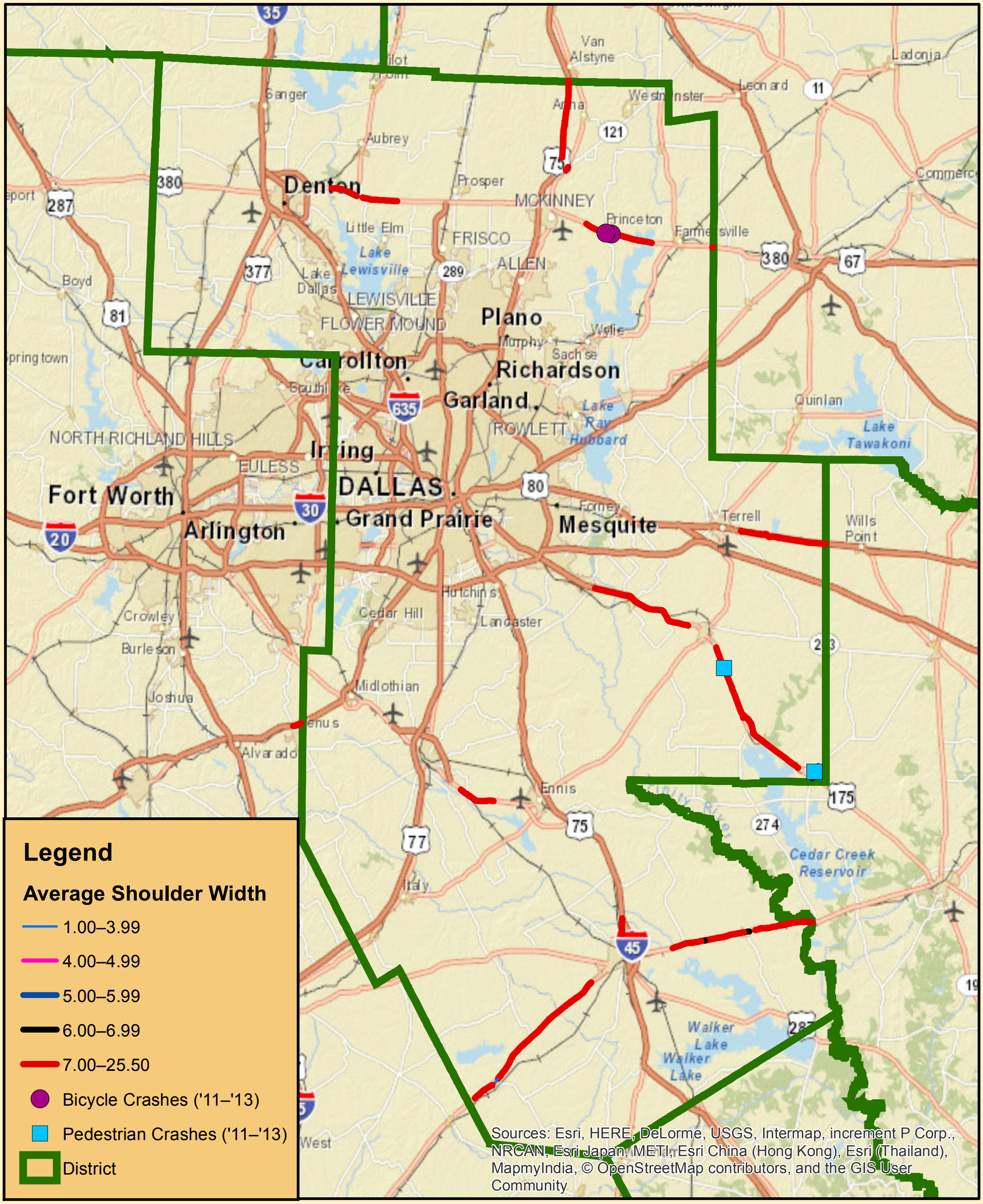
Speed > 35 mph
AADT > 400 vpd

TxDOT District 17

Rural Multilane Paved Shoulders with Pedestrian and Bicycle Crashes

0 4.25 8.5 17 25.5 34 Miles

Coordinate System: Albers
Central Meridian: 96°0'0"W
1st Std Parallel: 20°0'0"N
2nd Std Parallel: 60°0'0"N
Latitude of Origin: 40°0'0"N



Criteria

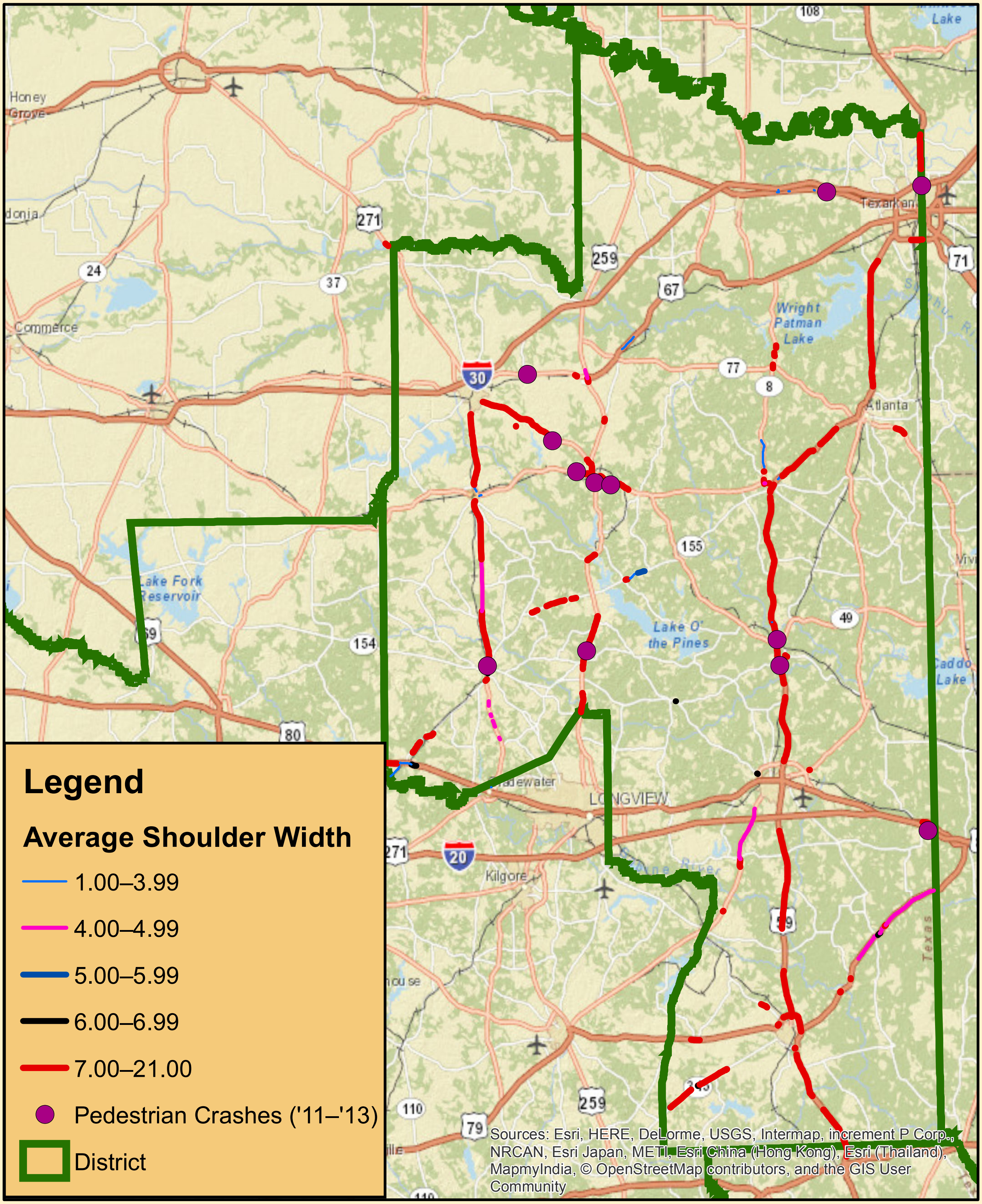
Speed > 35 mph
AADT > 400 vpd

TxDOT District 18

Rural Multilane Paved Shoulders with Pedestrian and Bicycle Crashes

0 3.5 7 14 21 28 Miles

Coordinate System: Albers
Central Meridian: 96°0'0"W
1st Std Parallel: 20°0'0"N
2nd Std Parallel: 60°0'0"N
Latitude of Origin: 40°0'0"N



Criteria

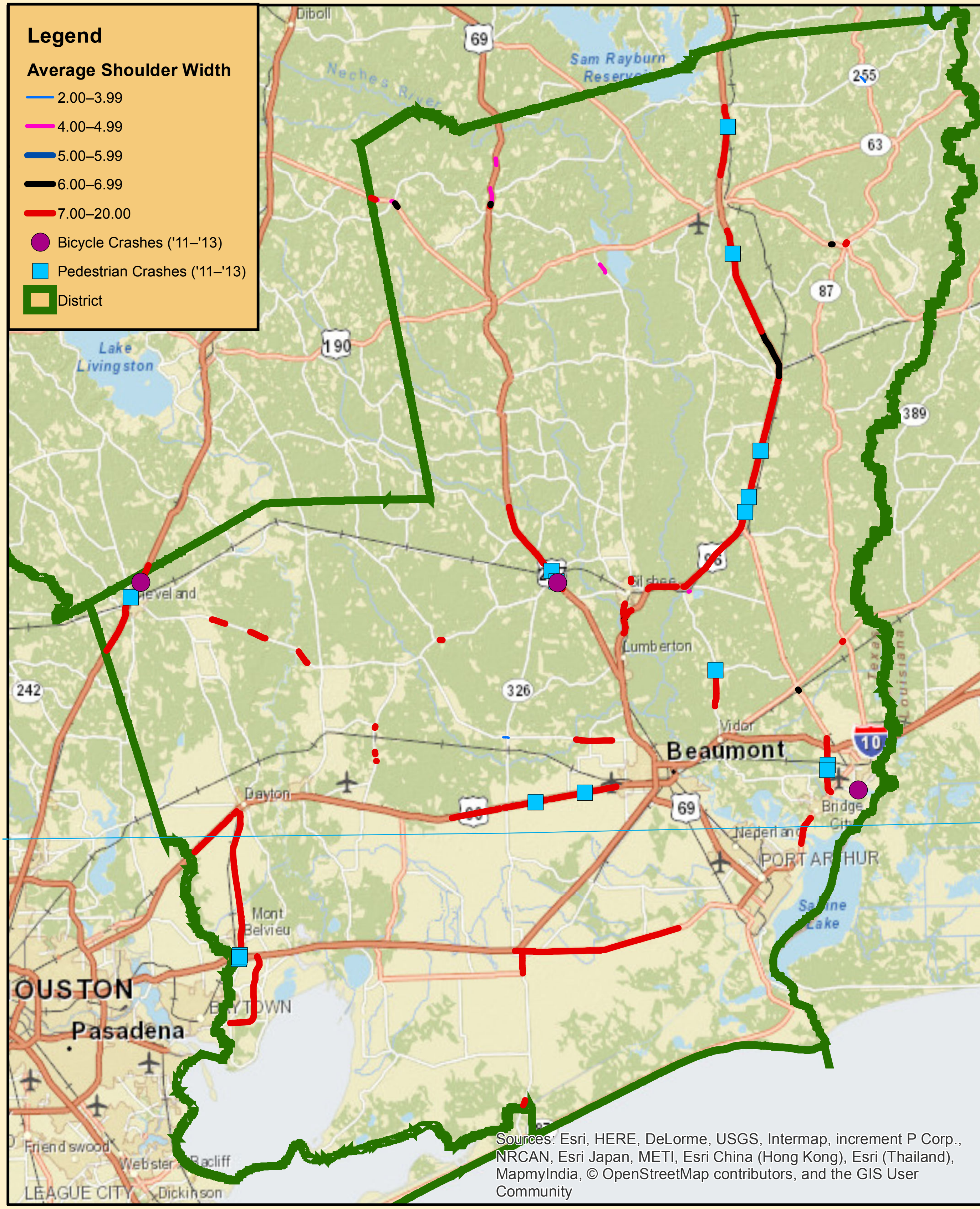
Speed > 35 mph
AADT > 400 vpd

TxDOT District 19

Rural Multilane Paved Shoulders with Pedestrian Crashes

0 3.75 7.5 15 22.5 30 Miles

Coordinate System: Albers
Central Meridian: 96°0'0"W
1st Std Parallel: 20°0'0"N
2nd Std Parallel: 60°0'0"N
Latitude of Origin: 40°0'0"N



Criteria

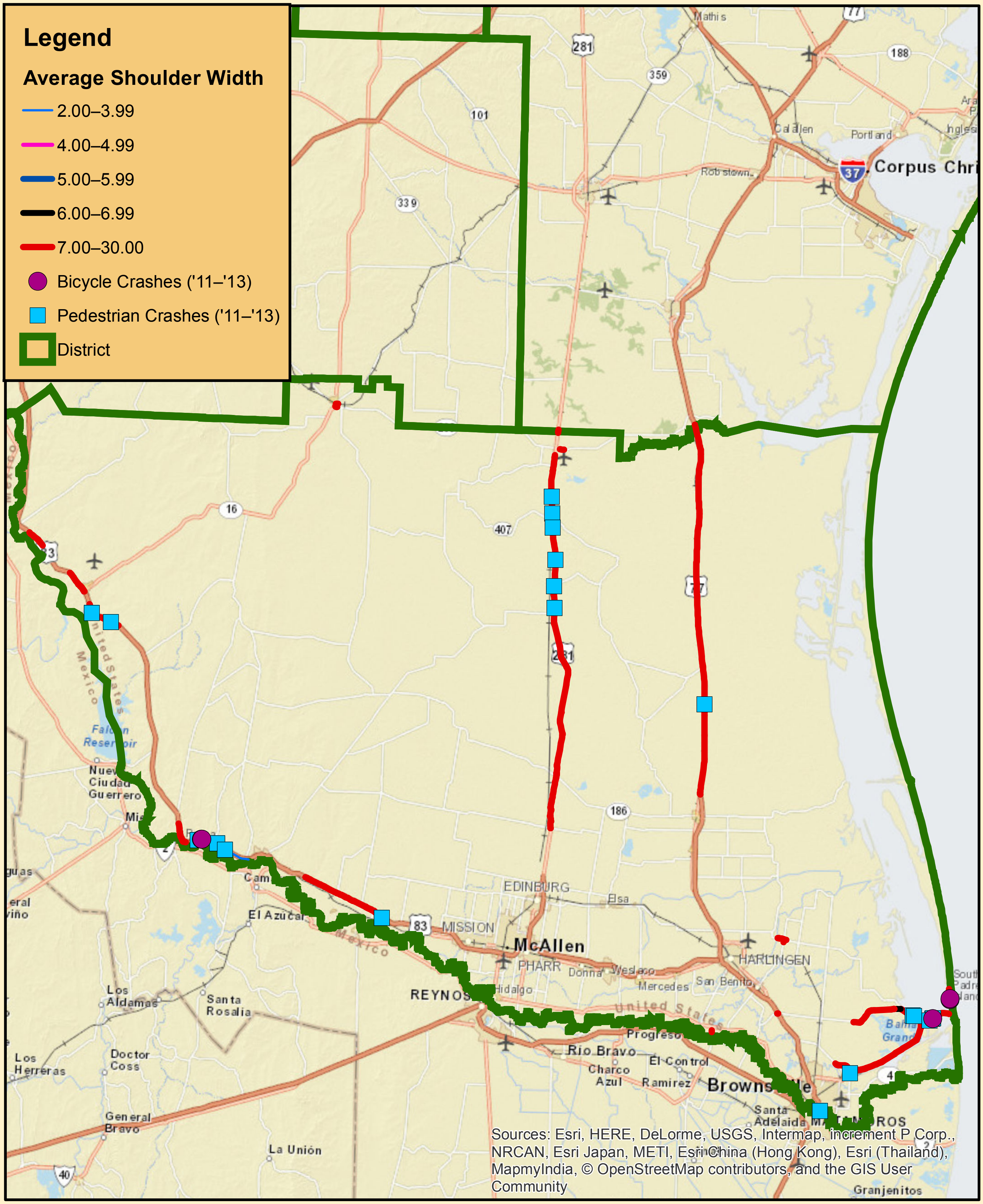
Speed > 35 mph
AADT > 400 vpd

TxDOT District 20

Rural Multilane Paved Shoulders with Pedestrian and Bicycle Crashes

0 3.5 7 14 21 28 Miles

Coordinate System: Albers
Central Meridian: 96°0'0"W
1st Std Parallel: 20°0'0"N
2nd Std Parallel: 60°0'0"N
Latitude of Origin: 40°0'0"N



Criteria

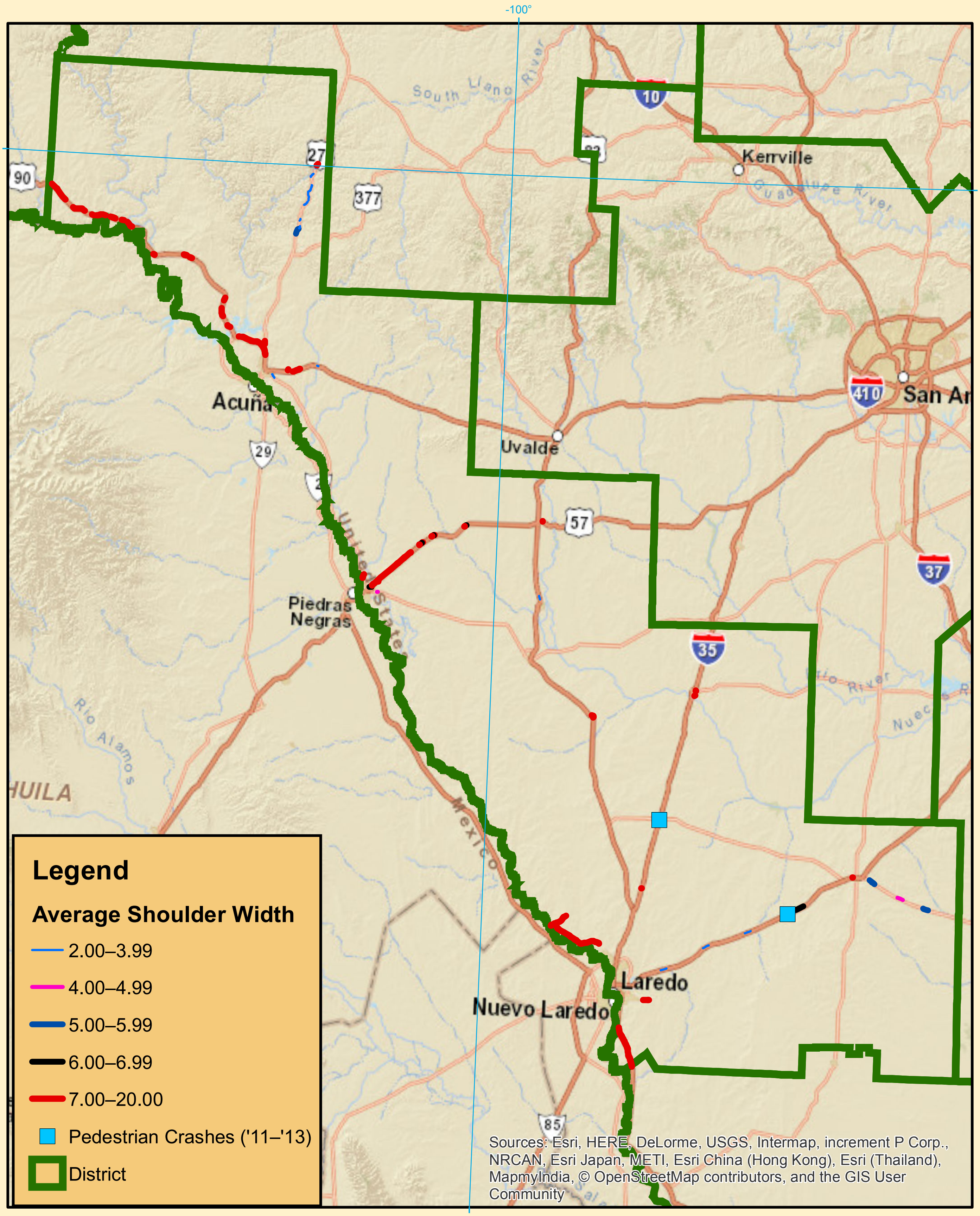
Speed > 35 mph
AADT > 400 vpd

TxDOT District 21

Rural Multilane Paved Shoulders with Pedestrian and Bicycle Crashes

0 5 10 20 30 40 Miles

Coordinate System: Albers
Central Meridian: 96°0'0"W
1st Std Parallel: 20°0'0"N
2nd Std Parallel: 60°0'0"N
Latitude of Origin: 40°0'0"N



Criteria

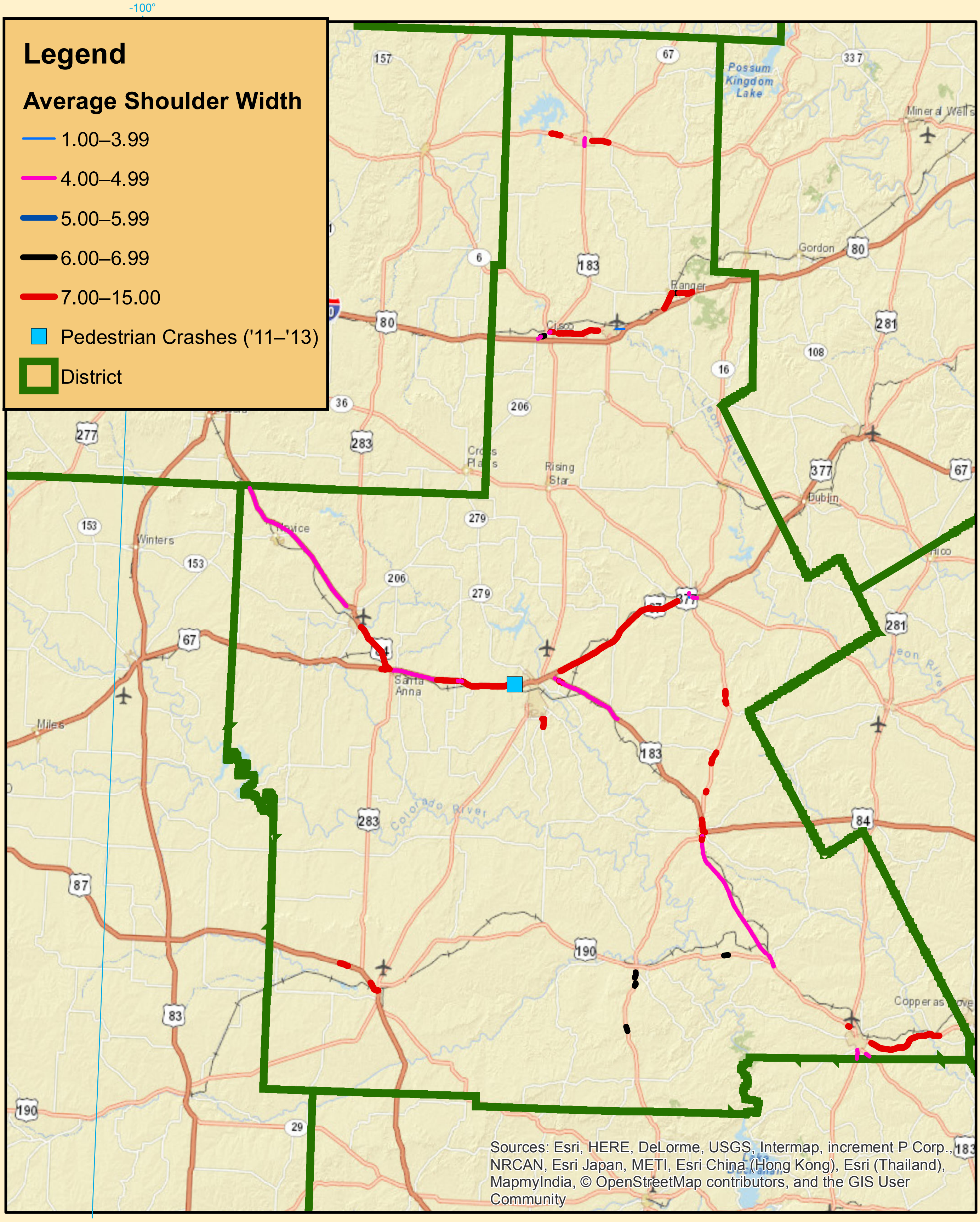
Speed > 35 mph
AADT > 400 vpd

TxDOT District 22

Rural Multilane Paved Shoulders with Pedestrian Crashes

0 5 10 20 30 40 Miles

Coordinate System: Albers
Central Meridian: 96°0'0"W
1st Std Parallel: 20°0'0"N
2nd Std Parallel: 60°0'0"N
Latitude of Origin: 40°0'0"N



Criteria

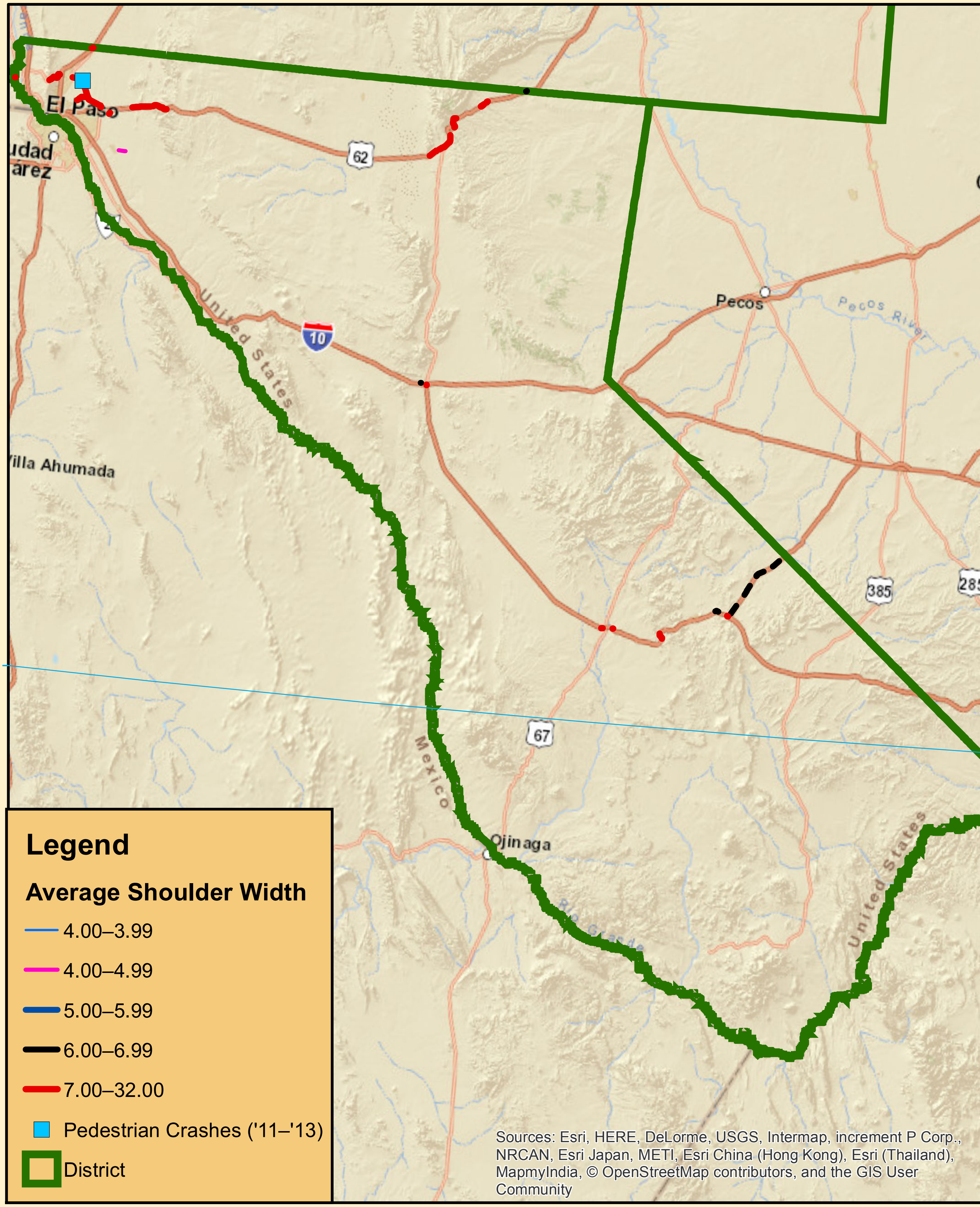
Speed > 35 mph
AADT > 400 vpd

TxDOT District 23

Rural Multilane Paved Shoulders with Pedestrian and Bicycle Crashes

0 4.5 9 18 27 36 Miles

Coordinate System: Albers
Central Meridian: 96°0'0"W
1st Std Parallel: 20°0'0"N
2nd Std Parallel: 60°0'0"N
Latitude of Origin: 40°0'0"N



Legend

Average Shoulder Width

- 4.00–3.99
- 4.00–4.99
- 5.00–5.99
- 6.00–6.99
- 7.00–32.00
- Pedestrian Crashes ('11–'13)
- District

Criteria

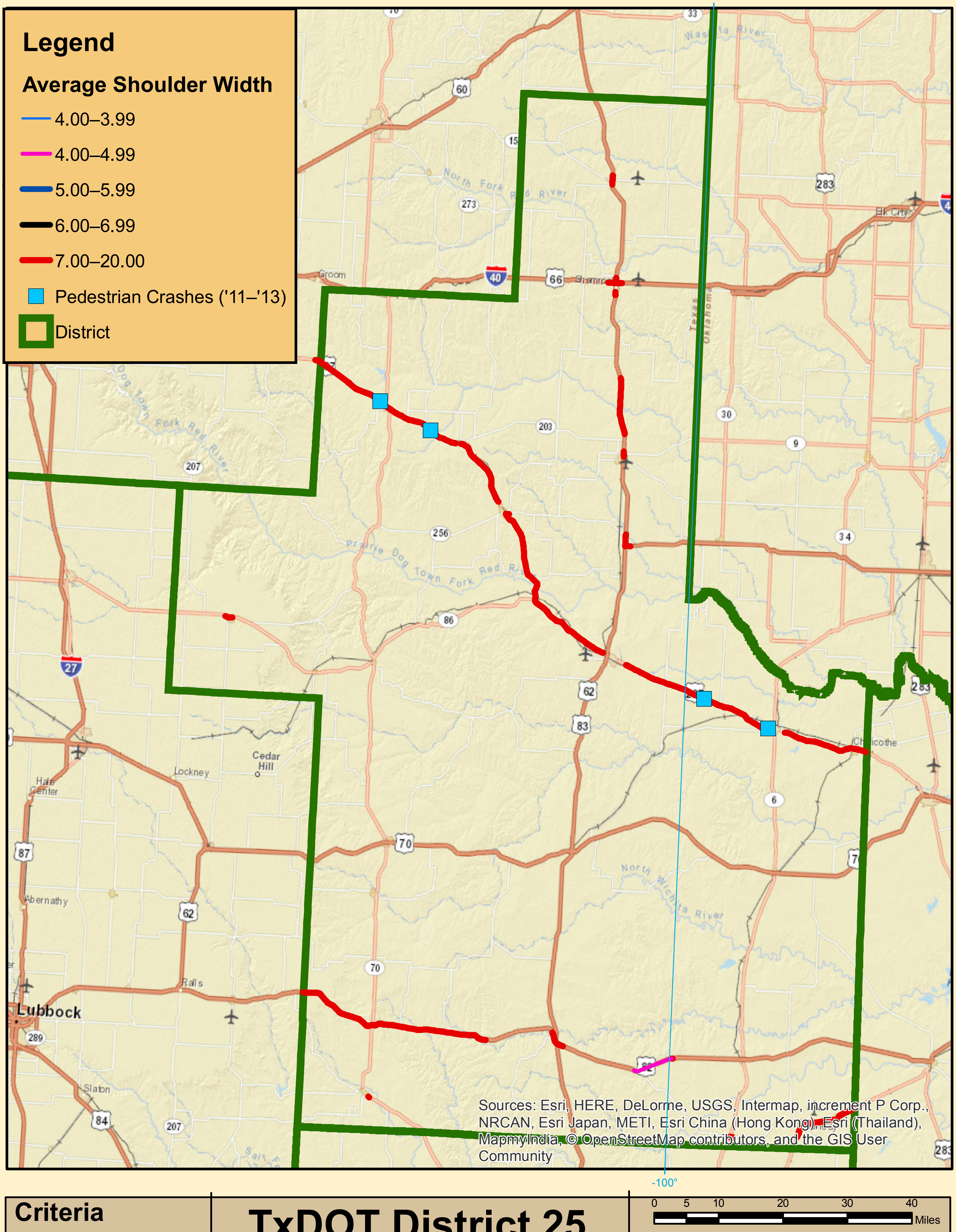
Speed > 35 mph
AADT > 400 vpd

TxDOT District 24

Rural Multilane Paved Shoulders with Pedestrian Crashes

0 5 10 20 30 40 Miles

Coordinate System: Albers
Central Meridian: 96°0'0"W
1st Std Parallel: 20°0'0"N
2nd Std Parallel: 60°0'0"N
Latitude of Origin: 40°0'0"N



Criteria

Speed > 35 mph
AADT > 400 vpd

TxDOT District 25

Rural Multilane Paved Shoulders with Pedestrian Crashes

Coordinate System: Albers
Central Meridian: 96°0'0"W
1st Std Parallel: 20°0'0"N
2nd Std Parallel: 60°0'0"N
Latitude of Origin: 40°0'0"N