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Capacity and Cost Benefits of Super 2 Corridors

Technical Report 0-6997-R1

Cooperative Research Program

TEXAS A&M TRANSPORTATION INSTITUTE
COLLEGE STATION, TEXAS

in cooperation with the
Federal Highway Administration and the
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16. Abstract
Super 2 corridors with passing lanes provide operational benefits to traditional two-lane highways by creating passing opportunities and reducing delay and crashes, leading to increased use of Super 2 corridors across Texas. However, as more passing lane length is added to a Super 2 corridor, the more it may resemble a traditional four-lane alignment and reduce the unique benefits of a Super 2 treatment. This project investigated the operational and economic benefits of Super 2 corridors compared to traditional four-lane and two-lane cross-sections. Researchers analyzed the operational performance of a simulated 40-mile corridor with varying average daily traffic (ADT); heavy vehicle volumes; length, number, and spacing of passing lanes; and access to identify operational benefits in key scenarios. Operational and benefit-cost inputs formed the basis of a model to quantify the relative economic benefits of Super 2 corridors. Operational analysis showed that, at volumes up to 17,000 vehicles per day, Super 2 cross-sections provided higher average minimum speeds and lower delay than other options with less than four lanes, though the two-lane cross-section with left-turn lanes had similar performance as Super 2 for volumes of 15,000 vehicles per day or higher. The cross-section with left-turn lanes was more stable at the highest volumes, suggesting that as volume and truck percentage increase, accommodating turning vehicles outside the through lane can improve operations more than an additional through lane or a passing lane. The economic analysis showed that Super 2 had the highest benefit-cost ratios in all ADT and truck percentage configurations, and they had the best net present value in most cases. In both the economic and operational analyses, the findings agreed with previous research that adding shorter passing lanes to a Super 2 corridor is more beneficial than providing fewer but longer passing lanes.

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CAPACITY AND COST BENEFITS OF SUPER 2 CORRIDORS

by

Marcus A. Brewer, P.E., PMP
Research Engineer
Texas A&M Transportation Institute

Brianne Glover, J.D.
Associate Research Scientist
Texas A&M Transportation Institute

Timothy D. Barrette, Ph.D., P.E.
Assistant Research Engineer
Texas A&M Transportation Institute

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

David Florence, P.E.
Assistant Research Engineer
Texas A&M Transportation Institute

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

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TEXAS A&M TRANSPORTATION INSTITUTE
College Station, Texas 77843-3135

DISCLAIMER

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

This report does not constitute a standard, specification, or regulation. This report is not intended for construction, bidding, or permit purposes. The engineer in charge of the project was Marcus A. Brewer, P.E. (TX #92997).

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

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VALUE OF RESEARCH ASSESSMENT

The research team completed a Value of Research (VoR) assessment as part of the project. The VoR assessment was based on the benefit areas selected at the beginning of the project (shown in Table 1).

Table 1. Selected Benefit Areas for VoR Assessment.

Selected	Benefit Area	Qualitative	Economic	Both	TxDOT	State	Both	Definition in context to the Project Statement
X	Traffic and Congestion Reduction		X			X		Improved capacity, reduced delay and percent time following, and higher average speeds for through traffic on rural two-lane highways.
X	Engineering Design Improvement			X			X	Provision for passing on rural two-lane highways. Left-turn accommodation on rural two-lane highways, particularly in the vicinity of Super 2 passing lanes. Length and spacing of passing lanes appropriate for conditions on each highway.
X	Safety			X			X	Reduction in crashes and associated injuries and fatalities associated with the improved passing and turning accommodation.

The VoR assessment is based on the assumption that one existing Super 2 corridor will be extended or one new corridor will be built annually based on this research project. Additional assumptions are as follows:

- Average length of corridor = 20 miles.
- AADT of corridor = 9000 vehicles per day.
- Percent heavy vehicles on corridor = 20 percent.
- Number of passing lanes in each direction of travel = 2 passing lanes.
- Length of each passing lane in the corridor = 3 miles.
- Previous cross-section of corridor = 2-lane undivided.

The assumptions above represent values that are in the lower to middle part of the range of values studied in the research. Increasing any of the values of those assumptions would add further benefit to the VoR calculations. The benefit-cost analysis spreadsheet tool developed in this research project (described in Chapter 5 of this report) calculated the monetary values of the necessary variables, which are as follows:

- Variable 1: Vehicle operating cost savings.
- Variable 2: Business and personal time cost savings.
- Variable 3: Safety benefits.
- Variable 4: Environmental benefits.
- Variable 5: Capital costs.

Table 2 shows the assignment of those variables to the appropriate economic benefit area for the VoR assessment.

Table 2. Value of Variables for VoR Assessment.

Economic Benefit Area	Variable 1	Variable 2	Variable 3	Variable 4	Variable 5	Total
Traffic and Congestion Reduction	$45,900,000			$400,000		$46,300,000
Engineering Design Improvement		$77,500,000			-$19,400,000	$58,100,000
Safety			$94,100,000			$94,100,000
					Total	$198,500,000

The research team entered the values shown in Table 2 into the TxDOT VoR Assessment spreadsheet to calculate the formal VoR measures. Those results are shown in Table 3. The results show that, based on the assumptions provided previously, the research project is estimated to have a benefit-cost ratio of approximately 5500:1 over a 10-year expected value duration, with over $1.7 billion in savings.

Table 3. Results of VoR Assessment for Project 0-6997.

Project #	0-6997			
Project Name:	Develop Capacity and Cost Benefits of Super 2 Corridors			
Agency:	TTI	**Project Budget**	$	299,846
Project Duration (Yrs)	2.0	**Exp. Value (per Yr)**	$	198,500,000
Expected Value Duration (Yrs)	10	**Discount Rate**		3%
Economic Value				
Total Savings:	$ 1,786,200,154	**Net Present Value (NPV):**	$	1,649,249,486
Payback Period (Yrs):	0.001511	**Cost Benefit Ratio (CBR, $1 : $___):**	$	5,500

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CHAPTER 1: INTRODUCTION

BACKGROUND

Super 2 corridors with passing lanes provide operational benefits to traditional two-lane highways by creating additional passing opportunities and reducing delay and crashes, leading to increased use of Super 2 corridors across Texas. However, specific benefits in improving capacity related to reductions in percent time following are not well known. In addition, as more passing lane length is added to a Super 2 corridor, the more it may resemble a traditional four-lane alignment and reduce the unique benefits of a Super 2 treatment. More information on these details will allow practitioners to make better decisions on which cross-section is more appropriate for a given location.

PURPOSE OF THE PROJECT

This project investigated the incremental operational and economic benefits of Super 2 corridors compared to traditional two-lane and four-lane cross-sections, according to the premise that a Super 2 treatment on a two-lane rural highway with high average daily traffic (ADT) provides capacity benefits approaching those of a four-lane alignment but at greatly reduced costs. In this project, the research team analyzed the operational performance of simulated 40-mile rural highway corridors with varying ADT; heavy vehicle volumes; length, number, and spacing of passing lanes; and access to identify operational benefits in key scenarios. Results from the operational analysis, combined with other benefit-cost inputs, formed the basis of a model to quantify the economic incremental benefits of Super 2 corridors compared to traditional two- and four-lane cross-sections. A spreadsheet tool performs the calculations in the benefit-cost analysis and is provided for practitioners to evaluate alternatives on current and future construction projects.

ORGANIZATION OF THIS REPORT

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

- Chapter 2 summarizes the findings from a review of current practices, operational and economic influences, and evaluation tools and techniques related to Super 2 corridors.

- Chapter 3 describes the research team’s activities in identifying study sites and collecting field data at active Super 2 corridors in Texas.
- Chapter 4 provides a description of the development of the microsimulation model to conduct the operational analysis, as well as the results of that analysis.
- Chapter 5 describes preliminary and final economic analyses, along with related tools and methods for analysis that can be used for similar comparisons, and it summarizes the findings from the final economic analysis.
- Chapter 6 summarizes the researchers’ findings and conclusions, and it provides recommendations for future action.

CHAPTER 2: REVIEW OF INFLUENCES ON PERFORMANCE

The research team reviewed current practices, operational and economic influences, and evaluation tools and techniques related to Super 2 corridors. This chapter summarizes the findings from that review.

OPERATIONAL INFLUENCES ON SUPER 2 CORRIDORS

Two-lane, two-way highways with a relatively high frequency of passing lanes, known as Super 2 highways in Texas and other parts of the United States and 2+1 highways elsewhere, are a useful tool to alleviate congestion issues on the two-lane road network at a lower cost than four-lane cross-sections. Auxiliary passing lanes are necessary when roadway geometric and operational characteristics, such as oncoming vehicle volume and roadway terrain and alignment, prevent passing using the oncoming lane (*1*). This section describes current policies and findings from relevant research on operational influences on the performance of Super 2 highways.

Current State and International Policies

Texas policy on Super 2 design can be found in Chapter 4, Section 6 of the Texas Department of Transportation (TxDOT) *Roadway Design Manual* (*2*). That section provides an overview of what Super 2 highways are and some general considerations for design, followed by a description of basic design criteria, the key elements of which are summarized in Table 4.

Table 4. TxDOT Super 2 Design Criteria (Table 4-6 in the *Roadway Design Manual* [*2*]).

Design Element	Minimum	Desirable
Design speed	See Table 4-2	
Horizontal clearance	See Table 4-2	
Lane width	11 ft	12 ft
Shoulder width	3 ft[a]	8–10 ft
Passing lane length	1 mile	1.5–2 miles[b]

[a] Where ROW is limited.

[b] Longer passing lanes are acceptable, but not recommended more than 4 miles. Consider switching the direction if more than 4 miles.

The discussion of basic design criteria also describes the taper length for beginning and ending a passing lane as L = WS/2 and L = WS, respectively, where:

L = Length of taper (ft).

W = Lane width (ft).

S = Posted speed (mph).

Figures are provided in the *Roadway Design Manual* to show examples of various configurations of passing lanes and how the taper rates are applied, including the appropriate separation distance when closing passing lanes in opposing directions.

Around the globe, road agencies in other countries have developed geometric standards for their respective variations of Super 2 highways, as have departments of transportation (DOTs) in other states within the United States. Table 5 gives an overview of international geometric standards, taken from a synthesis by Romana et al. (*3*), shown with corresponding Texas design criteria for comparison. The synthesis reviewed multiple findings from selected countries, so each of those findings is reproduced in the table, resulting in some countries having two entries.

Table 5 indicates that international 2+1 roads typically have a median area, and supporting information indicates that they frequently have a median barrier (*3*). This is the case in Sweden, which began converting existing 13-meter (42.6-ft) cross-section two-lane, two-way roads to 2+1 in 1998. More recently, Sweden has begun using 2+1 roads on 9- and 10-meter (29.5- and 32.8-ft) cross-sections of existing two-lane, two-way roads using an intermittent passing lane approach (*4*, *5*), accomplished by widening certain areas of the corridor to accommodate the passing lanes. Table 5 also indicates that lane widths on international 2+1 roads are typically in the range of 3.00 to 3.75 meters (9.8 to 12.3 ft), though shoulders are frequently less than 1 meter (3.3 ft) in width.

Table 5. Comparison of International 2+1 Roadway Cross-Sections (*3*).

Country	Median Barrier	Lane Width for Direction of Travel with Single Lane (m)	Lane Width for Direction of Travel with Two Lanes (m)	Width of Paved Shoulder (m)	Width of Median (m)	Total Paved Width (m)
Sweden (expressway)	Yes	3.75	3.25	0.50	1.75	13.00
Sweden (highway)	Yes	3.25	3.25	0.75	1.00	12.25
Germany (Class 1)	No	3.50	3.25–3.50	0.50–0.75	1.00	15.50
Germany (Class 2)	No	3.50	3.25–3.50	0.50–0.75	0.50	15.00
Finland	Yes	3.75	3.25–3.50	0.90–1.25	1.70	14.35
Finland	No	3.75	3.25–3.50	1.25	0	13.00
Denmark	No	3.75	3.50–3.75	0.50	1.00	13.00
Norway	Yes	3.50	3.25	0.75–1.50	2.50	14.75
Ireland	Yes	3.50	3.50	0.50–1.00	1.00	13.00
Ireland	Yes	3.25–3.50	3.50	0.50	1.00	12.25
United Kingdom	No	3.50	3.50	1.00	1.00	13.50
United Kingdom	No	3.50	3.50	1.00	0.75	13.00
South Korea	No	3.50	3.25	1.50	1.50	14.50
South Korea	No	3.50	3.25	1.50	0.50	13.50
France	Yes	3.00	3.00	1.50	1.50	13.50
France	No	3.25	3.25	0.50	1.00	12.50
Poland	Yes	3.50	3.50	1.00	0.50	13.00
Poland	No	3.50	3.50	1.00	0.50–1.00	13.00–13.50
Spain	Yes	3.50	3.20	1.00–1.50	1.60	14.00
Spain	Yes	3.50	3.25–3.50	1.50	1.00	14.25
Japan	Yes	3.25	3.25	1.00	1.25	13.00
Texas, United States	No	3.35–3.65	3.35–3.65	0.90–3.00	0	11.85–16.95

Note: 1 m = 3.28 ft

In the United States, a number of states have provisions in their respective roadway design guides describing the construction requirements for Super 2–type roadways or single passing lanes on two-lane, two-way highways. In several states where that information is not easily obtainable, there is at least discussion in the media regarding the use of Super 2 highways or evidence that research on those types of highways has been sponsored by the state DOT. Table 6 summarizes the states with some evidence of the use of Super 2 highways (or similarly designed two-lane roads), along with specific geometric data where available.

Table 6. State Policies and Other Documentation of Super 2 or 2+1 Roadways.

State	Term(s)	Summary
Arizona (*6*)	• Passing lanes • Climbing lanes	• Intervals of 3 to 5 miles, alternately in the opposite directions of travel • Length of passing lanes should allow several vehicles in line behind a slow-moving vehicle to pass before reaching the transition to the normal section • Passing lanes should not be longer than 2 miles and not be shorter than 1,300 ft • Climbing lanes used under certain circumstances
Arkansas (*7*)	• Alternating passing lanes	NA
California (*8*)	• Passing lanes • Climbing lanes	• Should not normally be constructed on tangent sections where the length of the tangent equals or exceeds the passing sight distance • Where the ADT exceeds 5,000, four-lane passing sections may be considered
Colorado (*9*)	• Passing lanes	• Minimum recommended sight distance of 1,000 ft on the approach to the lane-add and lane-drop tapers • Location should consider intersections and high-volume driveways as well as bridges and culverts • Minimum length, excluding tapers, should be 1,000 ft
Connecticut (*10*)	• Climbing lanes	• No design criteria for passing lanes • Climbing lanes should have a lane width of 11 ft and shoulder width of 4 ft
Florida (*11*)	• Passing lanes • Climbing lanes	• Passing lanes follow the same criteria as normal lanes; climbing lanes follow the same criteria for normal lanes, and the lane should not terminate until well after the crest of the hill
Idaho (*12*)	NA	• Passing lanes should be considered if volumes exceed ADTs in the *Design Manual* • If separate passing lanes are used, the lanes should be separated by at least 1,500 ft • Minimum length should be 0.25 mile
Illinois (*13*)	• Passing lanes	• Passing lanes may be warranted on two-lane facilities where passing opportunities are not adequate • Typical spacing for passing lanes may range from 3 miles to 10 miles • The optimal length of passing lanes is usually between 0.5 mile and 1 mile
Iowa (*14*)	• Super 2	• Lane width of 12 ft • Shoulder width 10 ft, partially paved • Passing lanes spaced about 5 miles • Climbing lanes provided on long/steep grades • Turn lanes provided where needed • Access limited to the extent practicable

Table 6. State Policies and Other Documentation of Super 2 or 2+1 Roadways (continued).

State	Term(s)	Summary
Kansas (*15*)	• Passing lanes	• Where passing lanes are provided, should be at regular intervals of approximately 5 miles • The width of passing lanes should be 12 ft • The preferred configuration is side-by-side passing lanes with one in each direction, thus creating a short four-lane section • Lengths are taken from Texas A&M Transportation Institute (TTI) Report 0-4064-1 (*16*)
Kentucky (*17*)	• 2+1	• Passing lane length is determined by the one-way flow rate; a minimum of 0.5 mile and maximum of 2 miles
Louisiana (*18*)	• Passing lanes	• No directives on passing lanes; passing lanes may be considered if the two-lane road does not adequately give safe passing zones
Michigan (*19*)	• Passing relief lanes • Super 2 (*20*)	• Design hour volumes used to identify candidate locations • The lane widths should be 12 ft • The desirable minimum length is 1 mile with an upper limit of about 1.5 miles • Spacing of 5 miles
Minnesota (*21*)	• Passing lanes	• Passing lanes should normally be constructed systematically at regular intervals • The optimal length of a passing lane to reduce platooning is usually 0.5 to 1.0 mile long
Missouri (*22*)	• Super 2	NA
Montana (*23*)	• Passing lanes	• Passing lanes may be determined based on an engineering study
Nebraska (*24*)	• Super 2	• Some level of access control limiting driveways and intersections
Nevada (*25*)	• Passing lanes	• Empirical sight distance data required
New Hampshire (*26*)	• Passing lanes	• Passing sections should be provided as frequently as possible in keeping with the terrain
Ohio (*27*)	• Passing lanes	• If capacity is restricted below the design level of service due to the lack of sight distance, consideration should be given to providing passing lane sections
Oklahoma (*28*)	• Super 2	• Designated passing lanes • Paved shoulders not less than 8 ft
Oregon (*29*)	• Passing lanes	• Should be considered on two-lane arterials without adequate passing sight distance • Should be considered only in areas where the roadway can be widened on both sides
Pennsylvania (*30*)	• Super 2	NA
South Dakota (*31*)	• Super 2	NA
Texas (*2*)	• Super 2	• Lane widths of 11 ft minimum, 12 ft desirable • Shoulder widths of 3 ft minimum, 8–10 ft desirable • Passing lane lengths of 1 mile minimum, 1.5–2 miles desirable • Longer passing lanes are acceptable but not recommended to be more than 4 miles

Table 6. State Policies and Other Documentation of Super 2 or 2+1 Roadways (continued).

State	Term(s)	Summary
Utah (*32*)	• Passing lanes	• Localized improvements that optimize existing capacity for minimal cost
Washington (*33*)	• Passing lanes	• Desirable where sufficient safe passing zones do not exist and the warrant for a climbing lane is not satisfied
Wisconsin (*34*)	• Passing lanes	• If 20-year traffic projections exceed 12,000 annual average daily traffic (AADT) or exceed 1,400 two-way design-hour volume, it may be appropriate to consider expanding the facility to four lanes

Capacity and Time Following

In a broad-scoped literature review, Romana et al. noted that 2+1 highways can actually reduce the capacity of the road, create safety concerns for roadways near capacity, reduce opportunities to pass vehicles in single-lane sections, and increase speed differential conflicts (*3*). The authors of the paper indicate the merging area can create a bottleneck, increasing conflicts and congestion, as well as higher speeds in the passing lane, all of which likely contribute to diminished performance. Many of these issues may stem from the presence of a non-traversable median in the European and Asian incarnations of this type of facility, which presents a physical barrier restricting overtaking at the end of the passing lane. Research from New Zealand investigated the use of intelligent transportation system–assisted merging to mitigate merge conflicts, improve vehicle merging behavior, and reduce driver frustration at the ends of passing lanes as part of a study on the benefits of 2+1 roads; however, researchers found that the theoretical benefits from the assisted merge resulted in only a 4 percent reduction of travel time assuming 100 percent compliance (*35*). Table 7 shows speed limits and traffic volumes typical of 2+1 highways at the international level; many of the values shown are similar to those commonly found in Texas.

Table 7. Comparison of International 2+1 Operational Characteristics (*3*).

Country	Speed Limit (km/h)	Speed Limit (mph)	Design Speed (km/h)	Design Speed (mph)	AADT (Vehicles per Day [vpd])
Sweden	90–110	55–70	—	—	4,000–20,000
Norway	90–110	55–70	—	—	6,000–22,000
Germany	100	65	100–110	65–70	7,000–25,000
Finland	100	65	—	—	8,000–13,000
Denmark	80–90	50–55	—	—	7,000–15,000
Ireland	100	65	100	65	≤14,000
United Kingdom	100	65	—	—	≤25,000
Austria (proposed)	≤100	65	—	—	7,000–18,000
New Zealand	100	65	—	—	10,000–25,000
Poland	100	65	—	—	10,000–25,000

Note: Values not reported in the references are indicated with a dash.

Korean researchers used microsimulation and the *Highway Capacity Manual* (HCM) to identify passing lanes of 2 km (3.2 miles) in length as appropriate to alleviate congestion on roads with volumes of 1,000 vehicles per hour, while noting that 1-km (1.6-mile) passing lanes were adequate to reduce delay at traffic volumes of 900 vehicles per hour (*36*). Researchers examined data from Poland in terms of the percentage of vehicles in platoons, changes in speed within passing lanes, passing rates, and changes in platoon size. The researchers observed a decrease in platoon size due to passing lanes of 6.6 percent, which the research team noted as being lower than comparable studies, potentially due to the presence of a high volume of heavy vehicles (*37*). The researchers also noted that longer passing lanes were associated with greater reduction in platooning, vehicles driving in the passing lane were driving faster than those in the non-passing lane, a greater percentage of vehicles passed in longer passing lanes, and the average speed was 10.5 km/h (6.5 mph) greater after the passing lane (*37*).

Research in the United States has shown that passing lanes in two-lane, two-way highway sections have impacts well beyond the boundaries of the actual passing lane (*38*). A study examined platooning on two-lane, two-way highways using data from three sites in Montana and found that the correlation between mean travel speed and headway was substantially lower downstream of passing lanes (*39*). Additional observational research from Montana used percent followers (i.e., the percentage of vehicles with short headways in the traffic stream) and follower density to quantify operational benefits of passing lanes, finding improvements of 33 to 42 percent immediately adjacent to the passing lane and again noting that benefits persisted for a considerable distance downstream from the passing lane (*40*). The percent followers metric was used to quantify the diminishing benefit of passing lanes as the space between passing lanes increased (*41*).

These studies collectively represent a large portion of the work used in National Cooperative Highway Research Program (NCHRP) Project 17-65, which focused on improving the analysis of two-lane highway capacity and operational performance. The NCHRP 17-65 report introduced the performance metric of follower density, defined as the percentage of vehicles with short headways (less than 2.5 seconds) times the traffic flow rate divided by the product of the number of lanes in the travel direction and the average speed, although the research team acknowledged that it was already informally used in HCM methodology (*42*). The study went on to indicate that the effective passing lane length could be determined as the distance from the passing lane at which follower density stops increasing, and they stated that the optimum passing lane lengths for specific traffic flow rates could be determined when the reduction in percent following vehicles reached 22.5 to 25 percent. Figure 1 shows the follower density as a function of distance from the passing lane for various traffic flows and 50 percent of the roadway that is non-passing, while Table 8 indicates the optimal passing lane lengths.

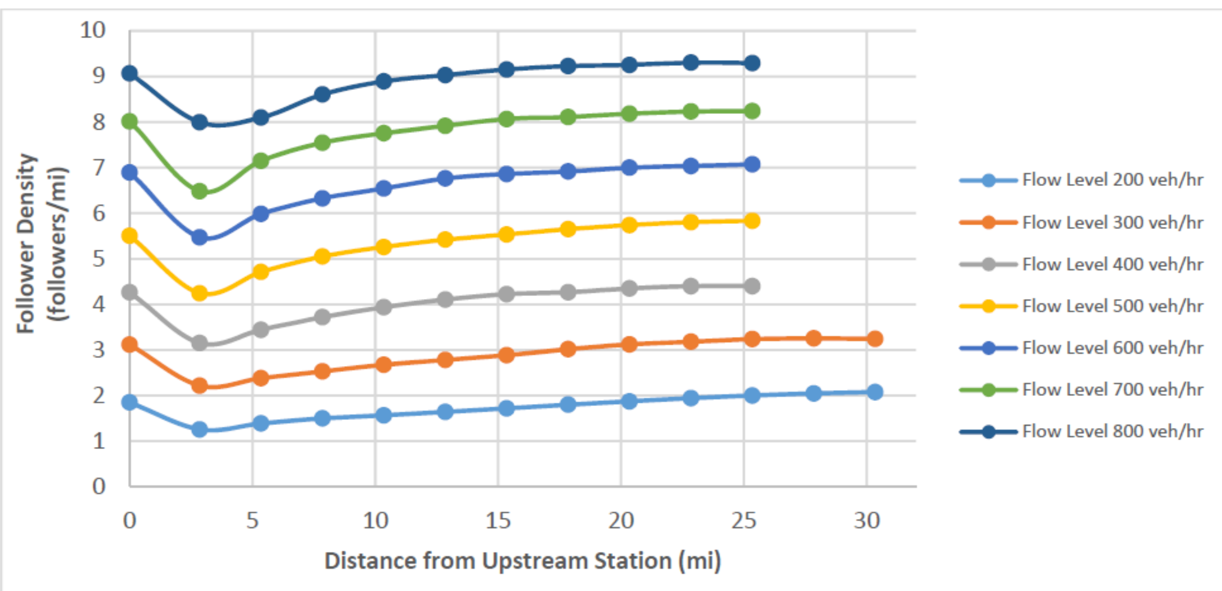


Figure 1. Follower Density as a Function of Distance and Flow (*42*).

Table 8. Optimum Length of Passing Lane from NCHRP 17-65 (*42*).

Traffic flow (veh/h)	200	300	400	500	600	700	800
Length of passing lane (mi)	0.9	1.0	1.2	1.2	1.6	1.9	2.0

A case study assessment of a highway section in Montana examined a road with a daily volume of 5,000 vehicles, finding that most of the benefit of the passing lane (in terms of percent followers, follower density, and average travel speed) was realized within ½ mile of the start of the passing lane (*43*). Similar findings have been observed in Texas, where most passing activity occurred within the first mile of the passing lane (*44*, *45*). Additional research in Texas has highlighted the need to consider the impact of trucks and heavy vehicles on passing lane length and passing sight distance requirements, particularly when platoons of trucks are present (*46*), and that trucks are at least 74 percent compliant in moving to the right lane in passing sections (*45*).

Previous Research in Texas

A substantial amount of research on Super 2 highways has been conducted in Texas, some of which has been referenced in previous sections. Given the relevance of these efforts to the current state of the practice in Texas regarding Super 2 highways and passing lanes in general, the following sections summarize these research efforts.

Design Guidelines for Passing Lanes on Two-Lane Roadways (Super 2)

The first statewide research effort (Project 0-4064) was completed in 2001 and focused on the development of guidelines for passing lanes on two-lane roadways (*16*). The project used on-site data collection in Kansas and Minnesota to allow the research team to familiarize themselves with the operation of Super 2 corridors by driving them, and to gather traffic flow information through the use of traffic counters.

As a second approach in the project, the research team administered a survey to drivers at several locations across Texas. This survey informed the research team about several key issues pertaining to passing lanes:

- Drivers stated that they were willing to wait 3 miles or less for a passing lane section.
- Drivers indicated they were unsure if they could use an opposing passing lane.
- The percentage of drivers that reported that they would be comfortable stopping on a shoulder decreased as the width of the shoulder decreased.
- Drivers preferred to see more frequent passing lanes.
- Drivers suggested the need for improved signing and markings.

In order to make informed suggestions regarding roadway geometry, the research team used traffic microsimulation via the program TWOPAS. This effort allowed the research team to make suggestions for passing lane length and spacing based on the terrain and traffic volume. Table 9 presents the suggested lengths and spacings.

Table 9. Recommended Values of Length and Spacing by ADT and Terrain (*59*).

ADT (vpd)		Recommended Passing Lane Length (Miles)	Recommended Distance between Passing Lanes (Miles)
Level Terrain	Rolling Terrain		
≤1,950	≤1,650	0.8–1.1	9.0–11.0
2,800	2,350	0.8–1.1	4.0–5.0
3,150	2,650	1.2–1.5	3.8–4.5
3,550	3,000	1.5–2.0	3.5–4.0

For lane width, the research team recommended 12 ft or values from TxDOT's then-current *Roadway Design Manual*. Special consideration was given to shoulder width in response to the common practice in Texas of drivers moving to the shoulder to allow faster vehicles an opportunity to pass. Ultimately, the researchers recommended 4-ft shoulders if rumble strips were not used and 6-ft shoulders if they were.

Operations and Safety of Super 2 Corridors with Higher Volumes

In 2011, a second research project (0-6135) concluded that was focused on operations and safety of Super 2 corridors (*47*). This multifaceted research effort reviewed the existing literature, synthesized the practices in other states, surveyed TxDOT regarding the state of the practice in Texas, reviewed crash data, compared computer simulation models, used field data to calibrate and conduct a simulation, and provided recommendations based on those efforts. The research team documented the following findings based on their review of the literature:

- Super 2s are most suitable for level terrain and rolling terrain where sight distance is restricted.
- Intersections and driveways should be avoided in the passing section.
- Location and configuration of passing lanes may be influenced by the need to address an operational problem, appear logical to the driver, provide adequate sight distance on approach and departure tapers, and avoid low-speed curves.

- The theoretical capacity of a two-lane highway is 1,700 passenger cars per hour (pcph) in one direction or 3,200 pcph in both directions.
- Minimum passing lane lengths typically range from 1,000 ft to 0.25 mile.
- Common passing lane spacings range from 3 to 10 miles.
- Minimum sight distance at the lane removal can be calculated on a site-specific basis using the formula: Length = Lane Width × Posted Speed.

The research team conducted a crash data analysis to examine the safety effects of Super 2 corridors. To conduct the study, the team assembled a dataset using the crash data for 53 centerline-miles of five Super 2 corridors in Texas. The analysis indicated a 35 percent reduction for segment-only fatal and injury crashes on the corridor in comparison to sites without passing lanes.

The field study conducted as a part of this research indicated that Super 2 corridors improved operation on rural two-lane highways. The research team noted that large numbers of vehicles began passing at the beginning of the lane. Contrary to Texas law, not all left-lane drivers were attempting to pass. However, large trucks generally moved into the right lane at the start of passing sections, allowing faster-moving traffic to pass. The data that were assembled from the field study indicated that left-lane use compliance was higher at the start of the passing lane than at the end, potentially indicating that drivers did not pull over after completing their passing maneuver.

The research team on Project 0-6135 ran 648 traffic microsimulations, which they used to analyze operational characteristics of Super 2 corridors using a hypothetical 10-mile-long roadway. The findings from the simulation efforts include:

- Calibration of the simulation model indicated that the Interactive Highway Safety Design Model's Traffic Analysis Module was an appropriate modeling tool for passing lanes.
- Univariate analysis indicated that the percent time spent following (PTSF) varied from 40 to 85 percent when no passing lanes were provided, resulting in 0.6 to 1.6 minutes of delay, which was reduced to 13 to 75 percent and 0.25 to 1.5 minutes with the addition of six passing lanes. The incremental benefit of adding passing lanes also diminished as more passing lanes were added.

- Multivariate analysis indicated that adding new passing lanes and extending their length improved operational performance. Additionally, the improvements realized from adding passing lanes were greater than those realized by extending lanes. Passing lane length was also associated with diminishing returns; as more passing lanes were added, the corridor began to function like a four-lane cross-section.
- Traffic volume was the key driver for performance, while truck percentage and terrain type had more limited impacts.

Based on the totality of the aforementioned efforts, the research team recommended that ADT be removed as an upper limit for the installation of passing lanes; however, the researchers stated that ADT should still be considered in terms of prioritizing installation locations. The researchers stated that adding passing lanes was a more desirable alternative to lengthening additional passing lanes. Four areas were identified as playing a major role when TxDOT (or any other road agency) is considering adding passing lanes: right-of-way, terrain, and roadway structure constraints; location of traffic generators; restrictive existing geometry; and sufficient sight distance at passing lane termination points. The findings from this study were used to make recommendation for revisions to the TxDOT *Highway Safety Improvement Manual* and the TxDOT *Roadway Design Manual*. The recommendations from that project form the basis of the guidance found in the current *Roadway Design Manual*.

Operational Analysis Methods

The results of traffic simulation studies have largely guided the implementation of Super 2 highways in Texas (*3*, *4*). Romana et al. noted that simulation tools such as VISSIM, Aimsun, TRANSMODELER, CORSIM, TWOPAS, and LASI are commonly used to represent driver behavior; however, field data are needed to validate the driver behavior in the models (*3*). Several research efforts have compared the various simulation software packages with each other as well as with other means of quantifying the level of service present on specific stretches of highway. A Swedish study investigated how delay, PTSF, and travel time varied with traffic volume using the Intelligent Driver Model traffic simulation and derived equations (*48*). Researchers at the California Department of Transportation (Caltrans) developed a series of equations that consider driver behavior, vehicle performance, traffic flow rate, and geometric design to estimate appropriate passing segment length, including the diverging and merging taper lengths (*49*). A study conducted by the University of Florida compared the ability of CORSIM with the 2010 HCM to evaluate two-lane highways in terms of PTSF and average travel speed, noting the potential usefulness of field studies to investigate the relationship between speed and flow (*50*). Korean researchers used TWOPAS, a software program specifically designed for analyzing two-lane highways, to estimate congestion in terms of percent time following on two-lane highways; researchers then compared the results to those obtained via the linear model in the HCM (*36*) and used both TWOPAS and the HCM to convince Korean road agencies to adopt 2+1 road design (*51*). A microsimulation using calibration data from two sites in Oregon found that traffic level and percent no-passing had considerable impacts on the effective length of the passing lane (*38, 41*). Performance metrics such as platooning and mean speed have been examined empirically on two-lane, two-way roads (*39*). In order to investigate certain facility types, such as rural two-lane highways with occasional intersections, researchers have actually modified the code for the software programs (*52*).

Polish researchers empirically examined a section of 2+1 road used as a bypass around a town that had several passing lanes located throughout, observing increases in mean speed in the 2+1 cross-sections while noting that high truck volumes impede the ability of drivers to merge at the end of the passing areas (*53*). One member of the Polish research team revisited the study location using a VISSIM simulation to specifically investigate the effect of heavy vehicle volume on roadway performance, noting that the 2+1 configuration was effective for heavy vehicle percentages up to 35 percent (*54*). Research from Germany used drones to simultaneously observe passing maneuvers and extract traffic volume and roadway geometry to examine Germany's existing passing sight distance model (*55*). An examination of two-lane, two-way roads in Spain led researchers to suggest that a linear model as outlined in the HCM was not an appropriate expression of the speed-flow relationship, instead recommending the application of an S-shaped third-degree polynomial (*56*). In Japan, traffic simulation using the program SIM-R was partnered with a field study to evaluate the effectiveness of 2+1 roads in areas prone to winter weather, finding that periodic placement of passing lanes was effective at increasing average travel speed and decreasing follower density in the passing lane, with the effect being noticeable for a ways downstream (*57*).

The safety benefits of passing lanes on two-lane, two-way highways have also been studied. The aforementioned Project 0-6135 found a 35 percent reduction in segment-only crashes and a 42 percent reduction in segment-and-intersection crashes (*44, 47, 58*). Data from Michigan were examined using empirical Bayes (EB) and cross-sectional approaches, finding that passing lanes are effective in improving safety and that the benefits extend up to 1 mile beyond the boundary of the passing lane (*59*). Examination of safety data from Poland indicated reductions in severe crashes of 47 percent in 2+1 sections but noted that the reduction was only 4 percent when considering upstream and downstream areas adjacent to the 2+1 section, which the research team attributed to crash migration (*37*). The Surrogate Safety Assessment Model (SSAM) software has been used to demonstrate that conflicts are a reasonable surrogate measure for safety on 2+1 roadways and noted that the crash rate decreased as passing lane length increased, using data from Poland for calibration and validation (*60*). Graduate-level research from Idaho examined crash rates and concluded that passing lanes do not necessarily reduce crashes in comparison to downstream segments (*61*). In Sweden, a before-and-after-with-control crash analysis of narrow two-lane highways that had been converted to 2+1 roads with a median barrier demonstrated decreases in fatal and serious injury crashes of 50 percent and personal injury crashes of 21 percent. Excluding intersection crashes, these values were 63 percent and 28 percent, respectively, with similar results obtained using the EB methodology (*5*). Research conducted in Wyoming used Wyoming-specific safety performance functions in conjunction with the EB methodology to demonstrate that passing lanes reduced fatal and injury crashes by 27 percent and total crashes by 44 percent, where basic before/after analysis had indicated little to no benefit, highlighting the need for rigorous statistical analysis when evaluating the effectiveness of crash countermeasures (*62*).

ECONOMIC INFLUENCES ON SUPER 2 CORRIDORS

As discussed in the previous section, Super 2 corridors provide operational benefits to traditional two-lane highways by creating passing opportunities and reducing delay and crashes. While Super 2 corridors have become increasingly common on rural highways because of these operational benefits, very little is known about their pure economic incremental benefits compared to a traditional four-lane alignment. To address this need, the following structured comprehensive literature survey summarizes information pertaining to each of the economic valuation components of Super 2 corridors. The subsequent economic analyses in Task 5 involved a benefit-cost analysis that analyzed tradeoffs between cost (e.g., construction cost) and benefits (e.g., road user cost, crash cost, and agency overhead cost) for Super 2 scenarios compared to a two-lane alignment as a benchmark. The following review of pertinent literature serves as a foundation to assess the economic impacts of Super 2 corridors in Task 5.

CA4PRS: Primary Tool for Integrative Economic Assessments

Agency efforts to quantify more accurate road user costs (RUC) for the betterment of transportation planning have benefited from use of innovative software analysis programs. A recent tool arising from these efforts is a state-of-the-art tool called Construction Analysis for Pavement Rehabilitation Strategies (CA4PRS), which has come into use because of its ability to analyze schedules, RUC, and work zone traffic impacts together (Figure 2).

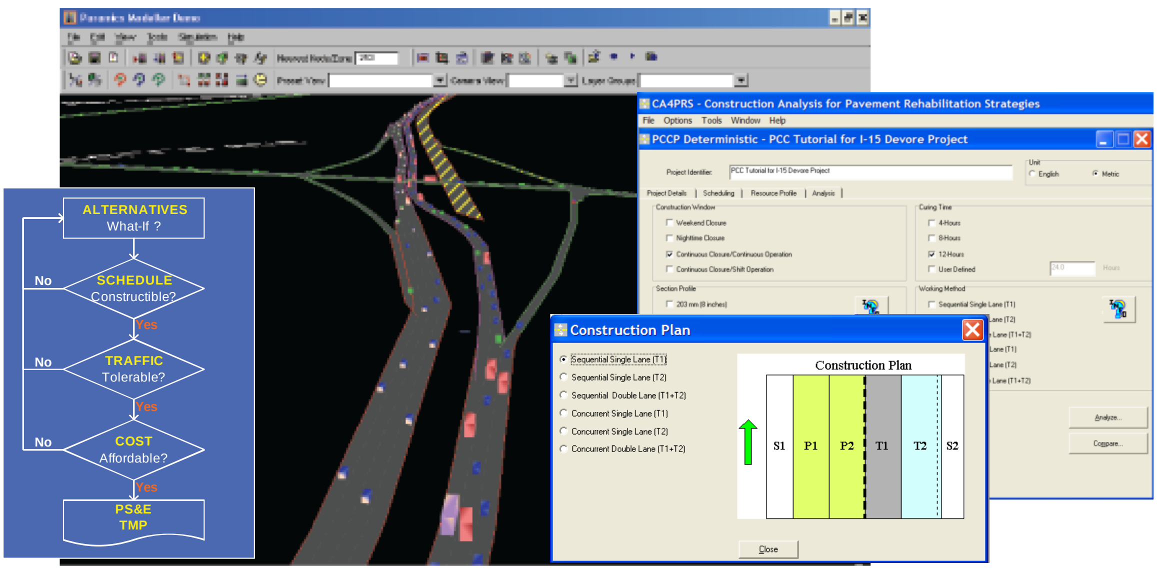


Figure 2. CA4PRS Schedule/Traffic/Cost Integration Analysis Framework.

CA4PRS was developed under the Federal Highway Administration (FHWA) pooled fund research program with a multistate consortium (California, Texas, Minnesota, and Washington). The software has three main functions: schedule, cost, and work zone estimates. CA4PRS's schedule analysis estimates the duration of highway rehabilitation projects in terms of the total number of closures by considering the following critical factors that affect project duration: project scope (lane-miles to be rebuilt), construction strategies (e.g., concrete, asphalt concrete, and milling), cross-section designs, construction windows (e.g., nighttime, weekend, and extended 24/7 operations), and contractor logistics and resource constraints (*63*). CA4PRS's work zone analysis, which is based on the HCM demand-capacity model, quantifies the impact of construction work zone closures on the traveling public in terms of RUC and time spent in queue (*64*).

CA4PRS has been widely used in California and has been implemented in other states as well. Demonstrations have shown that CA4PRS is user-friendly, easy to learn, and valuable in any project phase. Its greatest value lies in its capability to provide information to the planner/designer to optimally balance pavement design, construction constraints, traffic operations, and agency budget for transportation agencies. Since 1999, the capabilities of CA4PRS have been confirmed on several major highway rehabilitation projects in states including California, Washington, and Minnesota. For example, CA4PRS was used with traffic simulation models to select the most economical rehabilitation scenario for the I-15 Devore Project (Figure 2) in California. The 2.8-mile concrete reconstruction project, which would have taken 10 months using traditional nighttime closures, was completed over two nine-day periods using one-roadbed continuous closures and around-the-clock construction. Implementing continuous closures rather than repeated nighttime closures in this project resulted in significant savings ($6 million in agency costs and $2 million in RUC). Alternative strategies enabled by use of CA4PRS led to an accelerated project process dubbed “Rapid Rehab” that was acknowledged in the post-construction meeting (*63, 65*). Validation studies have proved the scheduling reliability and accuracy of the software; as a result, there has been nationally growing acceptance of the program including recent arrangements by FHWA for free group licenses for all 50 states (*66*).

CA4PRS can play a pivotal role in conducting the economic assessments of Super 2 corridors. The Task 5 preliminary economic analysis, based on the findings from this review, used CA4PRS to conduct a benefit-cost analysis that compared the construction and RUC of Super 2 corridors to a four-lane alignment as a benchmark. Table 10 provides an example of outputs from CA4PRS on the I-15 Devore project as a demonstration of its applicability to a tradeoff analysis among project schedules, costs, and benefits.

Table 10. Results from CA4PRS on the I-15 Devore Project near Los Angeles by Caltrans (*65, 66*).

Construction Scenario	Schedule Comparison		Cost Comparison ($M)			Max. Peak Delay (Min)
	Total Closure	Closure Hours	User Delay	Agency Cost	Total Cost	
One Roadbed Continuous (24/7)	2	400	5.0	15.0	20.0	80
72-Hour Weekday	8	512	5.0	16.0	21.0	50
55-Hour Weekend	14	770	14.0	17.0	31.0	80
10-Hour Night-time Closures	220	2,220	7.0	21.0	28.0	30

Quantification of Costs: Construction Cost and Agency Cost

According to the Arkansas Department of Transportation, the estimated construction cost of adding one additional lane on a traditional, two-lane rural roadway is $2.25 million per mile, while the cost to expand to a full four-lane alignment is $3.38 million per mile (*67*). The Florida Department of Transportation estimates that a single-lane capacity-added project costs approximately $623,000 per mile, while widening a two-lane roadway to four lanes costs $2.3 million (*68*). As this discrepancy implies, the total cost of a project with a particular purpose, scope, and length could vary widely depending on factors such as time, location, traffic, project contracting, special provisions, public outreach, acquisition of right-of-way, and accommodation of utilities. Therefore, this review considered a balanced two-track approach (i.e., general considerations that apply to all projects and specific factors that influence individual projects) for a wider applicability of research results.

Analytical Steps and Principles of Construction Cost Estimate

Construction cost estimates are vital to making key project decisions and establishing project success metrics. Logical and reasonable cost estimates are necessary to maintain public confidence and trust throughout the life of a major project (*69*). The total program cost (TPC) estimate includes construction, engineering, acquisition of right-of-way, utilities, and related costs. The estimate of TPC is typically based on the receiving agency's historical cost database, which is updated regularly. Through an extensive literature search related to the TPC estimate

(*64*, *70*, *71*, *72*, *73*, *74*, *75*, *76*, *77*, *78*), the research team recommended that the following five steps be followed in sequential order towards a reliable TPC estimate:

1. Calculation of material volumes for major pavement items.
2. Estimation of pavement costs based on the unit price of typical line items searched from the historical bid database.
3. Estimation of traffic control and management item costs.
4. Estimation of the agency's engineering supporting cost.
5. Estimation of the roadway and project cost by factoring the costs of pavement and traffic items with multipliers to cover non-pavement items and indirect costs.

FHWA (*69*) has set the following key principles that should be considered when a TPC estimate is prepared:

- **Integrity:** Cost estimates must be calculated through an open or transparent process. Any uncertainties should be explained in an easily understood manner in laymen's terms.
- **Cost items:** A TPC estimate should include all costs and the value of any resources needed to complete the National Environmental Policy Act of 1969 (NEPA) work, design, right-of-way activities, environmental mitigation, public outreach, construction, overall project management, specific management plans (e.g., transportation management plans), and appropriate reserves for unknowns, as well as costs and resources paid to others for work related to the project such as utility adjustments, environmental mitigation, and railroad relocations.
- **Inflation:** After the cost estimate is prepared, the TPC should be suggested in year-of-expenditure dollars by applying an appropriate inflation rate per year to the proposed midpoint of contract time.
- **Estimate basis:** The accuracy of any estimate depends on the amount of information that is known about the project when the estimate is prepared. Therefore, TPC estimates should be done with the best information available, and the basis for that estimate should be included in the description.
- **Contingency for uncertainties:** The TPC should be determined in a way to reflect the uncertainties associated with the project. There should be methods or tools of

assessing and reassessing project risk and uncertainties. Costs that are associated with potential risks can be included in the form of a contingency amount.

- **Validation:** When the project experiences a cost overrun over time, an action should be taken to identify problems and revise TPC estimate procedures.

Quantification of Agency Overhead Cost

A delay in the project schedule increases agency costs largely due to increased indirect costs, such as office overhead, overtime payments, and use of rental equipment longer than originally contracted (*64, 79*). In contrast, pursuing a Super 2 option over the traditional four-lane alignment capacity-added project can save part of the agency cost by accomplishing key milestones faster and/or completing the entire project sooner than originally scheduled. The savings or added costs include the estimates for the following: construction work zone enhancement enforcement program (CWZEEP), agency engineering cost (AEC), and moveable concrete barrier (MCB) rental. The economic analysis quantifies the agency cost by accounting for these three major cost estimate factors. Table 11 shows a list of agency cost estimating factors and presents methods to quantify their monetary value (*80*).

Table 11. Agency Cost Calculation Metrics.

Factors	Rates	Methods

CWZEEP	• $700/day/officer
	• Number of officers
	  o 2.5/day for nighttime
	  o 4.5/day for extended closure
	• Overtime rate of 1.2
		Highway patrol cost/day × number of days saved (increased) × overtime rate × 3 shifts for extended closure

AEC	• $320/day/staff
	• Number of staff
	  o 3/day for nighttime
	  o 4/day for extended closure with 3 shifts
	• Overtime rate
	  o 1.1 for nighttime
	  o 1.5 for extended closure
		Staffing cost/day × number of staff/day × number of days × overtime rate × 3 shifts for extended closure

MCB*	• Barrier cost
	  o $60/meter for the first month
	  o $11/meter for the second month
	• Transformer cost
	  o $30,000 for the first month
	  o $15,000 for the second month
		Length of barrier to be installed × appropriate monthly rates

*MCB cost applies to the extended closure only.

Quantification of Savings in Road User Cost

Concepts and Tools for Road User Cost. The RUC considers the concept of opportunity cost, defined as time lost by motorists to traffic delays that could have been spent on other efforts (*8*). The RUC plays an instrumental role in work zone impacts assessment because it is used to identify impacts on service levels, determine lane-closure strategies, and identify incentives/disincentives rates. In addition, in the best procurement contracting method known as A (cost) + B (time), the daily RUC serves to help the contractor determine the monetary value of time (B) when making a bid. In the incentives/disincentives contracting method, the daily RUC is used as the basis for determining an appropriate incentive/disincentive rate.

The RUC is comprised of the following three elements (*81*):

- The travel time change due to delays during construction.
- The average number of passengers per vehicle.
- The hourly cost per passenger.

Externalities such as air-quality cost and vehicle noise factors have rarely been reflected in the calculation of RUC (*82*). The most widely used state-of-the-practice software for calculating RUC is currently the Highway Capacity Software (HCS). This is based on the HCM and MicroBENCOST (*78*). Developed in 1995, HCS is a computer version of the HCM for calculating RUC (*82*). MicroBENCOST was based on the 1985 HCM and the 1977 American Association of State Highway and Transportation Officials (AASHTO) *Red Book,* with special emphasis on the calculation of vehicle operating cost. MicroBENCOST emerged as an alternative to QUEWZ, which has been used since the early 1980s. In addition, FHWA recently developed the Microsoft® Excel® spreadsheet-based QuickZone as an estimating tool for work zone delays (*78*). QuickZone was developed to evaluate traveler delays due to construction. QuickZone provides a complete and realistic view of total construction costs based on the estimation and quantification of work zone delays and the resulting user costs (*83*). The combination of MicroBENCOST, QuickZone, and HCS are currently being widely used for the calculation of queue length and work zone delays.

Components of Road User Cost. The determination of RUC incorporates the concept of the demand-capacity model from the HCM (*84*). Demand is defined as hourly traffic volumes at a certain point of interest. Capacity is defined as the maximum possible traffic service flow, which can be selected from the manual. In general, it is assumed that in normal conditions capacity ranges from 2,200 to 2,300 passenger cars per hour per lane (pcphpl) and that in construction conditions it ranges from 1,500 to 1,600 pcphpl. Using a passenger car equivalent (PCE) factor, it is generally assumed that a truck is equal to 1.5 passenger vehicles (2.5 for a rolling setting and 4.5 for a mountain setting). Capacity varies because of the following factors:

- Project location.
- Percentage of heavy vehicles (H): $H = 100 / [100 + P(PCE - 1)]$, where P = percentage of trucks.
- Width of lanes (W): W = 1.00 if width is 12.0 ft, W = 0.95 if width is 11.0 ft, and W = 0.90 if width is 0.90 ft.
- Shoulder and lateral clearance (S): S = 1.00 if both shoulders are available, S = 0.95 if one shoulder is available, and S = 0.90 if no shoulder is available.
- Number of lanes open to traffic (N).

Adjusted capacity can then be calculated by multiplying the above factors: Adjusted capacity = basic capacity × H × W × S × N.

The RUC is not tangible, but when considering the concept of opportunity cost for the time that motorists could spend doing something else such as recreation or work, its value as time saved by completing the project early becomes important to road users. The four major factors to account for when estimating the RUC are:

- Additional travel time (time lost due to construction lane closures).
- The average number of motorists per vehicle.
- The monetary value of time to motorists in the vehicle.
- The percentage of trucks at a construction work zone.

The travel-time changes arise from differences in average travel time at the work zone in two different traffic conditions (i.e., traffic conditions before construction, and predicted traffic conditions during construction when normal flow is disrupted by lane closures for construction). The value of motorists' wasted time (cost per hour) on the roadway should be considered as a key parameter in the calculation of the RUC. Different pay rates should also be applied to passenger cars and trucks.

Quantification of Savings in Reduction of Crash Risk

Review of Potential Methods. Severe crashes on two-lane highways are commonly associated with cross-centerline passing maneuvers. Passing lanes can reduce crash risks by providing reliable passing opportunities without the need for the passing driver to use the lane normally reserved for opposing traffic, which breaks up traffic platoons for drivers and reduces the need for passing maneuvers downstream (*85*). Construction of passing lanes is considered one of the most common and cost-effective practices to improve traffic safety on rural two-lane roadways (*16*) and has been widely used by many states (*85*).

To measure the safety effectiveness of a passing lane implementation, the most widely used means is to perform either a cross-sectional study that compares safety between locations or a before-after (B/A) study that focuses on the changes in safety over time (*58, 86*). Each method has strengths and weaknesses. One major advantage of the cross-sectional method is that the regression models can be used for alternative improvements analysis on other highway sections. A disadvantage is that a typical regression model cannot consider all potential factors; some will not be significant in the model, while others may not be measurable within the parameters of the study, and the factors not taken into consideration might affect the accuracy of the final model. On the other hand, the main advantage of the B/A approach is that it is a controlled experiment that analyzes differences from samples with approximately the same characteristics except the treatment, minimizing the potential effects of other factors. Two drawbacks to this approach are that the resource and time requirements are often beyond the means of some state DOTs, and results may not be equally applicable in other locations (*86*).

Early research studies (*87*, *85*, *88*) evaluated safety effectiveness through cross-sectional studies with simple statistical methods using crash rates that were based on traffic volumes and crash counts. One such evaluation study on 15 sites across 12 states (*87*) concluded that the installation of a passing lane on a two-lane highway lowered the accident rates in both directions with no unusual safety problems found to be associated with either lane-addition or lane-drop transitional areas of passing lanes. Another cross-sectional research study (*88*) found similar results from sites in Michigan; the passing lane installation reduced the accident rate by 12 percent. Furthermore, a safety evaluation of existing passing lanes in Missouri (*85*) discovered that the total accident rate on National Highway System segments with passing lanes appears to be 12–24 percent lower than for conventional two-lane highways. However, cross-sectional evaluations that were based solely on traffic volumes and crash counts could yield biased research outcomes, producing a generalized conclusion that is not repeatable and verifiable in other locations (*62*).

In contrast, the B/A approach using the EB method with a comparison group is regarded as more rigorous than the cross-sectional approach or the simple (or naïve) B/A approach, combining the strengths of both the simple B/A approach (temporal effects) and the cross-sectional approach (spatial effects) (*58*). To provide a statistically reliable and accurate result, many factors other than the treatment effect need to be taken into consideration as well. One of these factors is the regression-to-the-mean bias, which is a statistical phenomenon that occurs whenever a nonrandom sample is selected from a population (*58, 86*). The profession has known for many years that this issue with simple B/A studies can often produce an over-estimated benefit as a result in a safety-effectiveness evaluation because selected sample locations often have an unusually high crash rate. These locations with high prior crash rates tend to have higher reductions in the after period even without any treatment, simply because the observed values regress or return to the long-term mean values (*86*). Crash migration could also affect the results of the safety-effectiveness evaluation of a passing lane treatment, which means the decrease of crash risk at the treated location could cause increases in the risks in nearby locations (*89, 90*). Statistical analyses need to take long-term trends into consideration as well (*91*). For example, a crash risk reduction could be the result of the treatment, but it could also be because of a national trend due to factors like increasing safety awareness of drivers. Of all the problems associated with the simple B/A method, the regression-to-the-mean bias is generally considered the most serious (*86*). Thus, the EB method (*92*) was developed to mitigate this problem. The method is based on the following three assumptions (*86*):

- The number of crashes at any site follows a Poisson distribution.
- The means for a population of systems can be approximated by a gamma distribution.
- Changes from year to year from different factors are similar for all reference sites.

The idea behind the EB method is to predict the number of crashes that would occur during the after period if the treatment had not been implemented. In general, this method consists of two steps (*92*):

1. Establish the foundation for the prediction by estimating the frequency of the studied crashes in the before period.

2. On the basis of this foundation, predict how the expected number of crashes would have changed from the before period to the after period.

The EB method evaluates the effect due to the treatment with higher accuracy by using two pieces of information (*58*, *86*): the crash history of a treated site, and the data about safety from reference sites with similar geometric characteristics.

Crash Risk Associated with Super 2 Corridors. To accurately evaluate the safety effectiveness of a Super 2 corridor, several researchers and agencies have conducted B/A observational studies using the statistically more rigorous EB method on Super 2 highway sections (*37*, *58*, *59*, *62*), and have found a positive correlation between Super 2 treatments and improved safety on crash risks.

Using the EB method, researchers (*58*) on Project 0-6135 studied the safety effectiveness of four Super 2 corridor sites in Texas. To ensure the robustness of the research method applied, four reference groups of Super 2 sites were stratified by spatial and operational similarities. A statistical calibration of the observed data was performed with a safety performance function developed from a negative binomial regression, with the data of those reference groups ranging from 1997 to 2009. As mentioned in the discussion of operational benefits, this study revealed that the installation of passing lanes led to a statistically significant crash reduction of 35 percent, or a 0.65 crash modification factor (CMF) for segment-only crashes and 42 percent (CMF of 0.58) for segment-and-intersection crashes with 95 percent confidence level. This research concluded that passing lanes provide added benefit at higher traffic volumes by reducing crashes, delay, and PTSF.

The *Highway Safety Manual* provided a baseline CMF of 0.75 for the implementation of passing lanes on two-lane highways (*93*). However, Persaud et al. (*59*) pointed out that this CMF value was based on earlier research studies that were too simple to validate the results, and therefore more analyses were needed to develop a statistically sound measure of the safety effectiveness of passing lanes. To find a more reliable set of CMF values for passing lanes, Persaud et al. conducted a safety-effectiveness evaluation based on traffic volume and crash history data from 100 reference sites (without passing lanes) and 231 passing lane sites in Michigan. Because of the limited numbers of sites eligible for the development of CMFs for passing lanes with a B/A study, two complementary analyses were conducted: an EB-based observational B/A study of sites with passing lanes and a cross-sectional analysis that used generalized linear modeling to estimate the difference in the safety performance of sections with and without passing lanes. In addition, a companion study of adjacent untreated sites within 1 mile was conducted with the same procedure to examine the possible spill-over (crash migration) effect. In this analysis, only crashes that did not involve animals or intersections or interchanges were considered, to emphasize the crash types most associated with the effect of passing lanes. The results were a set of CMFs shown in Equation 1 and Table 12 for several types of crashes estimated from the model with all coefficients above 95 percent confidence level (*59*). Where a CMF has been estimated with statistical significance less than 10 percent, a note has been made.

$$crashes\ per\ year = exp^{(\alpha+\beta_3)}(AADT)^{\beta_1}(segment\ length)^{\beta_2} \tag{1}$$

Table 12. Implied CMFs from Cross-Sectional Models for Nonanimal, Non-intersectional Crashes (*59*).

Crash Type	CMF	CMF (with 1-Mile Adjacency)	Crash Type	CMF	CMF (with 1-Mile Adjacency)
Total	0.67	0.63	Wet	0.81^{α}	0.71^{α}
Injury	0.71^{α}	0.65	Dry	0.53	0.57
Target$^{\beta}$	0.53	0.46	Peak months	0.54	0.54
Day	0.60	0.58	(June–August)		
Night	0.91^{α}	0.81^{α}	Nonpeak	9.72^{α}	0.68

Note: CMFs from models formed from Equation 1.
$^{\alpha}$ The estimated CMFs should not be considered statistically significant.
$^{\beta}$ Target crashes include run-off-the-road, head-on, rear-end straight, sideswipe same direction, and sideswipe opposite direction crashes.

Other variables that were not significant were excluded in the final models. For this study, every effort was made to eliminate the confounding effects of other factors by selecting reference sites that were as similar as possible to the passing lane sites (*59*). The results of this study supported the effectiveness of passing lanes in improving safety. Additionally, the results suggested the benefit extends as far as 1 mile upstream and downstream of the passing lane (*94*).

The Wyoming Department of Transportation (WYDOT) constructed and studied nine passing-lane segments on a 26-mile rural two-lane highway between 2005 and 2006; however, a preliminary B/A analysis using naïve statistics found no significant safety improvement of these Super 2 treatments (*62*). After a rigorous investigation using the EB method with the same datasets, Schumaker et al. found a statistically significant safety improvement of the Super 2 corridor treatment. The CMFs in this research were estimated based on the crash rates calculated using the mean AADT and length of segment for both section types (treated and untreated), and the Poisson test of significance was performed to validate the statistical rigorousness. The result of this study conveyed a conclusion that the CMF for the passing lane segments was 0.58 at a 95 percent confidence interval; that is, there was a 42 percent reduction, from 0.86 crash per million vehicle-miles (MVM) to 0.48 crash per MVM (*62*).

A comparison of these two studies shows the importance of using a reliable safety impact assessment (*95*). WYDOT estimated the construction cost of building a 10-mile passing lane project to be $5.85 million. With the results of the basic B/A analysis, the assessed economic benefits from the avoided crashes were negligible, and the project was at risk of being canceled in favor of a traditional four-lane alignment option. However, when the agency performed an EB-based analysis a year later, the economic benefits of improved safety were substantial: $9.20 million for reductions in fatal (K) crashes, $0.42 million for injury (A) crashes, $0.13 million for evident injury (B) crashes, $0.13 million for possible injury (C) crashes, and $3,200 for property-damage-only (O) crashes (*96*). The findings from these two studies of Wyoming sites support the finding in the profession that the naïve B/A approach has often led to imprecise results. In support of that finding, the Schumaker et al. study (*62*) recommended that transportation agencies always perform a reliable statistical analysis such as the EB method instead of simple (naïve) B/A comparisons. In summary, the use of a rigorous and reliable method for determining economic impact assessments of passing lanes, especially on the safety risk valuation, is important.

Environmental Requirements and Guidelines

Background

The main environmental impacts associated with transportation projects can be grouped into seven effects (*97*):

- Animal mortality from road construction.
- Animal mortality from collision with vehicles.
- Modification of animal behavior and movement patterns.
- Alteration of the physical environment (e.g., soil erosion and deforestation).

- Alteration of the chemical environment (e.g., air pollution and roadway runoff).
- Spread of exotics.
- Increased development of land due to increased human mobility, leading to habitat fragmentation.

To ensure that transportation projects are built in a safe and responsible manner to minimize adverse impacts to the environment and public interests, all transportation projects require reviews under the NEPA. The NEPA review also provides a framework for meeting other environmental reviews, such as the Endangered Species Act of 1973, the National Historic Preservation Act of 1966, the Clean Water Act (CWA), the General Bridge Act of 1946, the Magnuson-Stevens Fishery Conservation and Management Act, and the Marine Mammal Protection Act of 1972.

In general, the NEPA process has two principal purposes: first, to ensure that an agency carefully considers information concerning potential environmental effects of proposed projects and actions, and second, to ensure that the information pertaining to these impacts is available to the public (*98*). Agencies must address numerous federal laws, but the NEPA provides the framework for all these laws. Based on the level of environmental impact of the proposed project or action, there are three basic options for the NEPA: categorical exclusion (CE) for minimal impact, environmental assessment (EA) for unknown impact, and environmental impact statement (EIS) for potentially significant impact.

Environmental Review Streamlining

The NEPA has been significantly streamlined to provide expedited review since its passage in 1969 by numerous administrative, legislative, and judicial actions. According to Seassio (*99*), some congressional members believed that NEPA review causes project delays and, consequently, causes economic losses to the country. In response to the criticism that EAs and EISs delayed federal decision-making, individual federal agencies established CEs, which typically require very little documentation and thus can be quickly applied to a proposed project. For example, 93.98 percent of projects (12,975 projects) funded under the American Recovery and Reinvestment Act of 2009 (*100*) as of February 2010 were under CEs (*97*). Congress expanded its efforts to streamline the NEPA for surface transportation projects with the passage of the Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users, which allowed FHWA to significantly decrease the average NEPA review time from 73 months to 36.85 months, and also established a 180-day statute of limitations for legal challenging on federal agency approvals for a highway project (*99*). The Moving Ahead for Progress in the 21st Century Act of 2012 (MAP-21) also significantly reformed the NEPA to speed up project delivery by promoting innovative approaches and established a performance-based programmatic approach (*98*). All those efforts significantly reduced the delay from NEPA reviews of proposed transportation projects. However, it was not achieved completely without a compromise of the robustness of NEPA's reviewing process. Therefore, more proactive solutions with early coordination, integration of modern information technology tools, and more succinct NEPA documentation were needed (*97, 99*).

Synchronized Review Process

To effectively coordinate among the diverse sets of environmental reviews, FHWA (*101*) provided a synchronized review process (SRP), which performs various environmental review and permitting procedures for a proposed project in a concurrent fashion. The SRP can be a formal agreement to merge review processes, or it can be used as a guideline to be applied ad hoc (*101*). Many SRPs rely on three to four checkpoints, which are specific milestones within the NEPA process where certain agencies request acceptance or approval from the other agencies to further the procedures. A typical SRP has the following steps (*101*):

- **Step A—Introductory Meeting:** occurs during the time of Notice of Intent or during project scoping. This critical process focuses solely on anticipated project locations or expected impact level.
- **Step B—Purpose and Need:** typically occurs soon after completion of scoping. The purpose and need statement serves as the foundation for the NEPA alternatives analysis and evaluations of multiple agencies. This checkpoint is one of the most critical.
- **Step C—Alternatives Screening Criteria:** The purpose of this checkpoint is to articulate screening criteria and establish measurable objectives based on project feasibility and environmental safety.

- **Step D—Alternatives to be Carried Forward:** The purpose of this checkpoint is to reduce the number of alternatives that will be studied in the EIS or EA to a reasonable level using the previously developed criteria.
- **Step E—Draft EIS or EA:** This checkpoint is to publish the draft EIS or an EA for public comment to help identify the preferred alternative early.
- **Step F—Preferred Alternative/Preliminary Least Environmentally Damaging Practicable Alternative (LEDPA) for Section 404:** The U.S. Army Corps of Engineers (USACE) maintains the authority to decide which alternative is the LEDPA for CWA Section 404 permitting. This checkpoint is for the selection process of the LEDPA.
- **Step G—Compensatory Mitigation:** The purpose of this checkpoint is to develop a plan to first avoid and then minimize impacts to the maximum extent practicable, prior to the development for compensatory mitigation for losses to the environment. However, the transportation agency is not prohibited from planning for mitigation early in project development.
- **Step H—Final EIS (FEIS):** For an SRP, at this checkpoint, each agency has the full body of information needed to document its decision as an FEIS or publication of the EA. At this point:
    - The transportation agency has selected a preferred alternative.
    - If each authority is applicable, the services have issued a concurrence letter or final Biological Opinion.
    - USACE has made a preliminary LEDPA determination and reviewed a conceptual or draft compensatory mitigation plan.
    - The U.S. Coast Guard has sufficient information to make a determination of completeness on the bridge application.
    - Each of the agencies has considered the public comments received during the draft EIS comment period and/or agency public notices in making its respective determinations.
    - All agency concerns and other environmental reviews have been addressed.
    - If a USACE public notice has not been issued, it may be issued concurrently with the FEIS.

- **Step I—Record of Decision (ROD):** The SRP culminates at this checkpoint by issuing an ROD for EIS or Finding of No Significant Impact for EA (if no significant impact is found). MAP-21 directs the U.S. Department of Transportation (USDOT) to issue a combined FEIS/ROD document unless specific criteria are met (*101*).

Expediting Reviews Process

Some transportation projects are large, complex, and highly controversial, thus requiring thousands of pages of EAs and EISs and several years of effort to finalize the environmental review process (*99*). However, most actions involved in a Super 2 corridor treatment are small-scale, routine actions with generally minimal environmental impacts that are easy to predict, such as road shoulder widening or addition of an auxiliary lane. For these routine actions, FHWA suggested a programmatic approach (*101*). A programmatic approach is a synchronized review process memorialized into a formal agreement for a suite of similar projects or a whole program, typically in the form of a Memorandum of Agreement (MOA) or a Memorandum of Understanding (MOU). Such an agreement should incorporate the most common components of the NEPA while providing the flexibility to be adapted to fit individual needs and circumstances to accomplish environmental compliance in an expeditious manner. The MOA or MOU serves as the contract and framework to carry out NEPA assignments by granting the participated state DOT the authority to conduct the federally mandated environmental reviews of certain designated highway projects while shifting some of the responsibilities and liabilities under the NEPA onto the participated state DOT (*98*). An agreement could be structured in the following way (*98, 101*):

- **Part 1—Purpose and Ground Rules:** This part should be an introduction of the purpose and ground rules for the agreement to be established, explicitly identifying the lead agency, participating agencies, scope of the agreement (i.e., for a single project, suite of projects, or a whole program), roles and responsibilities for each agency at different checkpoints, and whether parts of the process can be optional.
- **Part 2—Threshold for Participation:** This part should set up a threshold to identify the eligible projects for participation in this agreement. In general, a determination of proposed action as a CE that is eligible for this agreement is based on an agency's experience with a particular kind of action and its environmental effects (*98*). The

North Carolina DOT, for example, uses a series of questions to help guide the agencies to filter out eligible projects for the expedited process (*101*). The threshold could include:

  - The type of USACE permit review (e.g., projects that qualify for a nationwide permit, programmatic general permit, or regional general permit).
  - The project size (e.g., projects that are less than X acres or less than Y ft).
  - The geographic area (e.g., projects that do not cross designated critical habitat, historically preserved areas, or specific watersheds of concern).
  - The type of project (e.g., projects that are an expansion of an existing rural two-lane highway to a three-lane highway).

- **Part 3—Assignments of Responsibility:** This part should address and clarify the responsibilities and roles assigned to the state DOT, FHWA, and other agencies if applicable, and how the state DOT implements the NEPA assignment program. Involvement with other agencies should also be stated here if applicable. This part should also illustrate the applicability of federal laws, certifications, and acceptance of jurisdiction that justify the program in this agreement. The details in the program should demonstrate the organizational and management capabilities, as well as the necessary monetary and personnel resource commitments, of the state DOT for assuming and implementing the FHWA environmental review responsibilities with full compliance.
- **Part 4—Monitoring of Compliance:** This part should provide the details on how FHWA ensures the state DOT will enforce all federal laws, as well as the details on how FHWA assesses and conducts audits of a state DOT's performance in this agreement through rigorous monitoring and oversight. This part should also provide the terms for FHWA to retain authority to revoke the program if the state DOT is unable to adhere to the responsibilities listed in the agreement.
- **Part 5—Dispute Resolution and Litigation:** While a synchronized review process can resolve many disputes, it cannot resolve them all. This part should clarify the steps taken if a disagreement on a specific project or in application of the agreement's procedures occurs. This could include what established dispute resolution procedures, such as those in law, regulation, or other MOA or MOU, should be applied, and who

will participate in the dispute resolution process or escalation procedures should an impasse occur. Also, this part should contain clarification of the procedures required in the event of legal actions or notices to sue under the NEPA against the agency to minimize the losses in project delay and legal liabilities.

- **Part 6—Training and Commitments:** This part should address the state DOT's commitment and plan to maintain the level of expertise and staffing necessary for the responsibilities in this agreement, as well as the partnership between the state DOT and FHWA to ensure the success of this program.
- **Part 7—Legal Clarifications:** As the final component of a formal agreement, this part could include provisions for:
    - Terms including lengths of agreements and conditions.
    - The process for modification, renewal, or termination of the agreement.
    - Definitions of terms used in the agreement.
    - Amendments to the agreement.

A programmatic approach could be beneficial in several ways (*101*). First, it allows agencies to explore and seek optimal resolutions for many similar actions to eliminate the time wasted on repetitive processes for each individual project. Such long-term efficiency could provide more predictability in transportation planning and economic benefits from faster project delivery and smaller staffing costs. Second, issues can be discussed and resolved once and for all prior to any specific projects, thus preventing potential economic losses. Third, an adaptive strategy can still be applied to the approach whenever a shortcoming in the development process is identified. Agencies have developed many programmatic approaches to process for these types of routine, recurring projects in an efficient manner. Caltrans and TxDOT each developed their own agreement with NEPA assignment to serve as a critical component and important tool for ensuring the overall success of the National Highway System with full achievement of environmental compliance (*98*).

CHAPTER 3: DATA COLLECTION

This chapter documents the efforts of the research team in the identification of suitable sites for the collection of geometric and operational data of Super 2 corridors and subsequent data collection activities at each site.

IDENTIFICATION OF SUITABLE CANDIDATE SITES

In order to identify suitable candidate sites for data collection activities, researchers conducted a thorough review of multiple sources of information. First, researchers solicited TxDOT district offices for known locations of Super 2 corridors. Next, the researchers' extant Super 2 database was reviewed. Later, the TxDOT Road-Highway Inventory Network (RHiNO) database was examined to cross-check the completeness of the researchers' database. Each of these files is examined in more detail in the following subsections.

TxDOT District and Area Responses to Super 2 Location Inquiry

Researchers received responses from the following TxDOT districts identifying the locations of Super 2 corridors in their jurisdiction:

- Atlanta (12 corridors).
- Austin (3 corridors).
- Bryan (7 corridors).
- Corpus Christi (39 projects).
- Yoakum (4 corridors).

The information provided by the districts included the highway name, county, control section, and boundaries. The Corpus Christi information was provided at a project level, whereas the information from the other districts was at a corridor level, which accounts for some of the overrepresentation of locations in the Corpus Christi District. Figure 3 shows a screenshot of the information the Atlanta District provided as an example of the information received.

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
1	Site Name (TBD)	Highway	District	County	Est. Install Date	Begin Const	End Const	CtrlSec	AADT	AADT Year	Begin DFO	End DFO	CtrlSec_ Mileage	From	To	Individual Passing Lane Segments
2	(Example)	SH 16	San Antonio	Atascosa/ McMullen				517-1 517-2						Jourdanton	FM 791	
3		SH 155	Atlanta	Cass				0520-03			0	17.202		US 59	county	
4		SH 155	Atlanta	Marion				0520-04			17.202	22.938	5.736	county	county	
5		SH 155	Atlanta	Upshur				0520-05			22.938	40.146	17.208	county	US 271	
6		US 82	Atlanta	Bowie				0046-04			530.144	542.33	12.186	FM 992	New Boston	
7		SH 8	Atlanta	Cass				0062-02			25.444	30.368	4.924	county	SH 77	
8		SH 8	Atlanta	Cass				0062-03			30.368	44.206	13.838	SH 77	SH 155	
9		SH 77	Atlanta	Cass				0278-01			35.744	47.109	11.365	US 59	state line	
10		SH 77	Atlanta	Cass				0277-02			5.991	23.705	17.714	county	SH 8	
11		SH 77	Atlanta	Cass				0277-01			0	5.991	5.991	US 259	county	
12		US 80	Atlanta	Harrison				0096-08			126.753	137.819	11.066	FM 450	FM 968	
13		SH 149	Atlanta	Panola				0394-01			24.135	30.27	6.135	LP 149	FM 959	
14		SH 149	Atlanta	Panola				0393-03			16.444	24.135	7.691	FM 959	SH 43	

Figure 3. Information Provided by the Atlanta District.

Researchers' Super 2 Database

At the onset of this project, the researchers' Super 2 database consisted of two files: a spreadsheet with the locations of existing and future Super 2 corridor locations, and a Google Earth KMZ file containing the bounds of a portion of the projects in the Excel file, including detailed location information of passing lanes and signage for an even smaller subset of projects that had been studied in detail during previous Super 2 research efforts. The researchers' initial database contained 43 existing Super 2 corridors and 21 locations where the existing highway was yet to be upgraded to a Super 2.

Conflation of Researchers' and TxDOT's Databases

The first step in identifying sites for data collection for this project involved reconciling the researchers' extant spreadsheet with the information provided by the TxDOT districts discussed in the previous subsection. Following the incorporation of the data provided by the TxDOT district offices, the number of constructed sites had increased to 90 locations, while the number of planned sites had grown to 58. Figure 4 shows an overview of the boundaries of the 90 constructed locations.

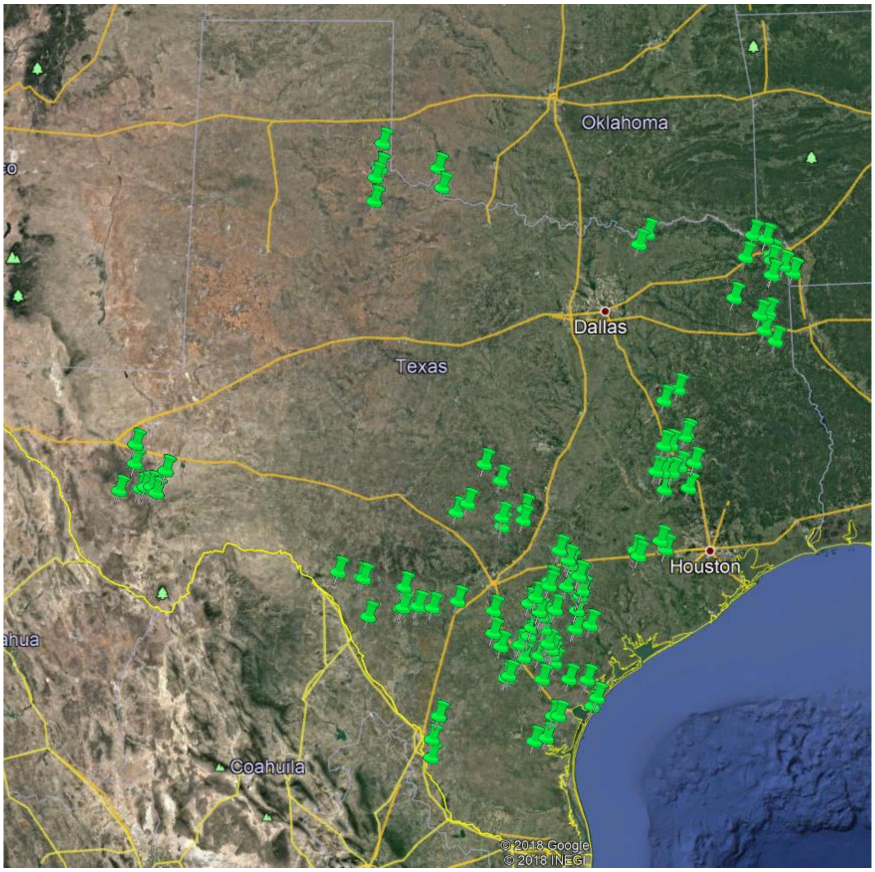


Figure 4. Combined Researchers' Database with District Responses.

From a practical standpoint, the number of sites reflected in the counts above overestimates the true number of Super 2 corridors for several reasons. First, Super 2 corridors are often constructed in a piecemeal fashion; what is now a long Super 2 corridor may have been constructed in several phases. The second reason for the overestimation of the number of Super 2 corridors is jurisdictional; while a Super 2 corridor may span multiple counties or districts from a driver's perspective, these corridors are represented as multiple separate segments in both the researchers' and TxDOT's databases. Finally, the Super 2 corridors are often broken where the control section used to linearly reference the roadway network changes. The control sections may change at municipal boundaries, jurisdictional boundaries, or major intersections. For the purposes of this study, it does not make sense to analyze multiple portions of what is an operationally consistent corridor, so adjacent Super 2 segments were considered to be one corridor. This process, which was conducted by examining the boundaries of the sites using Google Earth, resulted in the identification of 49 Super 2 corridors within the state. The locations of these corridors were mapped into ArcMap and overlaid on the TxDOT RHiNO file. The

TxDOT RHiNO file was then queried to display only the roadways on the state highway system (i.e., state highways, FM/RM routes, US highways, and interstates). Next the RHiNO segments between each of the end points of a Super 2 corridor were selected. Once all appropriate segments were selected, the segments were exported as a new geodatabase layer. Figure 5 shows an image of the layer, color-coded by traffic volume at the RHiNO segment level.

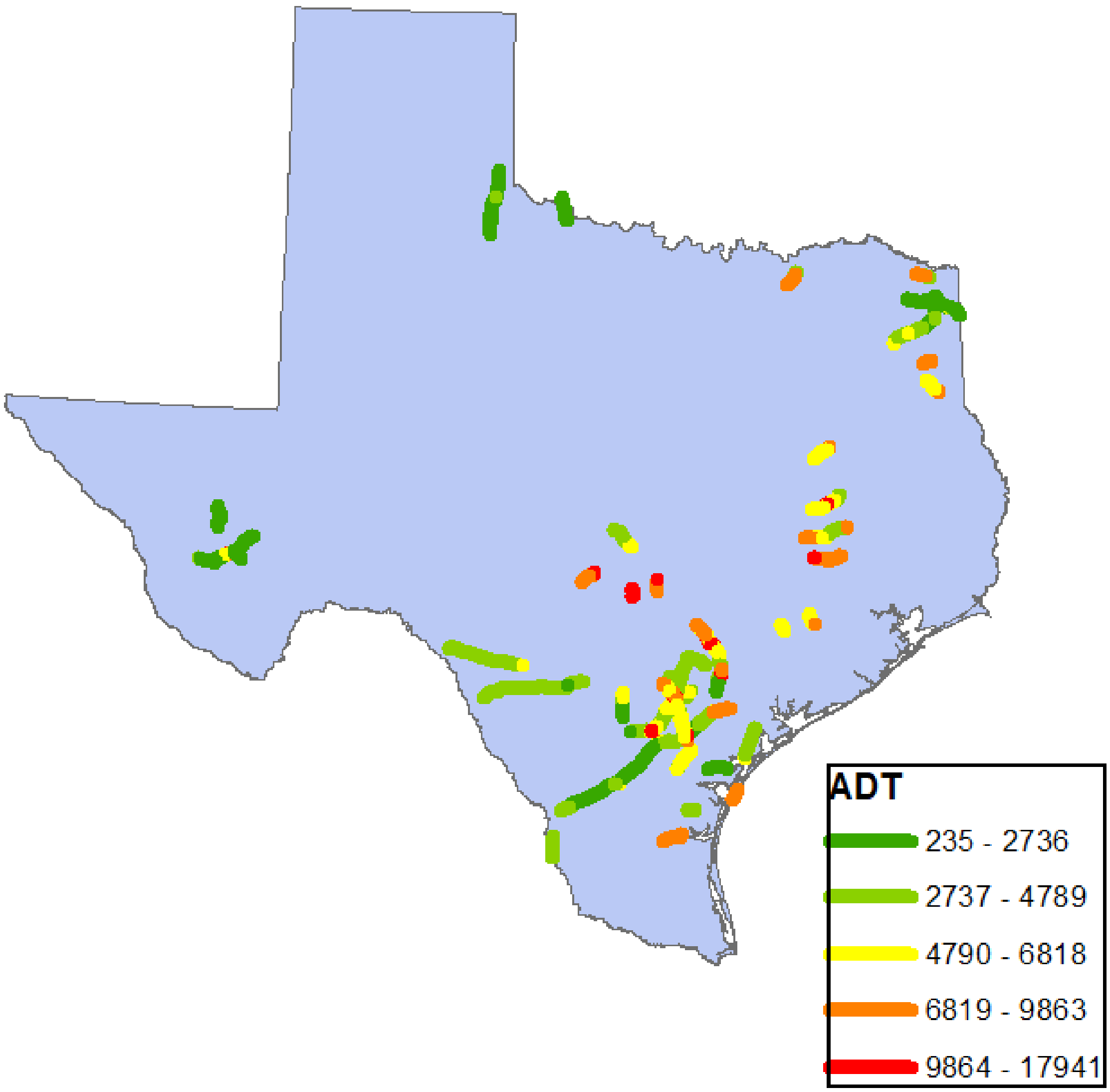


Figure 5. Known Super 2 Corridors in Texas Colored by Volume.

Candidate Site Prioritization

The segments in the RHiNO file did not correspond directly to the Super 2 corridors. Consequently, to gain corridor-level insight about the Super 2 highways, several RHiNO segments had to be combined for each corridor. This was accomplished by creating a corridor-level ID field in ArcMap and manually populating that field with a value that indicated that adjacent segments were part of the same corridor. Following this procedure, weighted average values (by length) for traffic volume and truck percentage were calculated. Using this information, researchers reviewed the initial list of 49 Super 2 corridors to develop a list of candidate study sites. In their discussion of which sites to include as candidate sites, researchers focused on identifying Super 2 corridors with relatively high and relatively low traffic volumes, to better identify locations that might be representative of locations in the state that are either likely to be expanded from two-lane to Super 2 highways or from Super 2 to four-lane highways based on traffic volume. Researchers also looked for sites with high truck percentages to help capture that effect in operations data to be collected and analyzed. Finally, researchers favored sites that were clustered relatively close together to make data collection more efficient by enabling the collection of multiple sites on each data collection trip. Ultimately, researchers identified 15 candidate sites for study; Table 13 shows this list.

Table 13. Candidate Study Sites after Researcher Review.

Site	County(ies)	Average Volume along Corridor	Truck Percentage	Potential for Inclusion
SH 105	Grimes	8,648	12%	High volume
SH 16	Gillespie	9,601	7%	High volume
SH 188	San Patricio	1,705	12%	Low volume
SH 361	Nueces	8,217	10%	High volume
SH 8	Cass	2,067	29%	Low volume, high truck %
US-281	Blanco	10,837	6%	High volume
SH 17	Jeff Davis	784	18%	Low volume
US-183	Gonzales	8,163	19%	High volume
US-183	Dewitt	2,355	23%	Low volume, high truck %
US-59	Live Oak	2,030	18%	Low volume
US-283	Wilbarger	1,828	28%	Low volume, high truck %
US-59	Duval/Webb	2,344	32%	Low volume, high truck %
US-67/90	Presidio/Brewster	2,076	11%	Low volume
US-67	Brewster	1,518	15%	Low volume

TxDOT RHiNO File Super 2 Locations

At the time of candidate site identification activities, researchers were aware of but had not yet vetted the RHiNO file field indicating that a road was a Super 2. The red lines in Figure 6 illustrate the sites identified as Super 2s in the RHiNO file.

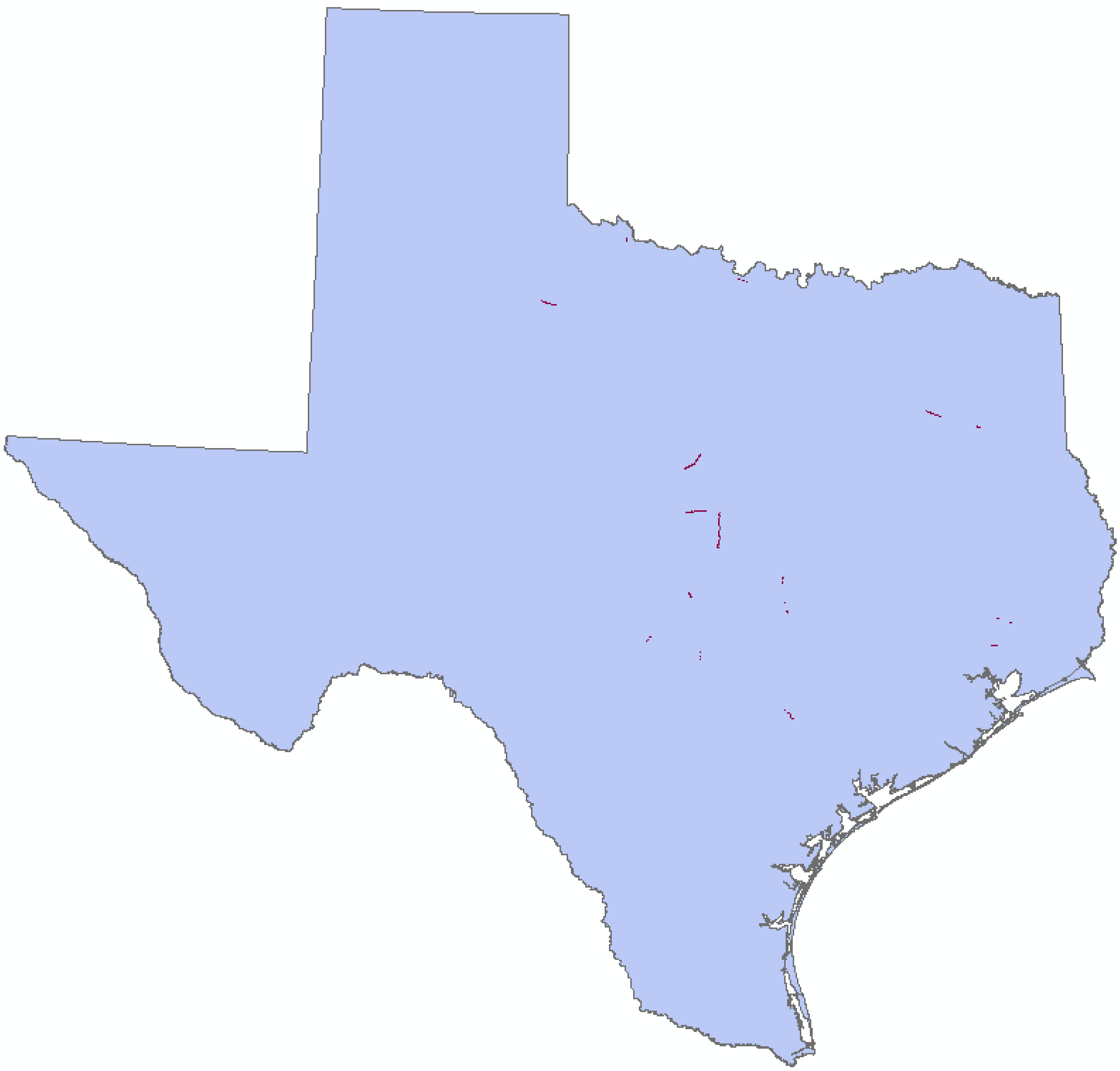


Figure 6. Super 2 Segments Shown in 2017 RHiNO File.

When contrasted with Figure 5, it is clear that a large portion of the Super 2 network in Texas was not indicated in the 2017 RHiNO file, which was the latest version available at the time of this work. In fact, the researchers' database indicated 1,146 centerline miles of Super 2 highway in Texas, while the RHiNO file indicated 122 miles. However, 100 of those 122 miles were not accounted for in the researchers' database and were subsequently added to an updated Super 2 file for use on future research.

DATA COLLECTION IN-FIELD ACTIVITY

Following site selection to identify Super 2 sites with high traffic volume and/or high truck percentages, researchers began field data collection in March 2019. The objectives of the field data collection were to document highway operating conditions approaching, within, and departing each passing lane study site. Two types of field data collection equipment were deployed: digital video recording equipment and road tube-based counter/classification equipment.

Digital video (equipment shown in Figure 7) was recorded at both the entry and exit from each of the five passing lane sections selected by researchers. At the passing lane entry, where the roadway cross-section in the direction of data collection expanded from one lane through a left-lane expansion taper to a two-lane (passing) section, video documented motorist behavior, vehicle classification, and drivers' lane selection. Where the passing lane ended (through a left-lane reduction taper), video documented motorist behavior, vehicle classification, drivers' lane selection, and merge conflicts as the two lanes merged to a single through lane. Researchers collected 24 hours of continuous video at each entry and exit location (i.e., the start of each passing lane and termination of each passing lane) for each passing lane study site. In total, 240 hours (24 hours × 2 locations per site × 5 sites) of video documenting the passing lane activities of over 12,000 motorists were collected.

Figure 7. TTI Portable Video Data Collection Equipment.

Counters/classifiers (commonly called tube counters; equipment shown in Figure 8) were used to document traffic volume, speed, headway, and classification at four locations within each passing lane data collection site. These devices were located:

- Before the start of each directional passing lane.
- At the beginning of each passing lane, where two full-width lanes (the right through lane plus the left passing lane) were available.
- At the end of each passing lane, where two full-width lanes were available and just before the left-lane reduction taper began.
- After each passing lane, where the lane reduction taper ended and only one directional traffic lane remained.

Figure 8. Traffic Counter/Classifier Road Tube Deployment.

Five Super 2 study sites were studied, applying the data collection approach outlined previously. The only site for which some data are missing is US-183 north of Gonzales. Additional counters were initially deployed at this site to document vehicle headways several miles downstream of a passing lane section. However, counter configuration problems prevented data collection with the last four counters at the site. An attempt was made to re-collect these data in June 2019, but technicians encountered road construction (specifically, repaving) at the study site, and the road work was not completed within a time frame to allow another data collection effort during this project. The five study sites are listed as follows, and details about the traffic data collected for each site can be found in the following subsections:

- US-281 south of Blanco.
- US-183 north of Gonzales.
- US-59 west of Freer.
- US-67/US-90 east of Marfa.
- US-67 north of Alpine.

US-281 South of Blanco

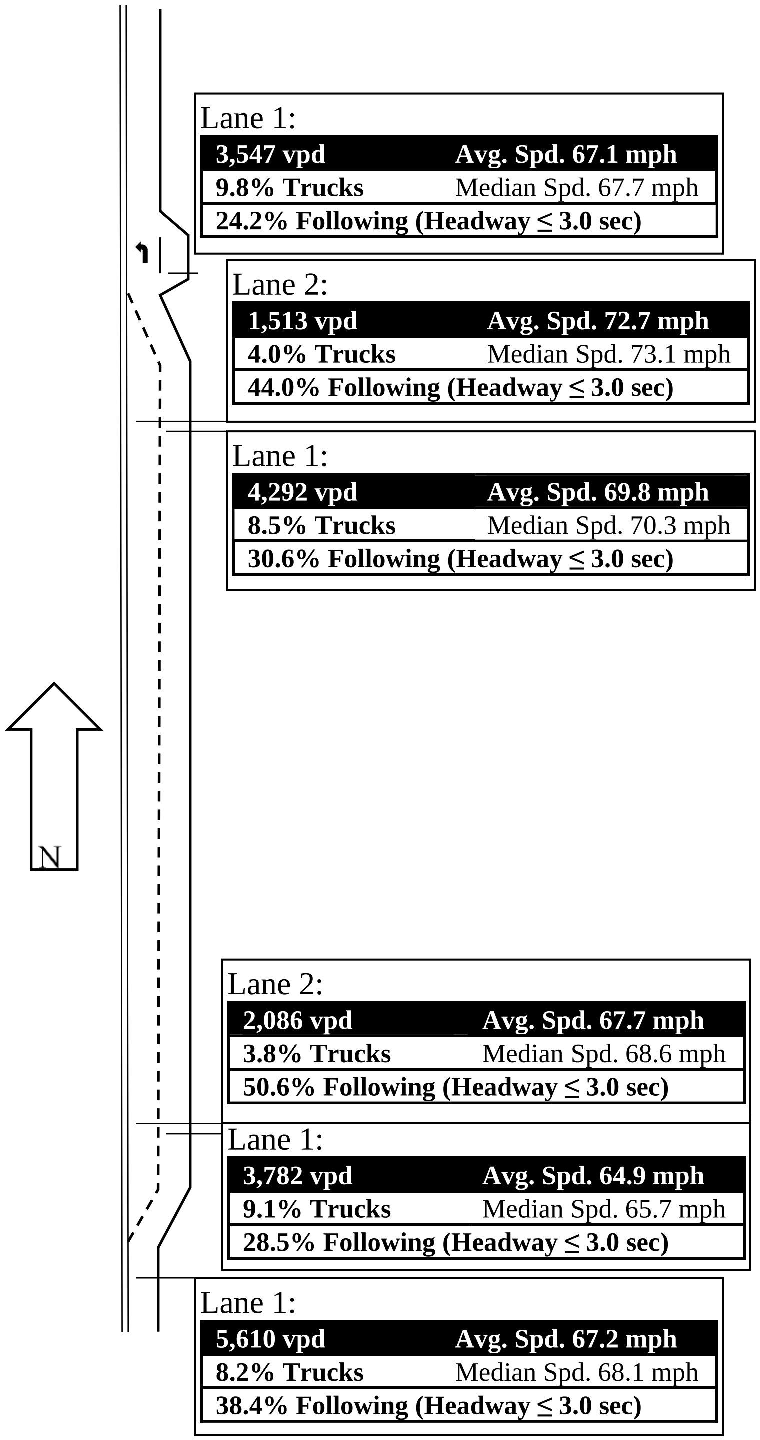
The US-281 study site is located along a rural portion of US-281 between San Antonio and Blanco, northwest of Canyon Lake and about 9.5 miles south of the city of Blanco. Through most of this area, US-281 is a two-lane highway with passing lanes in alternating directions. The passing lane selected for study is in southern Blanco County and is on northbound US-281 between FM 306 and FM 473 West (Figure 9). The speed limit through the study portion of US-281 is 75 mph, and the roadway cross-section features three 12-ft travel lanes (i.e., a single southbound lane, a northbound passing lane, and a northbound through lane) and 9-ft shoulders on each side of the road.

TxDOT's Transportation Planning and Programming Division (TP&P) reports a 2017 ADT count of 10,102 vpd in this highway section. Vehicle classification from 2017 was reported as 94 percent autos and light trucks and 6 percent heavy vehicles.

Researchers' March 2019 traffic count (Figure 10) is consistent with the TxDOT ADT value, though truck percentages are slightly higher at 8 to 10 percent heavy vehicles. At the northern end of the study section, just past the end of the passing lane, a left-turn lane is present for northbound US-281 traffic to turn (left) onto FM 473. The data show that this reduces traffic on northbound US-281 by about 39 percent and has a reducing impact on the following percent for the northbound traffic stream (because vehicles turning onto FM 473 create gaps in the northbound US-281 traffic stream).

Source: Google® Maps

Figure 9. US-281 Study Site Location Map.



Direction of travel: Northbound

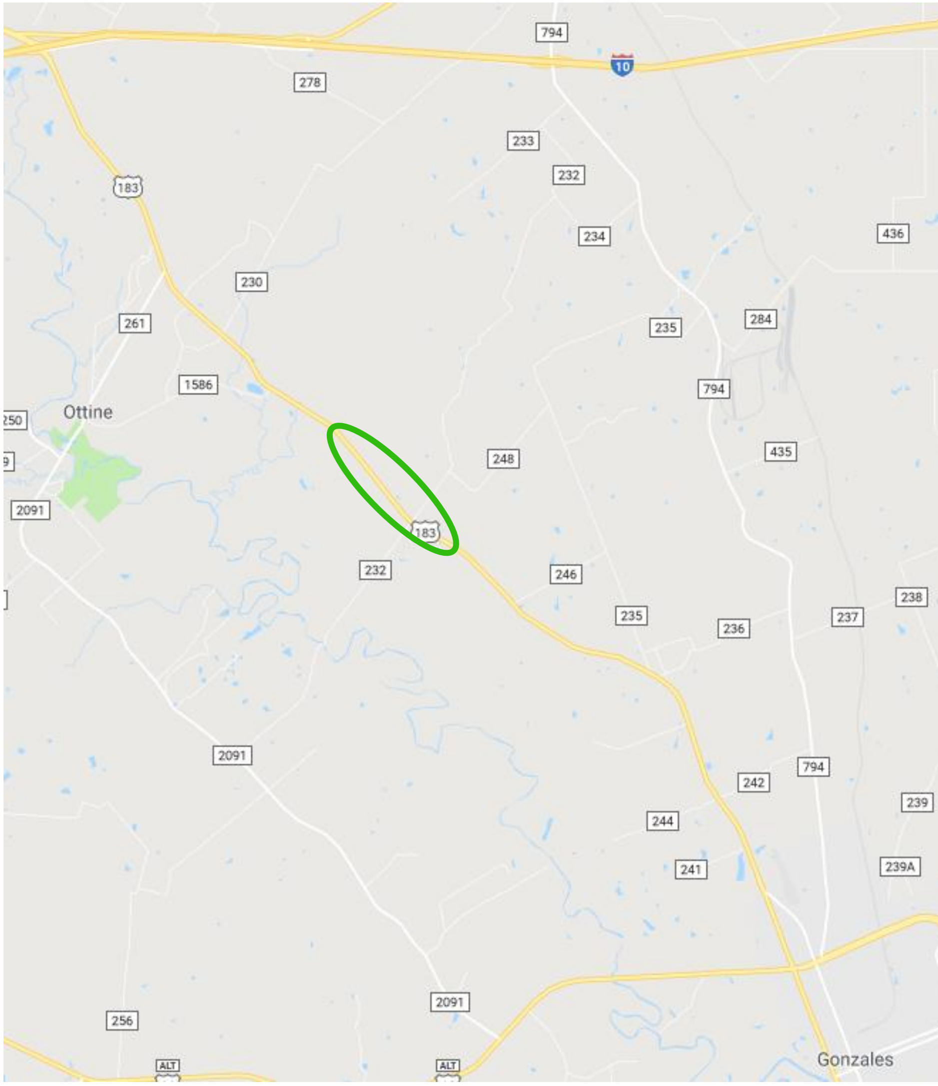
Data collection date: 3/20/2019

Note: Left-turn lane at end of passing lane reduces volume and affects following percentage.

Figure 10. Study Site 1: US-281 South of Blanco, Texas.

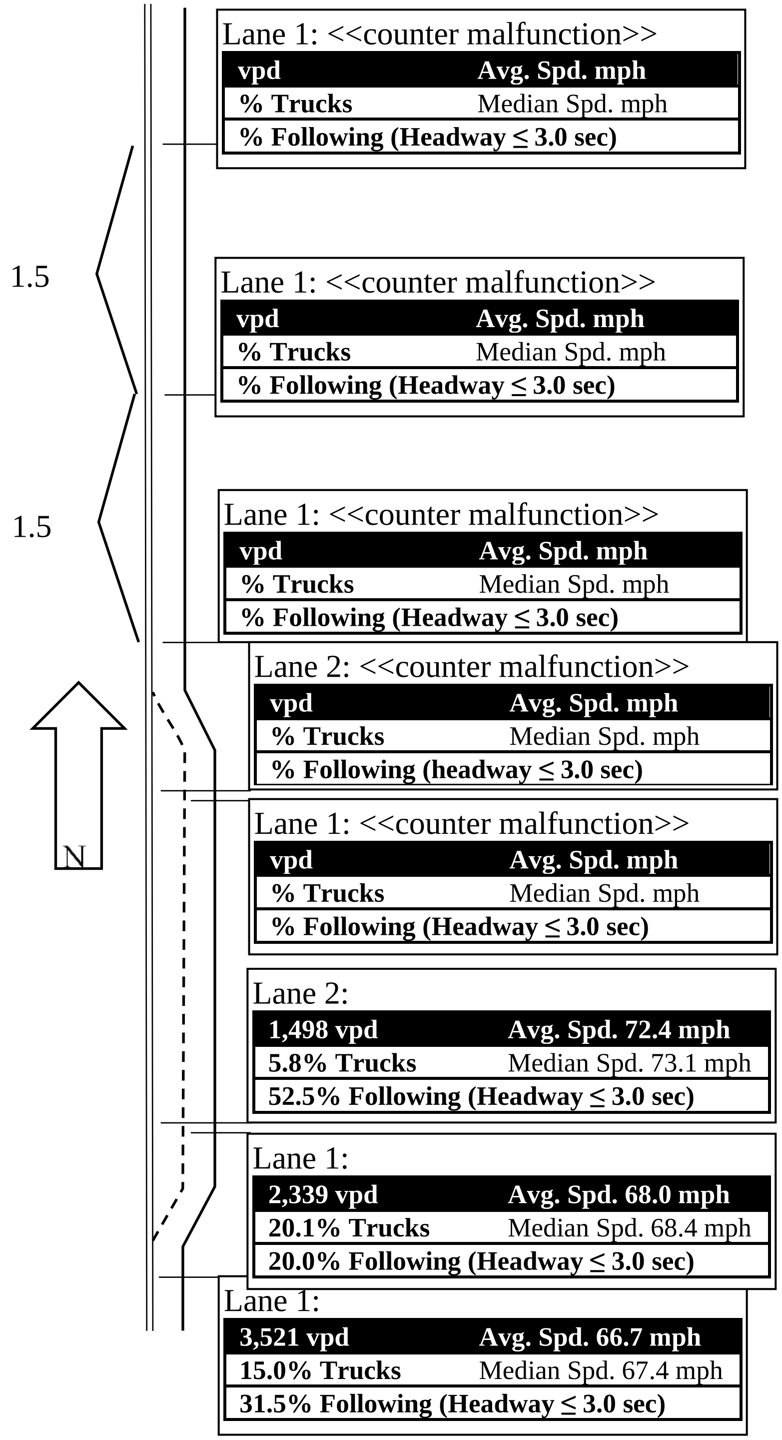
US-183 North of Gonzales

The US-183 study site passes through a largely rural area midway between I-10 to the north and the city of Gonzales to the south. The northbound passing lane study site is about 5.5 miles northwest of the city of Gonzales. Through most of this area, US-183 is a two-lane highway with passing lanes in alternating directions. The passing lane selected for study is in northern Gonzales County from south of the US-183 junction with County Road 232 to south of the US-183 junction with FM 1586 (Figure 11). The speed limit through the study portion of US-183 is 70 mph, and the roadway cross-section features three 12-ft lanes (i.e., a single southbound lane, a northbound passing lane, and a northbound through lane) and 12-ft shoulders on each side of the road. TxDOT's TP&P reports ADT of 7,978 vpd and a vehicle classification of 87 percent autos and light trucks and 13 percent heavy vehicles; this is roughly consistent with research study counts from April 2019 (Figure 12).



Source: Google® Maps

Figure 11. US-183 Study Site Location Map.



Direction of travel: Northbound

Data collection date: 4/16/2019

Note: Pavement work caused postponement of makeup data collection at last four count stations.

Figure 12. Study Site 2: US-183 North of Gonzales, Texas.

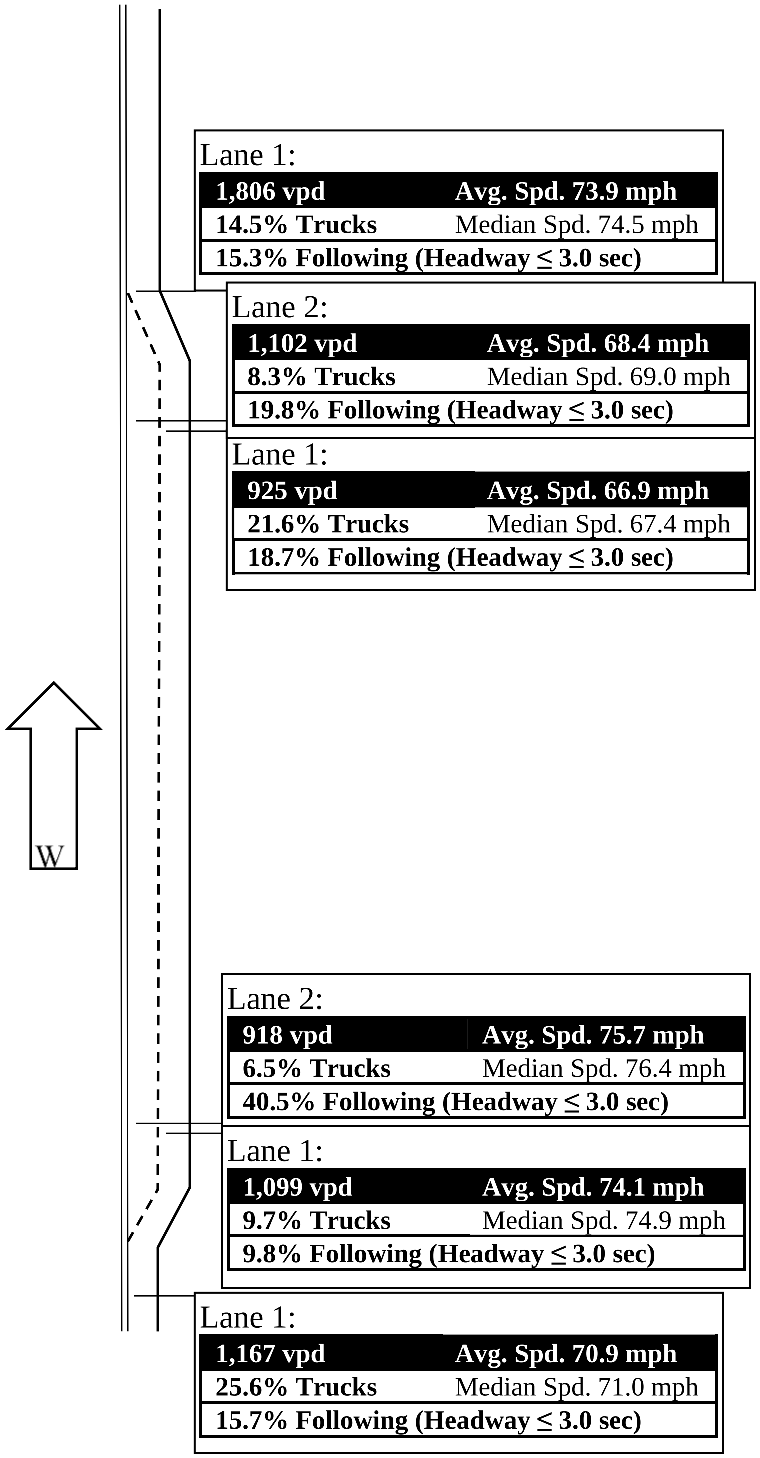
US-59 West of Freer

The US-59 study site is located along a rural portion of US-59 between Freer and Laredo, about 16 miles southwest of the city of Freer. Through most of this area, US-59 is a two-lane highway with passing lanes in alternating directions. The passing lane selected for study is in eastern Webb County and is on westbound US-59 between FM 2050 and FM 2895 (Figure 13). The speed limit through the study portion of US-59 is 75 mph, and the roadway cross-section features three 12-ft lanes (i.e., a single southbound lane, a northbound passing lane, and a northbound through lane), a 3-ft shoulder on the north side of the highway (in the direction of the passing lane), and a 10-ft shoulder on the south side of the highway.

TxDOT TP&P reports a 2017 ADT count of 2,134 vpd, with 64 percent autos and light trucks and 36 percent heavy vehicles. Researchers' traffic count (April 2019) is substantially higher than the TxDOT ADT value, with a westbound (directional) volume alone of around 2,000 vpd (Figure 14). The April 2019 traffic count also showed a lower proportion of heavy vehicles, with traffic classification revealing 15 to 25 percent heavy vehicles depending on traffic counter location.

Source: Google® Maps

Figure 13. US-59 Study Site Location Map.



Direction of travel: Westbound

Data collection date: 4/29–30/2019

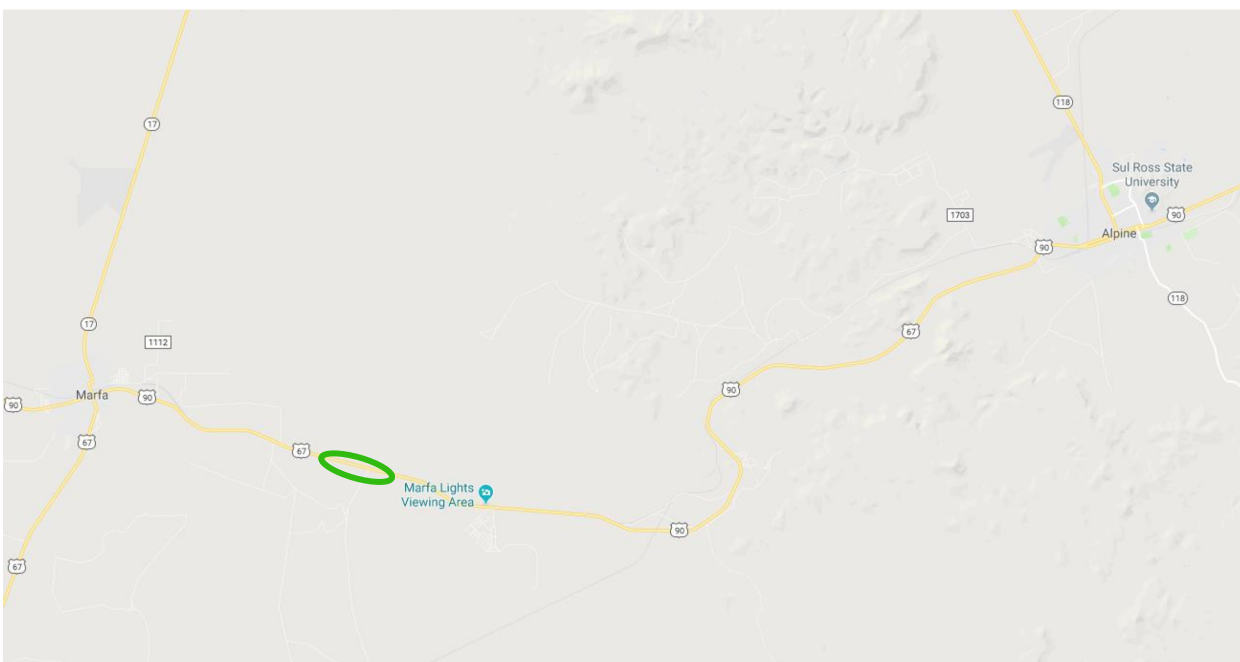
Note: Count at first station appears low.

Figure 14. Study Site 3: US-59 West of Freer, Texas.

US-67/US-90 East of Marfa

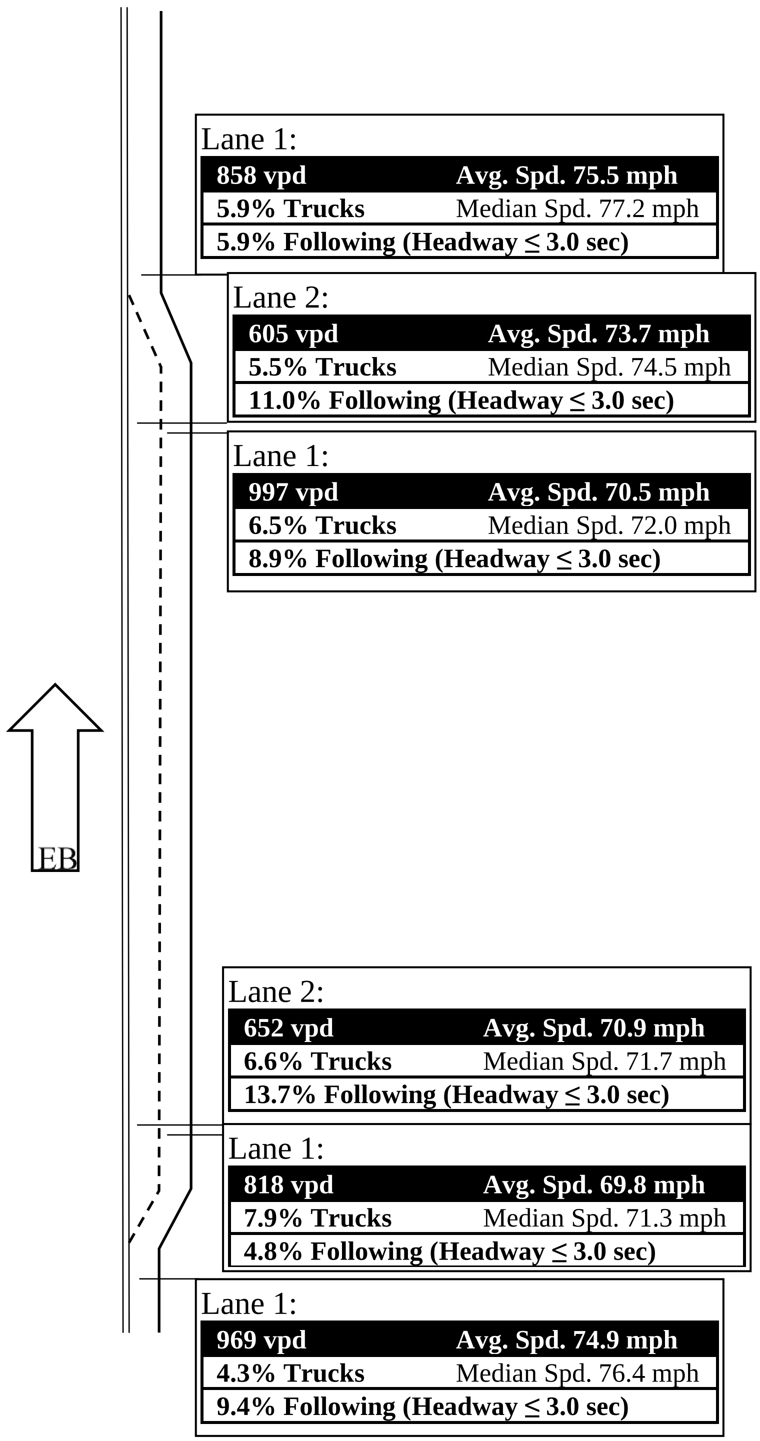
The US-67/US-90 study site is located along a rural portion of US-67/US-90 about 5 miles east of Marfa, between the cities of Marfa and Alpine. The passing lane along this portion of US-67/US-90 is unique (compared to the previously listed study sites on the project) in that the intermittent passing lanes are found in a side-by-side configuration. The passing lane portion selected for study is in northeastern Presidio County and located on eastbound US-67/US-90 (Figure 15). The speed limit through the study portion of US-67/US-90 is 75 mph, and the roadway cross-section features four 12-ft lanes (i.e., a passing lane and a through lane in each direction) and a 3-ft shoulder on each side of the highway.

TxDOT TP&P reports a 2017 ADT count of 2,817 vpd, with 89 percent autos and light trucks and 11 percent heavy vehicles. Researchers' traffic count from May 2019 is roughly equivalent to the TxDOT ADT value, with an eastbound (directional) volume of around 1,500 vpd (Figure 16). The May 2019 traffic count also showed a lower proportion of heavy vehicles than the 2017 TxDOT ADT data, with traffic classification revealing 5 to 8 percent heavy vehicles depending on traffic counter location.



Source: Google® Maps

Figure 15. US-67/US-90 Study Site Location Map.



Direction of travel: Eastbound

Data collection date: 5/21-22/2019

Note: Count at first and last stations appears low.

Figure 16. Study Site 4: US-67/US-90 East of Marfa, Texas.

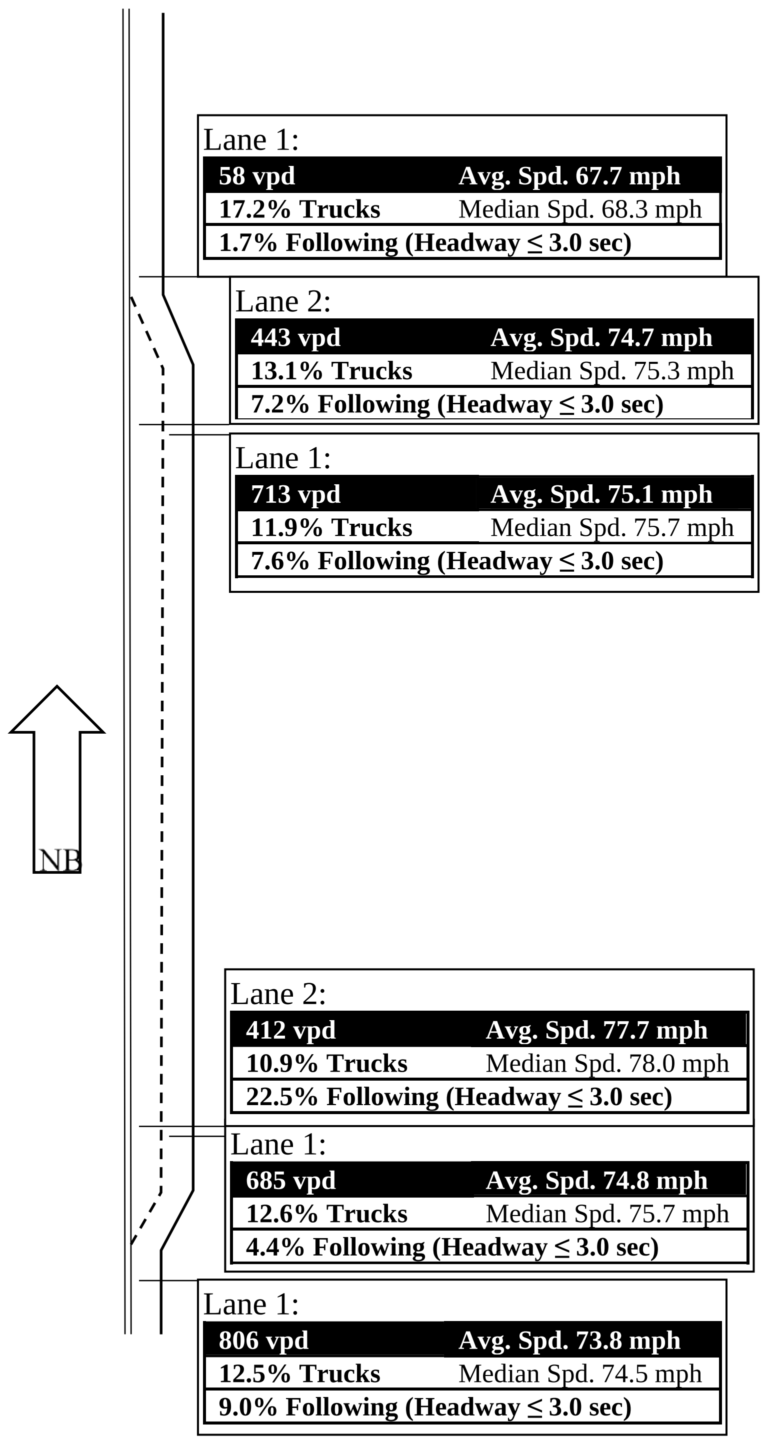
US-67 East of Alpine

The US-67 research study site is located along a rural portion of US-67 about 1.1 miles north of US-90 and roughly 9 miles east of the city of Alpine. The passing lane selected for study is the northbound US-67 passing lane section, which is in northern Brewster County (Figure 17). Like the US-67/US-90 site, passing lanes are intermittent along the highway and configured in a side-by-side fashion. The speed limit through the study portion of US-67 is 75 mph, and the roadway cross-section features four 12-ft lanes (i.e., a passing lane and a through lane in each direction) and a 3-ft shoulder on each side of the highway.

TxDOT TP&P reports a 2017 ADT count of 1,547 vpd, with 85 percent autos and light trucks and 15 percent heavy vehicles. Researchers' traffic count from May 2019 is higher than the TxDOT ADT value, with a northbound (directional) volume alone of around 1,100 vpd (Figure 18). The May 2019 traffic count did show a similar proportion of heavy vehicles compared with the 2017 TxDOT TP&P data, with 12 to 17 percent heavy vehicles depending on traffic counter location.

Source: Google® Maps

Figure 17. US-67 Study Site Location Map.



Direction of travel: Northbound

Data collection date: 5/21-22/2019

Note: Counter error appears to have caused low count at fourth (final) station.

Figure 18. Study Site 5: US-67 North of Alpine, Texas.

CHAPTER 4: CAPACITY AND OPERATIONAL ANALYSES

In Task 4, the research team focused on analyzing the operational characteristics of Super 2 corridors, particularly capacity and PTSF. In addition, researchers also needed to analyze selected two-lane and four-lane cross-sections for comparison to Super 2. The field data collected in Task 3 provided a basis for these analyses, with operational data from real-world Super 2 corridors being used to calibrate simulation models. The simulation models were used to determine the effects of key geometric variables on rural highway operations. This chapter documents the efforts of the research team in the development of microsimulation models to analyze operations on Super 2 corridors and selected comparison cross-sections, as well as a summary and discussion of the results from those models.

DEVELOPMENT OF MODEL AND SCENARIOS FOR ANALYSIS

The capacity analysis of rural highways required an assessment of operations for the simulation corridor via microsimulation. The model used for that microsimulation needed to have the capability to:

- Accurately replicate car-following behavior and lane-changing maneuvers.
- Track individual vehicles as they travel through the system.
- Account for the physical characteristics and performance parameters of the vehicle fleet using rural two-lane Texas roadways.
- Determine various measures of effectiveness (MOEs) (i.e., PTSF, average speed, travel time, headway, number and location of passing maneuvers for various passing lane lengths, and conflict potential in passing lanes).

The research team investigated multiple options of available microsimulation models and determined that VISSIM 2020 (*102*) is the most equipped simulation software for performing the operational analysis of the simulation corridor. VISSIM 2020 offers many calibration parameters including speed profiles, reduced speeds, adjustments to vehicle dimensions, yielding rules, and many variables for adjusting driving behavior. In addition, VISSIM 2020 offers the ability to set a distribution of lane-change distances, which is a crucial parameter for merging behavior observed in Super 2 passing lane segments. Finally, VISSIM is currently the only simulation software that offers the ability to model passing in the opposite direction as seen on rural two-lane facilities.

This section describes the development of the simulation corridor, the selection of scenarios, the methodology for generating input data into the model, and the configuration and calibration of the model to collect data representative of a real-world Super 2 corridor.

Development of Simulation Corridor

In considering how to use the model most efficiently, researchers decided to design a generic rural highway corridor for the simulation-based capacity and performance analyses. A generic simulation corridor allowed researchers to incorporate passing lanes of consistent, predefined lengths and to place access points at key locations along the simulated corridor such that those driveways and intersections contribute to consistent conditions across the analyzed cross-section designs. The generic simulation corridor (oriented as a north-south corridor) was designed to accommodate the desired cross-section configurations selected for study, which governed the required length of the corridor. The geometric variables of interest for this simulation analysis were as follows:

- Cross-section:
  - Two-lane undivided (2U).
  - Two-lane undivided with left-turn lanes at highway intersections (2U+LT).
  - Four-lane undivided (4U).
  - Four-lane divided (4D)
  - Super 2 (2S).
- Number of passing lanes per direction on the simulation corridor for the Super 2 cross-section:
  - Three passing lanes.
  - Six passing lanes.
- Length of passing lanes within the Super 2 cross-section:
  - 2 miles.
  - 3 miles.

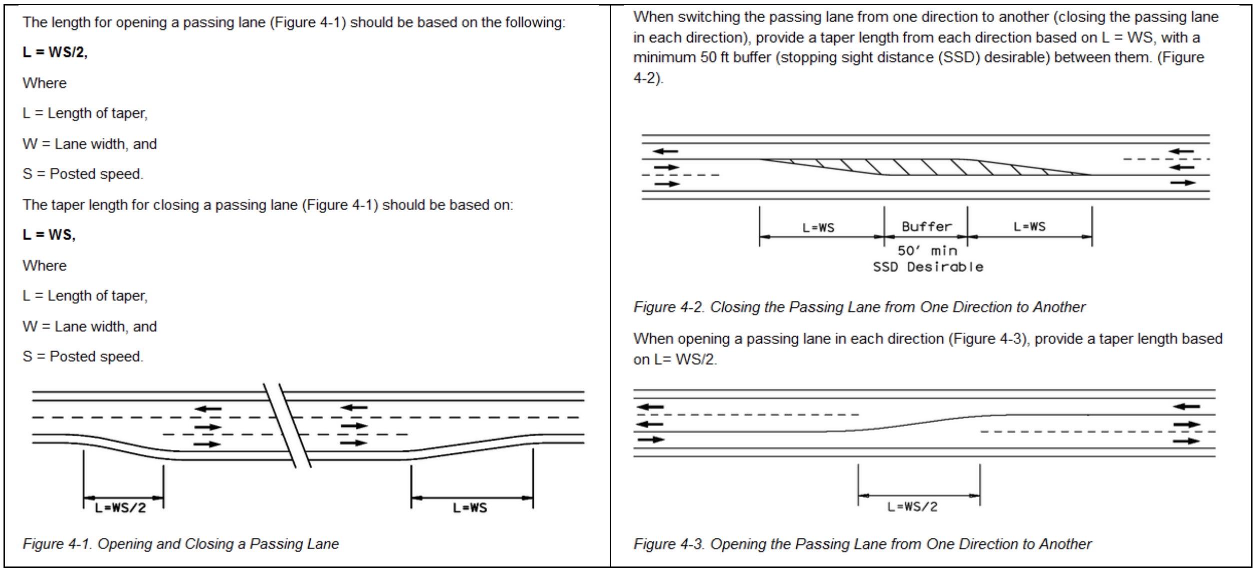
The passing lane parameters apply only to the 2S design but govern the length of the entire corridor in the simulation because that length must remain constant for all cross-sections to produce a thorough analysis. The maximum length of the simulation corridor is determined by the 2S configuration with six passing lanes per direction of 3 miles each. Table 14 lists the eight cross-sections used in the evaluations.

Table 14. Test Bed Corridors (Cross-Sections) Included in the Simulation.

Abbreviation	Cross-Section	Passing Lane Length	Number of Passing Lanes in Each Direction
2U	2-lane undivided	None	None
2U+LT	2-lane undivided with left-turn lanes at highway intersections	None	None
4U	4-lane undivided	None	None
4D	4-lane divided	None	None
2S-23	Super 2	2 miles	3 passing lanes
2S-33	Super 2	3 miles	3 passing lanes
2S-26	Super 2	2 miles	6 passing lanes
2S-36	Super 2	3 miles	6 passing lanes

Note: Super 2 and 4-lane cross-sections did not include left-turn lanes at highway intersections.

The team decided that the passing lane lengths should not include the passing lane transition tapers or the buffers between passing lane transitions of opposite directions. Using equations from the TxDOT *Roadway Design Manual* (*2*) for a posted speed limit of 70 mph and a lane width of 12 ft, the research team calculated the required taper lengths for opening and closing a passing lane (420 and 840 ft, respectively). Figure 19 shows those equations and accompanying graphics from the *Roadway Design Manual*. Researchers used a length of 0.04 mile (211 ft) for the buffer dimension displayed in Figure 19.



The length for opening a passing lane (Figure 4-1) should be based on the following:

L = WS/2,

Where

L = Length of taper,

W = Lane width, and

S = Posted speed.

The taper length for closing a passing lane (Figure 4-1) should be based on:

L = WS,

Where

L = Length of taper,

W = Lane width, and

S = Posted speed.

Figure 4-1. Opening and Closing a Passing Lane

When switching the passing lane from one direction to another (closing the passing lane in each direction), provide a taper length from each direction based on L = WS, with a minimum 50 ft buffer (stopping sight distance (SSD) desirable) between them. (Figure 4-2).

Figure 4-2. Closing the Passing Lane from One Direction to Another

When opening a passing lane in each direction (Figure 4-3), provide a taper length based on L= WS/2.

Figure 4-3. Opening the Passing Lane from One Direction to Another

Figure 19. Roadway Design Manual Equations for Passing Lane Tapers and Buffers (*2*).

In addition to the transition taper lengths, the research team included 1 mile before the first passing lane in each direction on the simulation corridor to allow the randomly generated vehicles to form platoons. Thus, for the scenario of a Super 2 corridor with 3-mile passing lanes and six passing lanes in each direction (2S-36), the first passing lane began at milepoint 1.00 of the virtual corridor; Table 15 and Figure 20 summarize key features associated with the first pair of passing lanes.

Table 15. Key Features for the First Pair of Passing Lanes in the 2S-36 Simulation Corridor.

Feature	Direction of Travel	Begin Milepoint	End Milepoint
Lane addition taper	SB	0.96	1.00
Passing lane	SB	1.00	4.00
Lane reduction taper	SB	4.00	4.16
Buffer between opposing passing lanes	NB	4.12	4.16
Buffer between opposing passing lanes	SB	4.16	4.20
Lane reduction taper	NB	4.28	4.32
Passing lane	NB	4.32	7.32
Lane addition taper	NB	7.32	7.40

Note: NB = northbound, SB = southbound.

Mile Point	Distance in ft	SB	NB
0.00	0		
0.50	2640		
0.92	4858	Taper	
0.96	5069	Taper	
1.00	5280	PL	
1.04	5491	PL	
3.92	20698	PL	
3.96	20909	PL	
4.00	21120	Taper	
4.04	21331	Taper	
4.08	21542	Taper	
4.12	21754	Taper	Buffer
4.16	21965	Buffer	Taper
4.20	22176		Taper
4.24	22387		Taper
4.28	22598		Taper
4.32	22810		PL
4.36	23021		PL
7.24	38227		PL
7.28	38438		PL
7.32	38650		Taper
7.36	38861		Taper
7.40	39072		
7.44	39283		

Figure 20. Diagram of Key Features for the First Pair of 2S-36 Passing Lanes.

The second pair of passing lanes in the 2S-36 corridor began with the southbound lane addition taper at milepoint 7.80, with lengths of the passing lane features identical to those in Table 15. The southbound lane addition tapers of subsequent passing lane pairs began at milepoints 14.20, 20.60, 27.00, and 33.40. The end of the final northbound lane addition taper was at milepoint 39.88, resulting in a corridor length of 40 miles.

Seven access points (intersections and driveways) were also placed along the simulation corridor. Minor driveways were inserted at milepoints 2.00, 14.20, and 23.80; three-leg intersections were inserted at milepoints 18.00 and 31.52; and four-leg intersections were inserted at milepoints 7.56 and 29.00. Driveways represented access points for a residential or agricultural land use that generates few vehicles daily and very low truck percentages. Highway intersections represented junctions with other roadways that were considered minor roads compared to the base simulation corridor, but these roadways had higher volumes than the driveways. With the S2-36 scenario as a baseline, the other Super 2 scenarios were then populated with passing lanes in similar locations, but those passing lanes were shorter in length and/or there were fewer passing lanes. The placement of passing lanes in the other Super 2 scenarios focused on locations such that the major road had a consistent cross-section at the location of the intersections in all comparison cross-sections; this practice had the added benefit that, for a given intersection, the passing lane in question typically started at the same milepoint and/or had the buffer between passing lanes at the same milepoint for at least two scenarios.

Scenarios

The capacity analysis involved running scenarios combining test bed corridors, truck percentage, and ADT in a full factorial analysis. There were eight test bed corridors (2U, 2U+LT, 4U, 4D, 2S-23, 2S-26, 2S-33, and 2S-36), three truck percentages (20, 30, and 40), and nine different ADT levels (ranging from 3,000 vpd to 19,000 vpd in increments of 2,000 vpd). This resulted in 216 unique scenarios considered in this analysis.

Generation of Microsimulation Input Data

The corridor used for the capacity analysis is a hypothetical facility, but the model inputs and the design elements of the corridor are consistent with data and designs found in rural highways across Texas. This section describes the development of the speed and volume distributions used in the VISSIM model. The speed and volume distributions were based on field data collected in Task 3.

Speed Distribution Development

VISSIM uses a distribution to represent the range of speeds traveled by users on the simulation corridor. The desired speed distribution represents the range of speeds that simulated vehicles prefer to travel. This value does not exactly equal the speeds directly recorded by the tube counters in Task 3 since the counter records the speeds of all vehicles crossing the point of measurement. The research team used the axle count to distinguish between passenger cars and trucks; two axles represented a passenger car, and three or more axles represented a truck. The team next considered the headway between the vehicles to exclude vehicles that are driving at speeds lower than their desired speeds. The team used a three-second headway threshold to determine if a vehicle was following another vehicle and assumed that following vehicles are not traveling at their desired speed. Therefore, all speeds for vehicles within a 3-second headway were excluded from the desired speed distribution. The research team used the remaining vehicle speed data to determine the cumulative percentage of recorded vehicle speeds for passenger cars and trucks for the facilities with a speed limit of 75 mph. The resulting distribution of measured speeds served as the speed distributions for passenger cars and trucks in the simulation prior to calibrating the network. Figure 21 shows the resulting speed distributions.

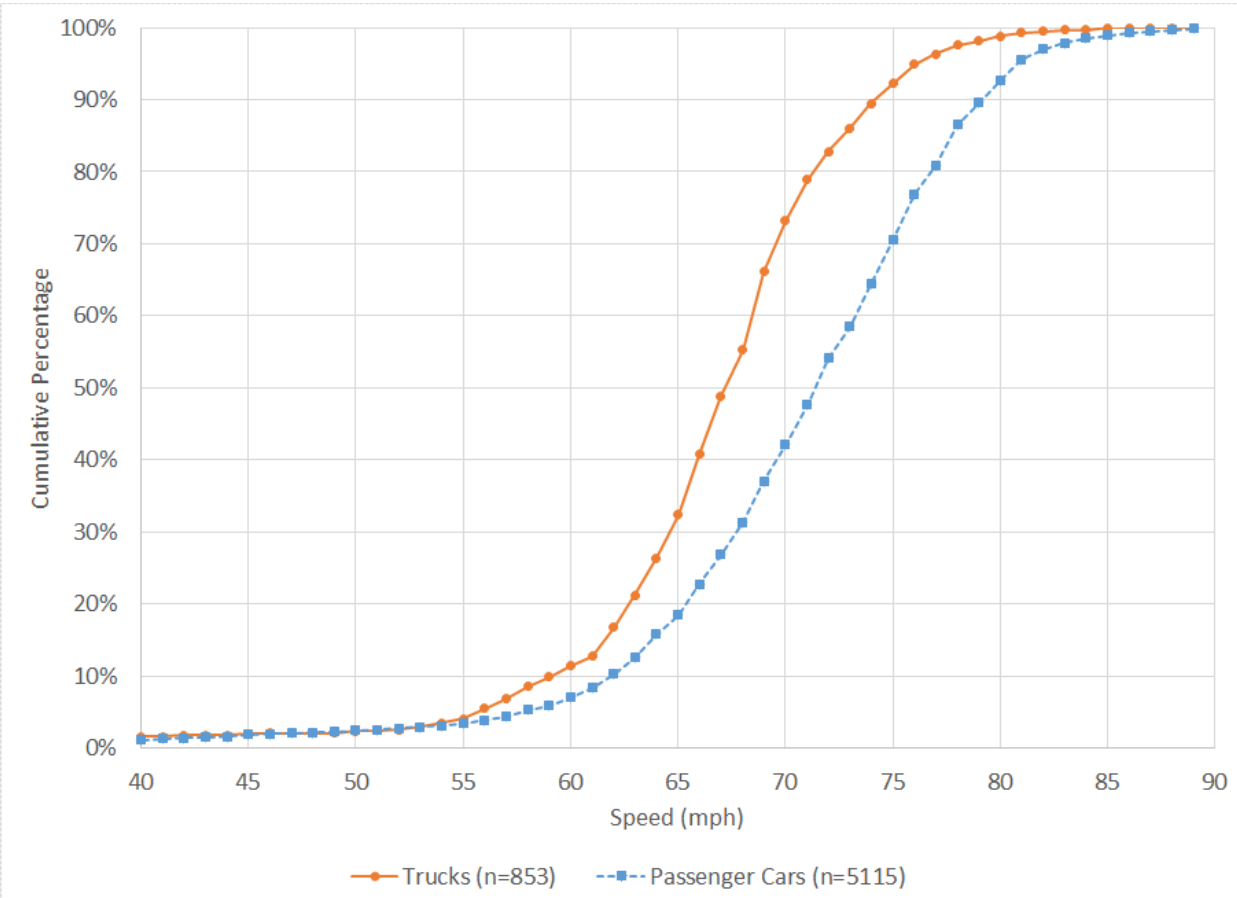


Figure 21. Initial Speed Distributions Based on Field Data.

The data confirm that the truck speeds are different from the passenger car speeds, where the passenger cars are more likely to travel at higher speeds than the trucks. The calibration process involved changing the speed distribution for the passenger cars to meet the calibration targets of certain speeds and lane usage within the passing lanes; that process is described in more detail in a subsequent section of this chapter.

Volume Distribution Development

The simulation required the number of vehicles entering the access points to the simulation corridor to be represented on a vehicle-per-hour basis. The team determined that volumes should represent the trends in volumes throughout the day for the facilities. These trends determine which percentage of the ADT for the scenario is generated within the simulation for each scenario. The team used the volume data collected from the US-183, US-59, and US-67 study sites in Task 3 to generate a generic volume distribution. The team normalized the ADT from these sites to aid the comparison of daily traffic patterns independent of the amount of traffic on the corridor. Figure 22 shows the volume trends for the three study sites and a plot of the average percentage of traffic from the three sites.

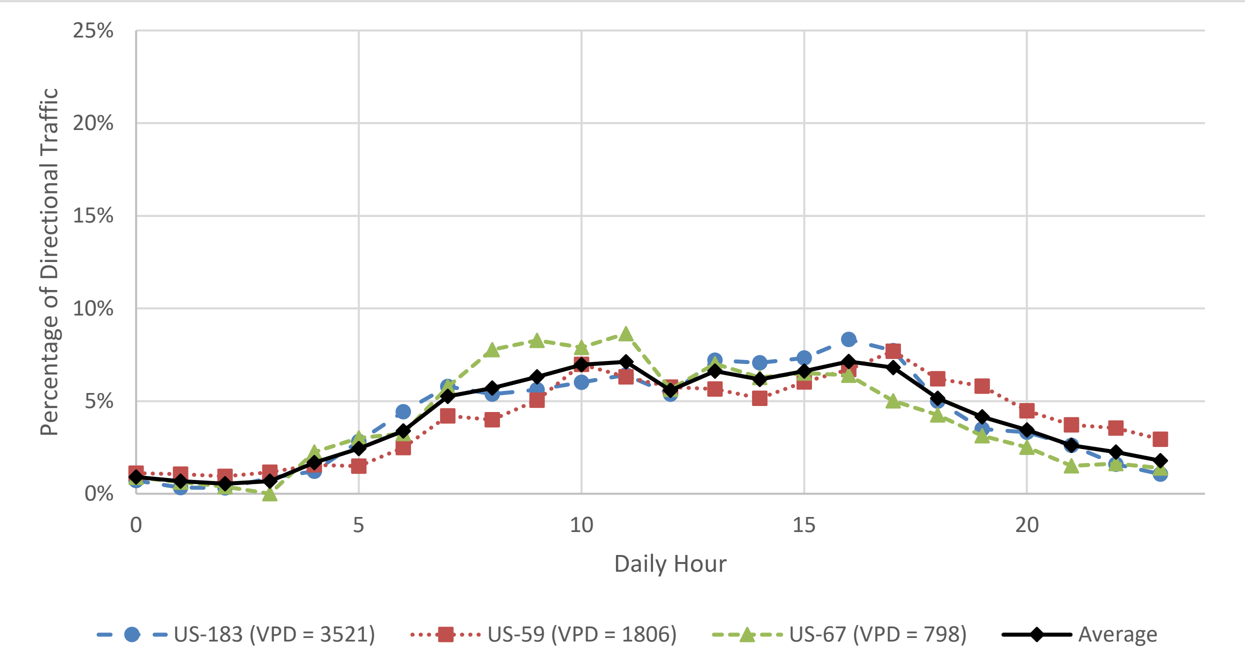


Figure 22. Percentage of Daily Traffic as a Percentage of Directional Volume by Site.

The traffic patterns for US-183, US-59, and US-67 followed expected patterns of a rural two-lane highway where there was low traffic in the late evening and early morning and a steady volume during the daylight hours. No hour of the day had a demand of greater than 10 percent of the daily traffic for any site, which is also indicative of a rural highway. The simulation used the average percentage of directional traffic for each hour to determine the number of vehicles to generate at each entry into the network.

Table 16 shows the volumes for each entry point to the simulation. The research team discussed appropriate values for representative volumes to driveways and intersections that provide access to and from Super 2 corridors, and available traffic count data suggested that 25 vehicles per day was a reasonable estimate for the range of volumes that might be found at a typical driveway. Similarly, available traffic data showed a range of volumes for minor roads at intersections; the research team observed in their review of the traffic data that many four-leg intersections carried routes on the state highway system (and, therefore, higher volumes) compared to the three-leg intersections that were often county roads or lower-volume FM roads. As a result, researchers decided to use a higher volume for the minor-road approaches to the four-leg intersections than at the three-leg intersections.

Table 16. Daily Volume Inputs for Access Points into the Simulation Corridor.

Access Point	Volume (Vehicles per Day)
Southbound entry to simulation corridor	Half of the ADT of the scenario (1,500, 2,500, 3,500, etc.)
Northbound entry to simulation corridor	Half of the ADT of the scenario (1,500, 2,500, 3,500, etc.)
Intersection 1: Driveway	25
Intersection 2: Four-leg highway intersection	500 per leg
Intersection 3: Driveway	25
Intersection 4: Three-leg highway intersection	250
Intersection 5: Driveway	25
Intersection 6: Four-leg highway intersection	500 per leg
Intersection 7: Three-leg highway intersection	250

Another key piece of information related to vehicle generation is routing. The research team designed the routing for the simulated corridor such that the volumes across different segments of the corridor remain close to equal. To do this, routing percentages coded into the simulation were calculated to ensure that the number of vehicles turning onto each leg equaled the number of vehicles that turned off each leg throughout the duration of the simulation. The team also made the following assumptions relating to routing within the VISSIM network:

- All intersection roadways and the simulation corridor have a 50/50 directional distribution.
- Driveways and three-leg highway intersections have 50/50 left/right-turning movements.
- Four-leg highway intersections have 40/20/40 left-turning/through/right-turning movements.
- Driveways and intersection roadways do not increase in volume as the ADT of the simulation corridor increases (i.e., intersections and driveways have fixed volumes, regardless of the ADT of the corridor).

- All vehicles turning out of driveways travel the entire remaining length of the corridor.
- Vehicles entering the network from highway intersections travel to other highway intersections along the simulation corridor.
- Routing maintains a constant percentage throughout the day.
- All the vehicles turning into the driveway intersections along the simulation corridor come from the southbound and northbound entry locations for the major roadway.
- All increased volumes on the simulation corridor go through the entire corridor, meaning that the same number of vehicles turn at each intersection at all ADT levels simulated.

The volume distribution development produced an origin-destination matrix for each scenario. This matrix summarized travel between access points on the simulation corridor. Table 17 shows an example of the origin-destination matrix for an ADT of 3,000 vpd. For comparison with other ADT levels, with increased ADT the extra traffic entering from the southbound and northbound entries travels the entire corridor to the northbound and southbound exits, respectively. Thus, the volumes on the driveways and the minor roads at intersections remain constant regardless of the ADT on the corridor. Consideration of all potential origins and destinations helps to identify how cross-sections will perform relative to others for different conditions.

Table 17. Origin-Destination Matrix for 3,000 ADT on Simulation Corridor.

Origin	Destination	Volume	Percentage of Volume at Origin
1-Driveway	North exit	12.5	50%
1-Driveway	South exit	12.5	50%
2-East leg	2-West leg	100	20%
2-East leg	North exit	200	40%
2-East leg	4-Intersection	50	10%
2-East leg	6-East leg	25	5%
2-East leg	6-West leg	25	5%
2-East leg	7-Intersection	50	10%
2-East leg	South exit	50	10%
2-West leg	2-East leg	100	20%
2-West leg	4-Intersection	50	10%
2-West leg	6-East leg	25	5%
2-West leg	6-West leg	25	5%
2-West leg	7-Intersection	50	10%
2-West leg	South exit	50	10%
2-West leg	North exit	200	40%
3-Driveway	North exit	12.5	50%
3-Driveway	South exit	12.5	50%
4-Intersection	2-West leg	25	10%
4-Intersection	2-East leg	25	10%
4-Intersection	North exit	75	30%
4-Intersection	6-East leg	25	10%
4-Intersection	6-West leg	25	10%
4-Intersection	7-Intersection	25	10%
4-Intersection	South exit	50	20%
5-Driveway	North exit	12.5	50%
5-Driveway	South exit	12.5	50%
6-East leg	6-West leg	100	20%
6-East leg	4-Intersection	50	10%
6-East leg	2-West leg	50	10%
6-East leg	2-East leg	50	10%
6-East leg	North exit	50	10%
6-East leg	7-Intersection	100	20%
6-East leg	South exit	100	20%

Table 17. Origin-Destination Matrix for 3,000 ADT on Simulation Corridor (Continued).

Origin	Destination	Volume	Percentage of Volume at Origin
6-West leg	6-East leg	100	20%
6-West leg	7-Intersection	25	5%
6-West leg	South exit	175	35%
6-West leg	4-Intersection	50	10%
6-West leg	2-West leg	25	5%
6-West leg	2-East leg	25	5%
6-West leg	North exit	100	20%
7-Intersection	South exit	125	50%
7-Intersection	6-East leg	20	8%
7-Intersection	6-West leg	20	8%
7-Intersection	4-Intersection	20	8%
7-Intersection	2-West leg	20	8%
7-Intersection	2-East leg	20	8%
7-Intersection	North exit	25	10%
South entry	1-Driveway	12.5	0.83%
South entry	2-East leg	140	9.3%
South entry	2-West leg	140	9.3%
South entry	3-Driveway	12.5	0.83%
South entry	4-Intersection	15	1.0%
South entry	5-Driveway	12.5	0.83%
South entry	6-East leg	127.5	8.5%
South entry	6-West leg	177.5	12%
South entry	7-Intersection	25	1.7%
South entry	South exit	837.5	56%
North entry	1-Driveway	12.5	0.83%
North entry	2-East leg	140	9.3%
North entry	2-West leg	140	9.3%
North entry	3-Driveway	12.5	0.83%
North entry	4-Intersection	15	1.0%
North entry	5-Driveway	12.5	0.83%
North entry	6-East leg	127.5	8.5%
North entry	6-West leg	177.5	12%
North entry	7-Intersection	25	1.7%
North entry	North exit	837.5	56%

Data Collection Configuration

The research team included many different data collection measurements in the VISSIM simulation to reduce the need of rerunning the simulation to collect additional data that were not originally included. The discussion in this chapter does not include summaries of all the data collected from the simulation but does include the relevant data and plots that support the conclusions drawn from the capacity analysis through the simulation analysis. All data collection within the simulation was based on one-hour intervals across the entire 24-hour duration of the simulations after the warm-up period. The measurements were also divided between vehicle types so that passenger car measurements could be considered apart from trucks as necessary. The following data collection measurements were included for the analysis:

- Measurements of all vehicles in the network (e.g., delay, speed, stops, travel time, and volume).
- Measurements of travel time and delay along segments of the corridor.
- Intersection node evaluations (e.g., delay, stops, volume, and queue lengths).
- Link segment data (e.g., lane usage, speeds, and volume).
- Vehicle record data to enable calculation of the PTSF.

Calibration of VISSIM Model

All microsimulation models require calibration to represent the corridor under evaluation. The research team used US-183 data and understanding of vehicle driving behavior to act as the calibration targets for the simulation. The model creator coded the following items into the simulation to ensure accurate representation of the vehicle behavior within the simulation:

- Changes in desired speed between the intersections and the simulation corridor.
- Reduced-speed areas at all turning movements with lower speeds for trucks than passenger cars.
- Conflict area decisions for gap acceptance.
- Priority rules for yield behavior at stop-controlled intersections.
- Lane-change distributions to simulate how some users change lanes earlier than others at the lane drop in the passing lane segments.
- Enabled passing in the opposite direction for two-lane segments of the corridor with no nearby intersections. The assumed speed of vehicles in the opposite direction for passing maneuvers was set to 75 mph, the look-ahead distance was 2,200 ft, and the overtaking speed factor was 1.3.

The research team selected the Wiedemann 99 driving behavior model for this analysis, due to overall high speeds along the corridor. VISSIM defaults to the Wiedemann 74 model, a model designed by the simulation creators, which is intended to model vehicles traveling at low speeds. The Wiedemann 99 model was developed later to provide a more accurate representation of vehicles traveling at high speeds. The research team experimented with changing the car-following parameters within the car-following behavior but did not find that this substantially affected the lane usage or recorded speeds within the simulation. The research team did edit the lane-change parameters within the model from their default values as part of the calibration process so that vehicles would have lane usage in passing lanes more consistent with observations in the field. Table 18 shows the lane-change parameters used for the simulation corridor.

Table 18. Lane-Change Parameters Used in Simulation Corridor.

Lane-Change Parameter	Default Value	Calibrated Value
Maximum deceleration of lane-changing vehicle (ft/s^2)	−13.12	−13.6
Maximum deceleration of trailing vehicle (ft/s^2)	−9.84	−9.84
Accepted deceleration of lane-changing vehicle (ft/s^2)	−3.28	−3.28
Accepted deceleration of trailing vehicle (ft/s^2)	−1.64	−1.64
Safety distance reduction factor	0.6	0.8
To slower lane if collision time is above (sec)	11	30
Maximum deceleration for cooperative braking (ft/s^2)	−9.84	−13
Cooperative lane change	No	Yes
Cooperative lane change − maximum speed difference (mph)	6.7	10
Cooperative lane change − maximum collision time (sec)	10	10

The research team placed data collection points on each lane 1,000 ft before and after the beginning of a passing lane within the simulation. These data collection points recorded information consistent with the data from tube counters so the data could be compared to field data from the US-183 study site to confirm that the simulation was representative of a real-world highway. The baseline case used for this calibration was the Super 2 cross-section with 2-mile passing lanes and three lanes per direction (2S-23), with 7,000 ADT and 20 percent trucks to approximate the volumes recorded on US-183. The US-183 study site vehicle distribution contained 15 percent trucks, while the baseline corridor used 20 percent trucks. To acquire the lane usage and speeds observed at the US-183 study site, the research team adjusted the desired passenger car speed distribution. This adjustment involved increasing the standard deviation of the measurement from 8 mph to 10 mph while maintaining the mean speed of 71 mph. Figure 23 plots the calibrated speed distribution with the original speed distribution from Figure 21.

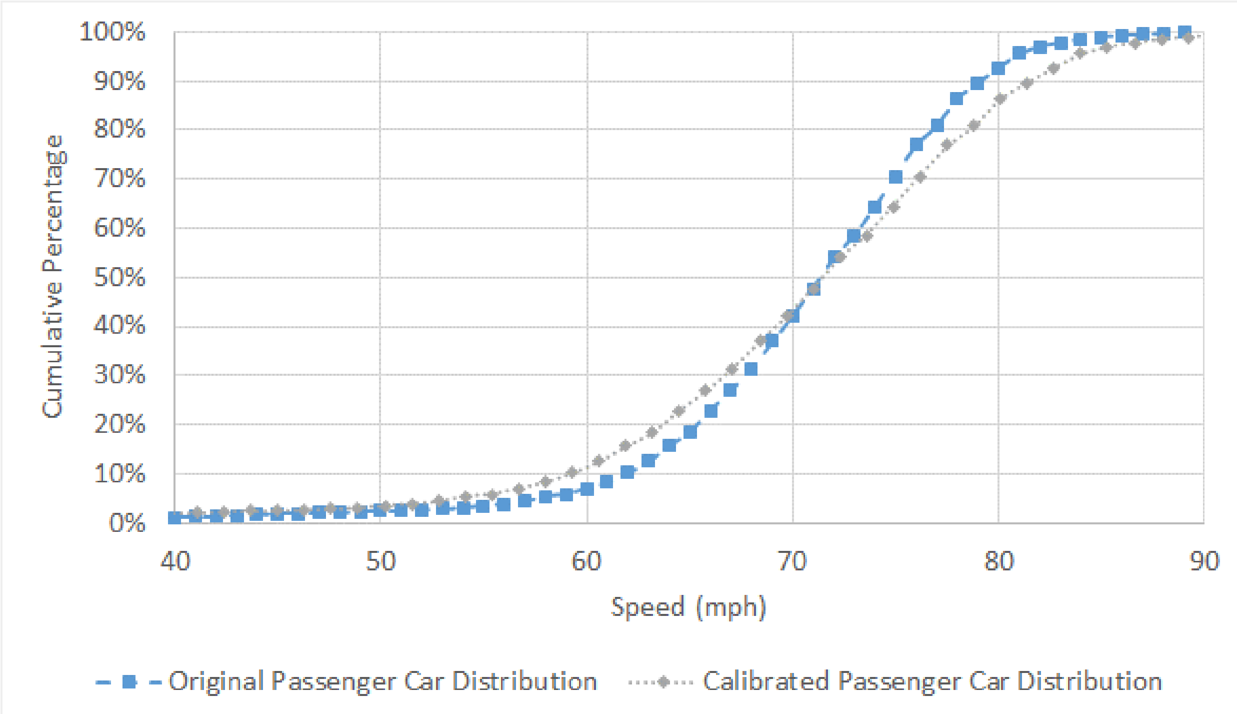


Figure 23. Original and Calibrated Passenger Car Speed Profiles.

To test the calibration, the research team ran five simulation seeds and averaged the results. The team compared the volumes, truck percentage, average speed, and median speeds in each lane within the passing lane and before the passing lane. Table 19 shows the results of calibration for the single lane of travel upstream of a passing lane.

Table 19. Calibration Results from Traffic Upstream of a Passing Lane.

Metric	Field Data (US-183)	Simulation Data	Difference (Sim − Field)	Percent Difference (Sim − Field)/Field
Volume (vpd)	3,521	3,636	115	3.3%
Percent trucks (%)	15.0%	20.2%	5.2%	34.5%
Average speed (mph)	66.7	67.7	1.0	1.5%
Median speed (mph)	67.4	68.9	1.5	2.2%
Percent following (%, headway ≤ 3.0 sec)	31.5%	33.1%	1.6%	5.0%

The truck percentage of the baseline scenario is 20 percent trucks instead of the 15 percent recorded on US-183. Therefore, the approximately 5 percent difference in the truck percentage upstream of the passing lane is expected since the simulation was created with 33.3 percent more trucks than the field data. The difference in trucks per day is on the order of about 175 vehicles, a small proportion of the approximately 3,500 vpd in that direction of travel. All the other metrics for this travel lane differ from the field data by 5 percent or less.

Table 20 and Table 21 present data for adjacent lanes 1,000 ft downstream of the beginning of a passing lane.

Table 20. Calibration Results of the Right Through Lane (Lane 1).

Metric	Field Data (US-183)	Simulation Data	Difference (Sim − Field)	Percent Difference (Sim − Field)/Field
Volume (vpd)	2,339	2,303	−36	−1.5%
Percent trucks (%)	20.1%	27.0%	6.9%	34.3%
Average speed (mph)	68.0	67.7	−0.3	−0.4%
Median speed (mph)	68.4	68.4	0.0	0.1%
Percent following (%, headway ≤ 3.0 sec)	20.0%	17.3%	−2.7%	−13.4%

Table 21. Calibration Results of the Left Passing Lane (Lane 2).

Metric	Field Data (US-183)	Simulation Data	Difference (Sim − Field)	Percent Difference (Sim − Field)/Field
Volume (vpd)	1,498	1,315	−183	−12.2%
Percent trucks (%)	5.8%	7.5%	1.7%	29.1%
Average speed (mph)	72.4	70.4	−2.0	−2.8%
Median speed (mph)	73.1	72.3	−0.8	−1.1%
Percent following (%, headway ≤ 3.0 sec)*	52.5%	57.2%	4.7%	9.0%

Note: The tube counter calculated the percent following for this lane with both lanes’ data. The simulation metric calculation follows the same measurement methodology for the percentage of following vehicles at this station.

The truck percentages in these lanes remained on the order of one-third higher than the field data, as expected. The simulation had fewer vehicles than the field data in both lanes. The research team found the observed differences between the simulation and field data to be acceptable since the errors were within the expected error rates of the tube counters used to collect the data. The speed measurements had little error, with the simulation slightly underestimating the average and median speeds. The percentage of following vehicles remained within acceptable differences to the field data for the research team.

RESULTS FROM CAPACITY ANALYSIS

This section presents the results from the 216 unique scenarios considered in this analysis.

Minimum Hourly Average Speed

The capacity analysis produced a wide range of output variables and MOEs to consider directly and to use in combination to produce additional MOEs. The VISSIM model provides hourly average speed as a direct output, with values including average, minimum, and maximum speeds for each hour. To identify the most congested conditions, researchers reviewed the minimum hourly average speed for each of the 216 scenarios and organized them by truck percentage to provide a basis for comparison. Figure 24 provides the results for the simulations with 20 percent trucks. Not unexpectedly, the 2U cross-section was the poorest performing option for all ADT levels, and speeds declined as volumes increased. Among the four Super 2 cross-sections, the 2S-36 option had the highest minimum speeds, which is also an intuitive result given the increased length and frequency of passing lanes available there. A consistent result among the Super 2 cross-sections for all ADT values was also that the 2S-26 cross-section had higher speeds than the 2S-33 cross-section; this result agrees with previous research that indicates a greater benefit from more passing lanes than from longer passing lanes. Given a choice between lengthening passing lanes or providing more passing lanes, the latter is preferable from an operational standpoint. Another intuitive result was that the 4U and 4D cross-section had the highest minimum speeds across all ADTs up to 13,000 vpd. The 4U cross-section appeared to break down at 19,000 vpd, where all but the 2U and 4D cross-section performed better. This observation supports safety research (*103*, *104*, *105*, *106*) that compared 4U cross-sections to other options, such as Super 2, and/or adding turning lanes at key access points. Findings from those comparisons indicated that 4U cross-sections often had higher crash rates (or lower crash reductions) than the alternative(s) being compared. The inconsistent results of the 4D at 15,000 to 19,000 ADT suggest that an outlier may be affecting the results at these higher volumes; it is reasonable to think that the results for all three of the higher volumes would be similar, but the speed at 17,000 ADT was within 0.3 mph of the speed at 13,000 ADT at about 68 mph, while the speeds at 15,000 and 19,000 ADT were the lowest of all the cross-sections.

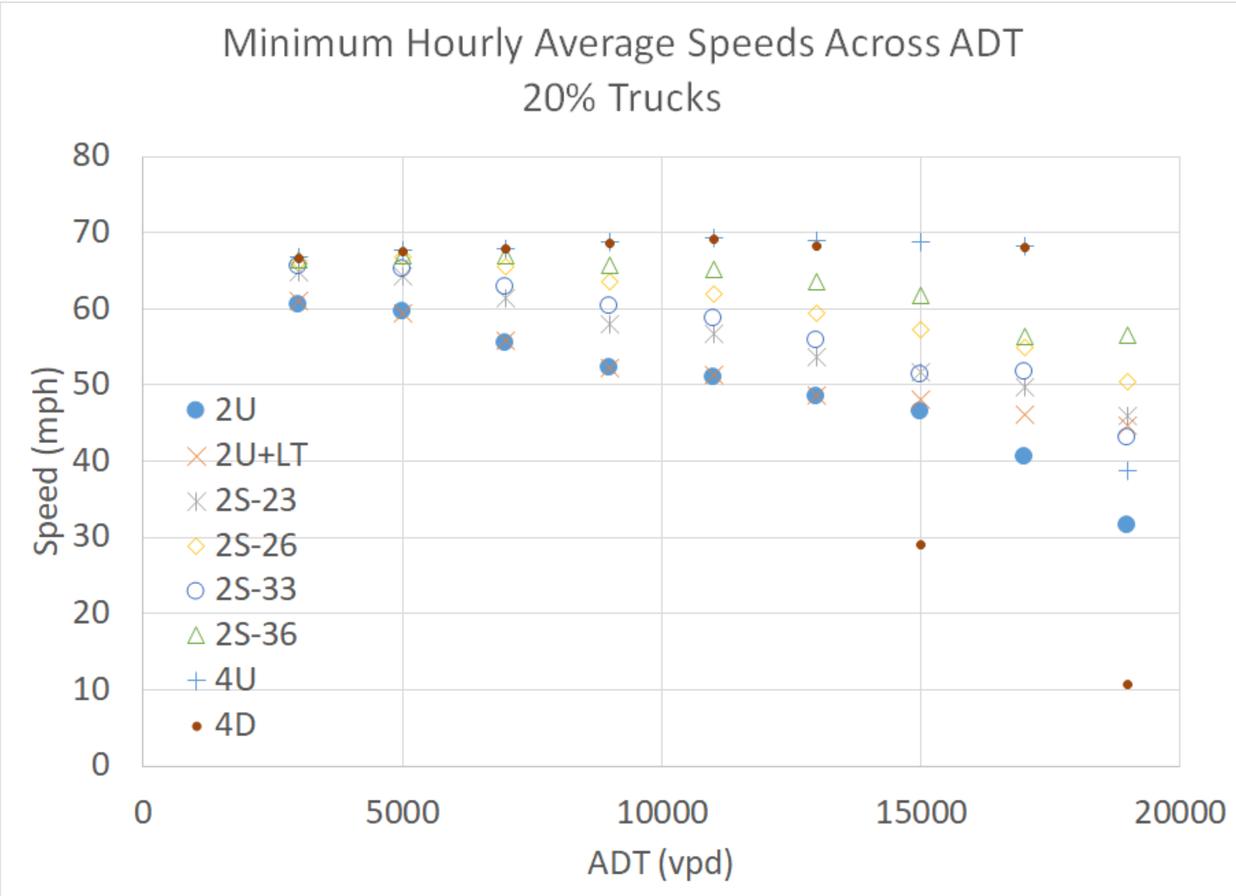


Figure 24. Minimum Hourly Average Speeds across ADT with 20 Percent Trucks.

Figure 24 also indicates that left-turn lanes for conditions with 20 percent trucks did not provide much additional benefit over the 2U cross-section except at the highest volumes. Above 15,000 vpd, however, the performance of the 2U+LT cross-section leveled off, while speeds on the 2U cross-section continued to decline. At the highest ADT level of 19,000, the 2U+LT cross-section outperformed the 4U and 4D alternatives and was better than or equivalent to the Super 2 alternatives with three passing lanes in each direction.

Figure 25 summarizes the minimum average speed results for simulations with 30 percent trucks. Results were similar to those with 20 percent trucks for volumes up to 15,000 vpd. At higher ADT levels, however, the effects of the additional trucks became more pronounced; 2U speeds declined further, to about 17 mph at 19,000 vpd, and 4U and 4D speeds declined even more sharply, even falling below 2U speeds, to about 13 to 14 mph at 19,000 vpd. As with the scenarios for 20 percent trucks, these sharp declines in performance for 4U cross-sections support safety research that encourages the use of other options instead of widening to 4U. The trend for the 4D cross-section was again erratic at the highest volumes, similar to the results with 20 percent trucks.

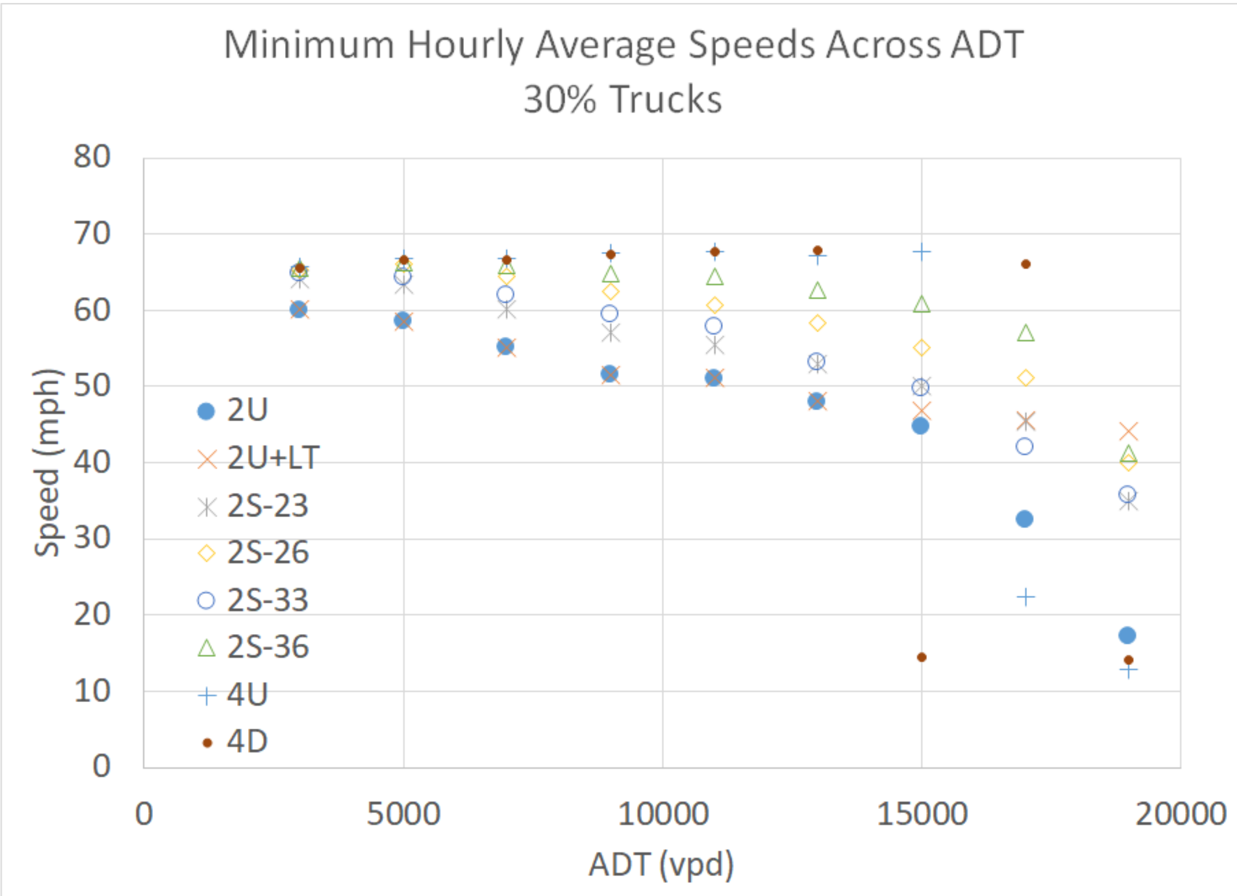


Figure 25. Minimum Hourly Average Speeds across ADT with 30 Percent Trucks.

The comparative trends among Super 2 options remained consistent at 30 percent trucks as with 20 percent, with 2S-36 producing the highest speeds at all volume levels and 2S-26 outperforming 2S-33. As with 20 percent trucks, the 2U+LT option was virtually identical to 2U below 15,000 ADT, but its minimum speed stabilized above that volume, such that it performed better than all other options at 19,000 ADT, with a minimum average speed of about 44 mph. In conjunction with the findings from the 20 percent scenarios, this suggests that the operational effects of turning vehicles may be more pronounced than platooned vehicles in the through lane, and providing accommodation for those turning vehicles outside the through lane, especially at higher volumes, may be a more beneficial alternative if a choice has to be made between passing lanes and turning lanes near an access point.

Figure 26 provides the chart of minimum hourly average speeds for scenarios with 40 percent trucks. The results in Figure 26 follow similar trends to those for 20 percent trucks and 30 percent trucks, though the incremental change in results at 19,000 vpd is even more pronounced with the higher proportion of trucks. As before, the 2U+LT cross-section stabilized at about 44 mph, but all other cross-sections had sharply declining speeds at 17,000 ADT and again at 19,000 ADT. The second-highest speed result at 19,000 ADT, from the 2S-36 option, was approximately 23.5 mph, or 20 mph slower than the 2U+LT option, and the 2U and 4U cross-sections dropped to about 11 mph. Speeds for the 4D cross-section were cut by about 55 mph from 13,000 ADT to 15,000 ADT and then remained at that level through 19,000 ADT, not showing the spike at the 17,000 ADT level that was seen for 20 and 30 percent trucks.

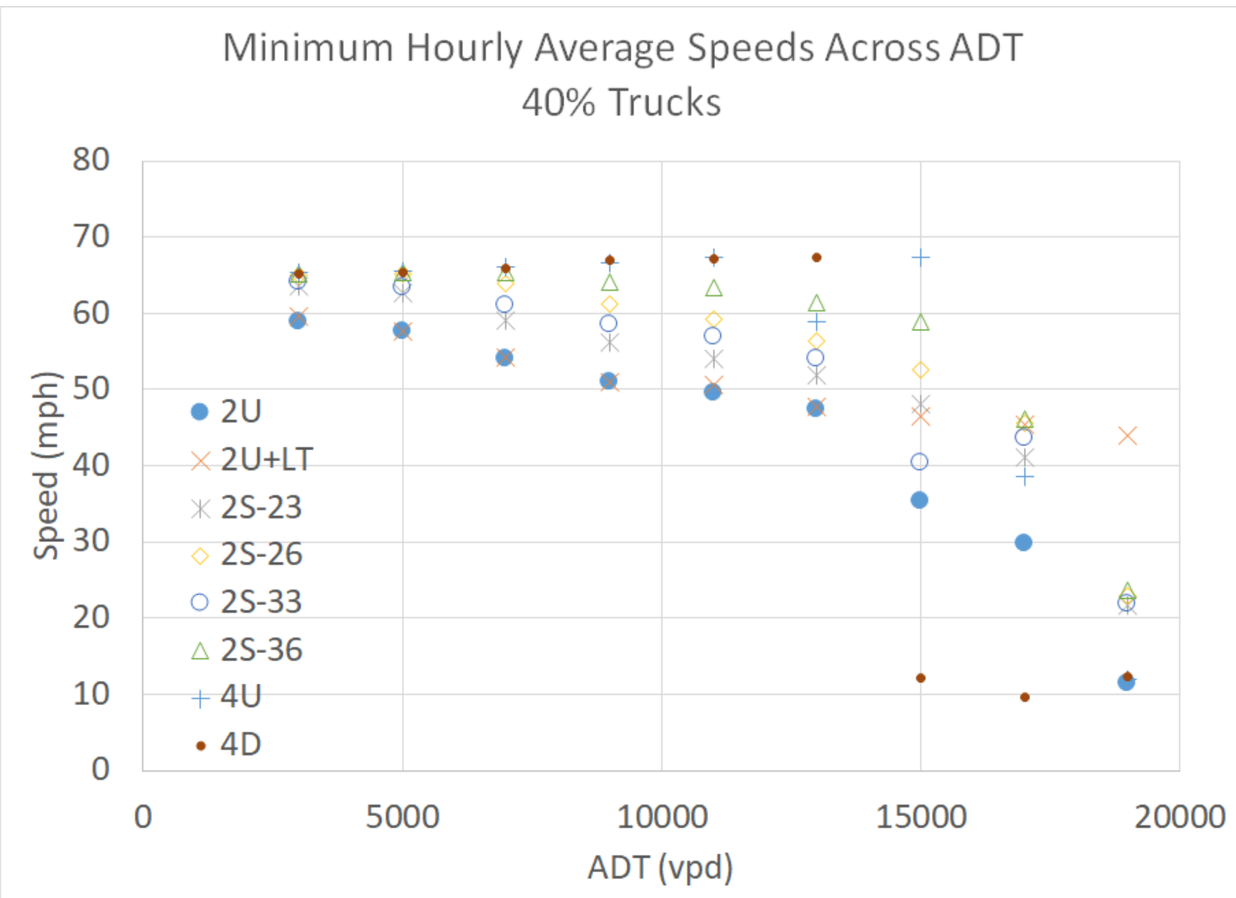


Figure 26. Minimum Hourly Average Speeds across ADT for 40 Percent Trucks.

Network Delay

The VISSIM model also produced a variety of delay measures from the simulation scenarios. The research team focused on total network delay to gain a better appreciation for the interaction among all traffic in the simulation for each set of conditions. Figure 27 shows the total network delay values (in hours of delay per day) for scenarios with 20 percent trucks and illustrates, as with the speed data results, that the 2U cross-section was the option with the poorest performance, as expected. The performance of the other cross-sections had a generally consistent hierarchy, with 2U+LT having the second-highest delay for each ADT level, 2S-36 outperforming the other Super 2 options, 2S-26 outperforming the Super 2 options with three passing lanes in each direction, and 4U producing the lowest delay at every volume. The 4D cross-section was similar to 4U for volumes up to 13,000 ADT but then varied widely at higher volumes.

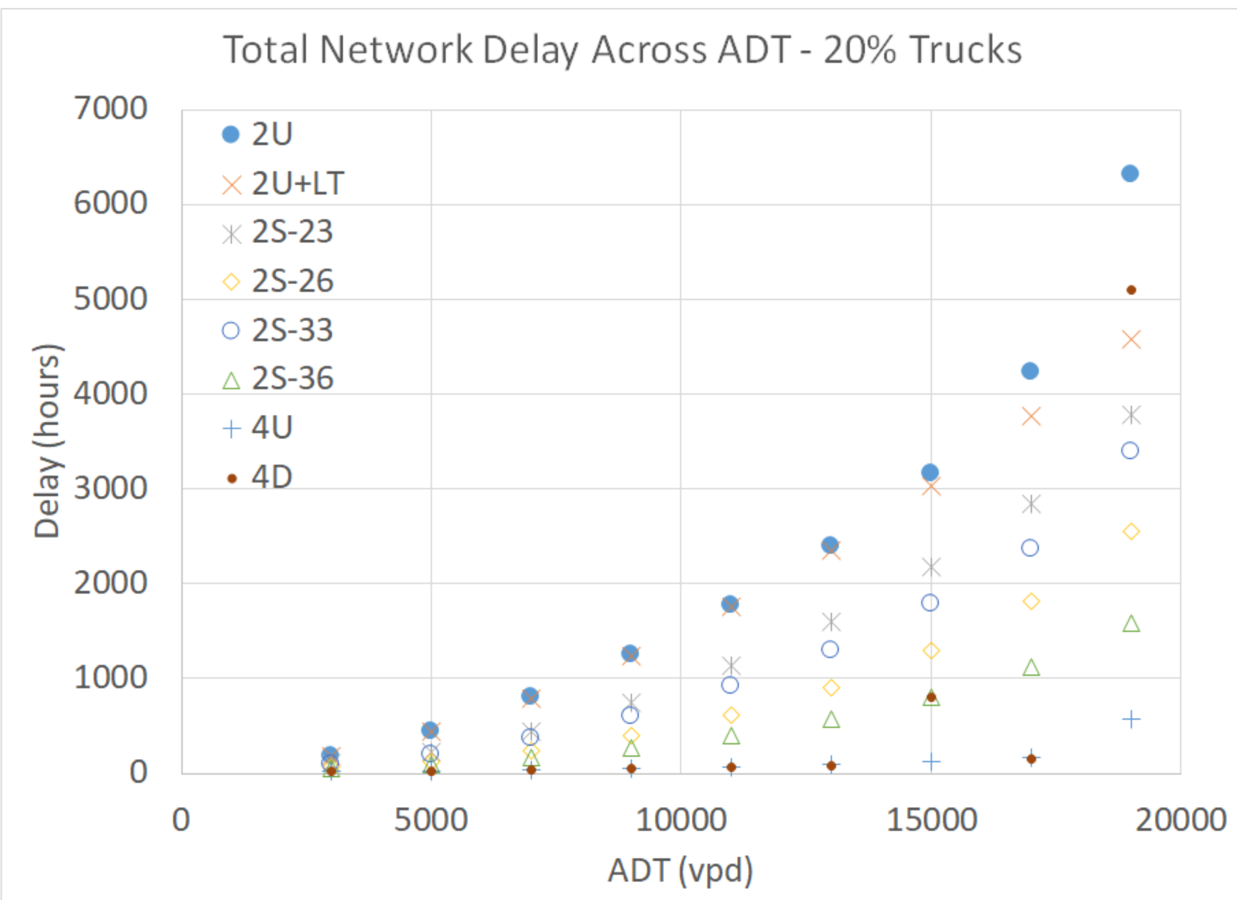


Figure 27. Total Network Delay across ADT with 20 Percent Trucks.

Figure 28 shows total network delay for scenarios with 30 percent trucks, and those results closely resemble the 20 percent scenarios for ADT values less than 17,000 vpd. At 17,000 vpd, the 4U cross-section experienced higher delay than the 2S-36 cross-section, which consistently outperformed all other cross-sections at all volumes. The 4U option further degraded at 19,000 vpd, with a similar result as the 2U+LT option, between 4,500 and 4,700 hours of delay over the course of the simulated day. The 4D options performed well up to 13,000 ADT and then became erratic at higher volumes. The Super 2 options with three passing lanes per direction also underperformed the 2U+LT option at 19,000 vpd.

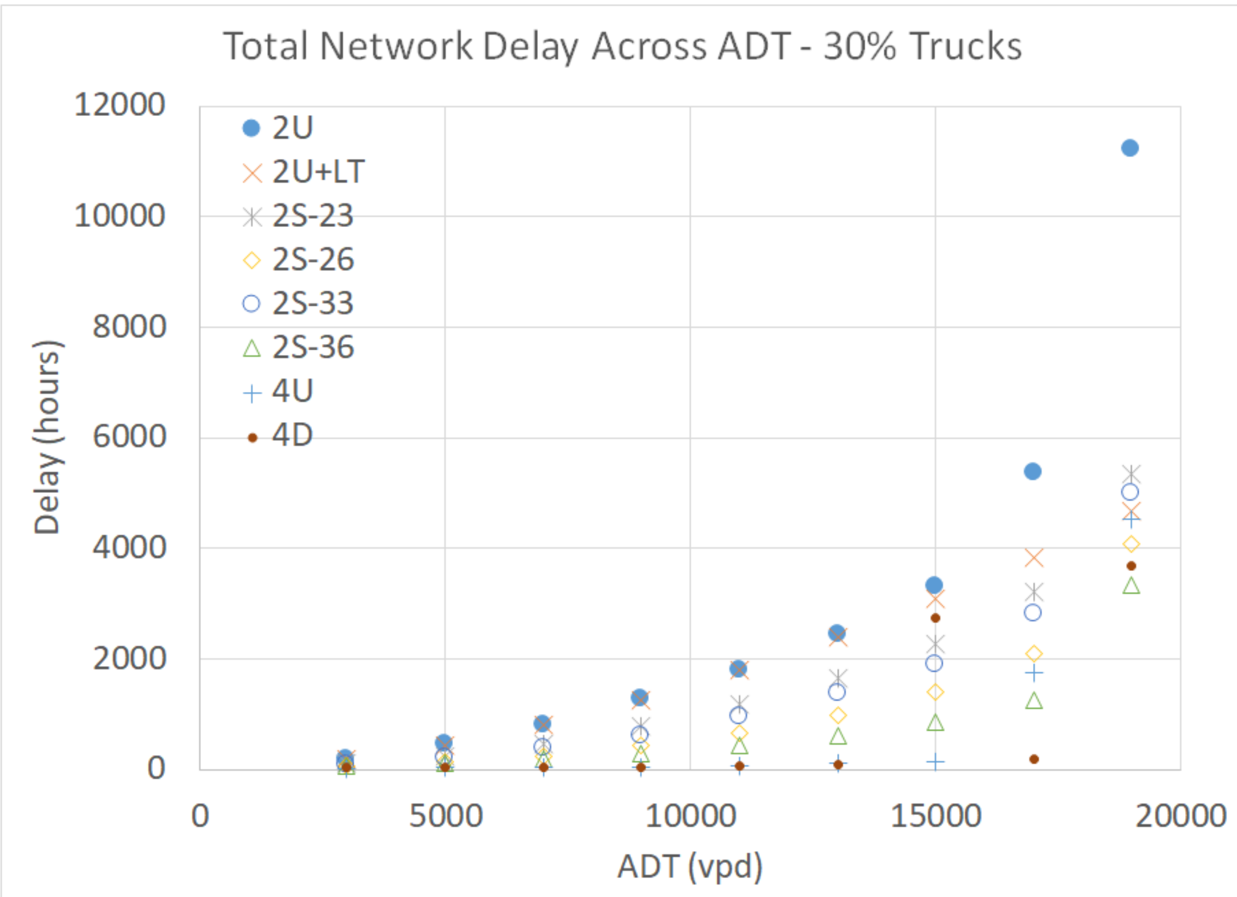


Figure 28. Total Network Delay across ADT with 30 Percent Trucks.

Figure 29 summarizes delay values for scenarios with 40 percent trucks and shows the same trend of increasing incremental changes at the two highest ADT levels, as delay values rise exponentially with ADT. The four Super 2 options and the 4U option maintained their performance relative to one another at all levels, and the 4D option rose at the 15,000-vpd level and then stabilized, but delay for the 2U+LT option increased at a lower rate and was the only option to produce less than 5,000 hours of delay at 19,000 ADT.

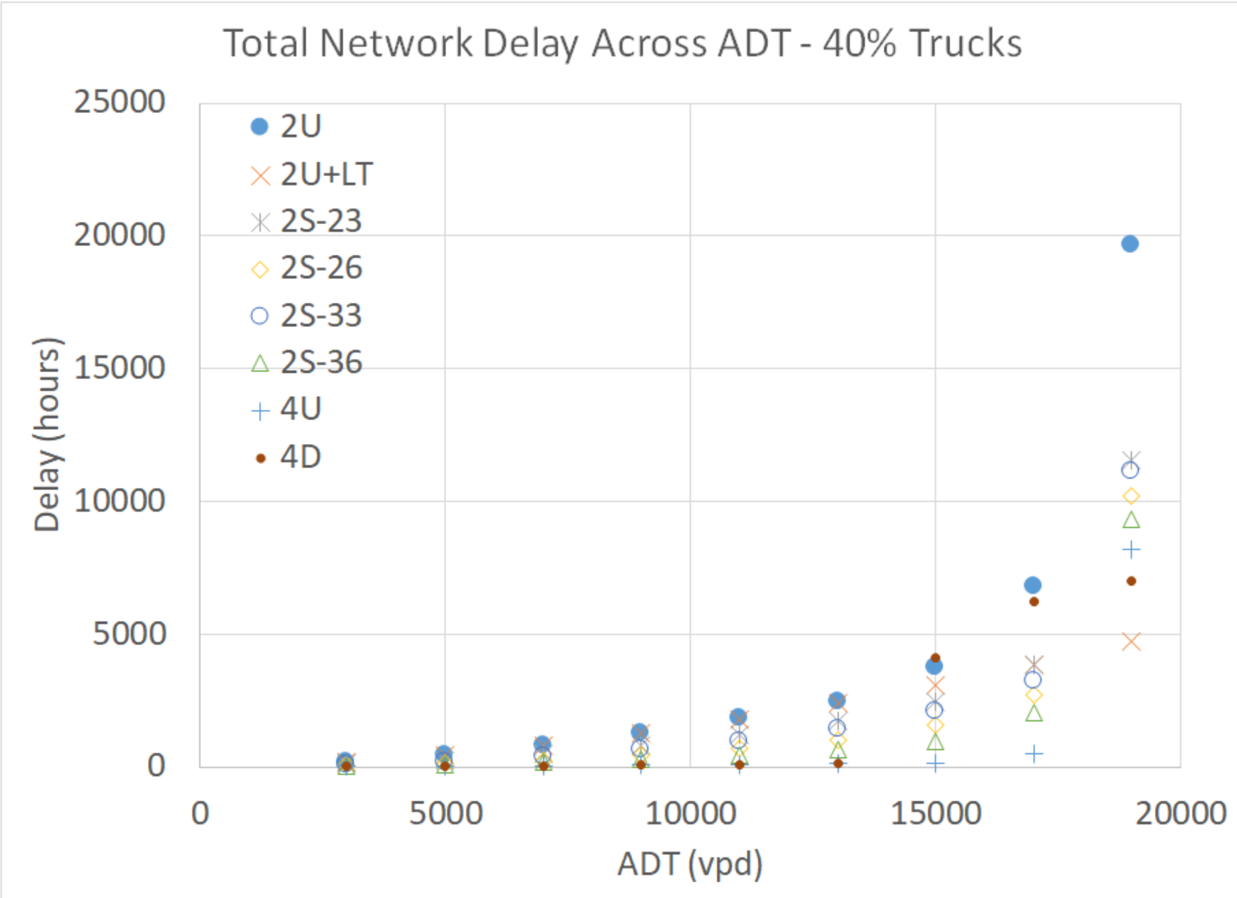


Figure 29. Total Network Delay across ADT with 40 Percent Trucks.

Another measure of delay is stop delay, which is the total standstill time of all vehicles in the simulation. Figure 30 summarizes the average stop delay (in seconds per vehicle) over the entire simulated day for every scenario. While stop delay considers only vehicles that are not moving, it shows a similar pattern to total network delay in terms of relative performance among the seven cross-section options across volume levels and truck percentages. The 2U and 4D cross-sections were more susceptible to stop delay than the other options as volumes and truck percentages increased, though the other options performed similarly at volumes of 13,000 vpd or below.

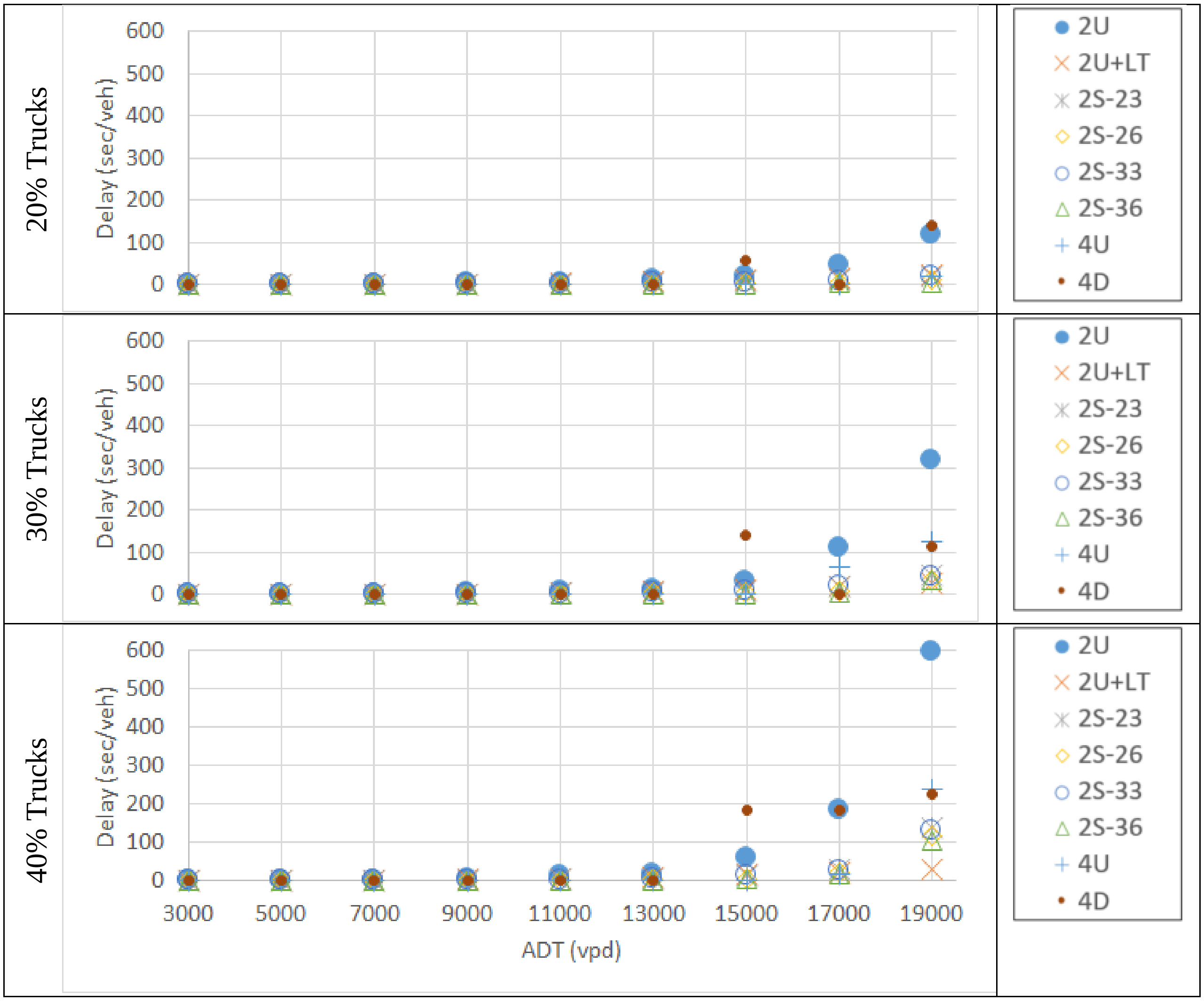


Figure 30. Average Stop Delay for All Scenarios.

Compared to the baseline 2U cross-section, as volumes increased, the 4U and 4D cross-section delays rose more than the options with left-turn lanes or Super 2 passing lanes, and the 2U+LT option had the lowest increase in delay at the highest volume and truck percentage, with less than one minute of delay per vehicle in that scenario. In comparison, the Super 2 options resulted in almost two minutes or less of delay per vehicle in the most congested scenario and a minute or less in all other scenarios. A more detailed investigation of the results of the simulations at higher volumes indicates that the four-lane scenarios are more susceptible than the Super 2 and 2U+LT scenarios to the effects of turning vehicles, particularly trucks, waiting in the left lane to turn, even with the median available in the 4D cross-section. This increase in stop delay also helps to explain the relative performance of the four-lane scenarios in network delay described in Figure 27 through Figure 29. The simulation results suggest that while the four-lane cross-sections provide more theoretical capacity for through vehicles than the two-lane options, the fact that the additional lanes in the 2U+LT scenarios are short in length and designed specifically for turning helps to discourage through drivers from using them. While traffic in a single through lane may have a lower average speed than a similar alignment with two through lanes, the vehicles do keep moving in that single lane rather than being disrupted by left-turning vehicles waiting for an appropriate gap to complete their turn. A comparative investigation of a four-lane cross-section with turning lanes, compared to 2U+LT, 4U, and 4D cross-sections, would provide more insight into this phenomenon.

Percent Time Spent Following

The final MOE generated from the outputs from the capacity analysis was a calculation of percent time spent following. The box plots in Figure 31 present the PTSF results for the two operational extremes in the simulation (i.e., 3,000 ADT with 20 percent trucks, and 19,000 ADT with 40 percent trucks) for all scenarios.

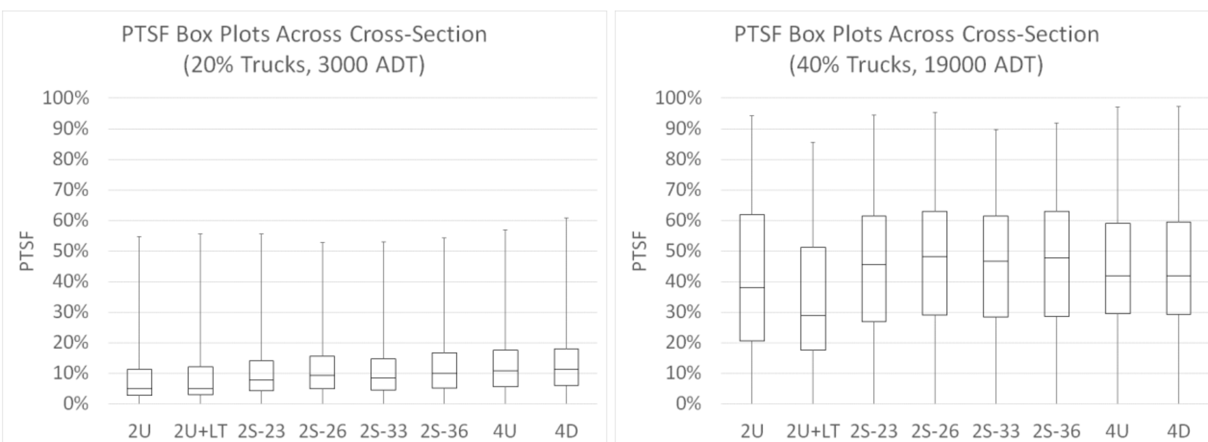


Figure 31. Percent Time Spent Following for Operational Extremes.

The data in Figure 31 indicate that PTSF does not vary widely among the eight cross-section options, particularly at lower volumes and truck percentages. For the lower extreme scenario, the maximum PTSF was below 60 percent for all but the 4D cross-section, and median PTSF values were generally 10 percent or less. For the upper extreme scenario, the 2U+LT cross-section was a somewhat better performer, with lower values for all box plot measures (i.e., maximum, median, 25th percentile, and 75th percentile). In particular, the median PTSF was just under 30 percent compared to over 40 percent for the other cross-sections, but the range between

25th and 75th percentiles for 2U+LT still largely overlapped with those of the other cross-sections.

The plots suggest that 4U and 4D had higher PTSF than 2U, which could be counterintuitive since those cross-sections provide a continuous additional lane for drivers to pass turning vehicles or slower through vehicles. However, taken in conjunction with the speed and delay results, the PTSF results do indicate that, for corridors with considerable turning traffic, providing accommodation for those turning vehicles can be operationally more beneficial than the added capacity of a through lane.

CHAPTER 5: ECONOMIC ANALYSES

This chapter documents the findings of the research team in using a sample of available data with current practices and tools to conduct analyses of the cost benefits of Super 2 corridors compared to two-lane and four-lane highways.

PRELIMINARY ANALYSIS

The research team conducted an effort early in the project to develop a preliminary economic analysis and lay the groundwork for the eventual economic analysis tool based on existing data. The preliminary analysis used available tools and data from previous projects to consider options for appropriate methodology and rigorous statistical methods, as well as potential applicability to the data obtained from this research project and suitability for practitioner use on future designs and construction projects.

Preliminary Data Collection

Researchers on Project 0-6135 identified Super 2 projects by conducting a survey. The survey questionnaire asked area engineers about locations of Super 2 corridors, passing lane length, facility and traffic information, and year of completion (*47*). However, in a process that is heavily dependent on manual effort to receive and process information, the opportunity for human error increases, introducing potentially inaccurate data into the rest of the research study process. Instead of gathering the data for this task in a similar fashion, the research team developed a method to compile information from data sources using the R statistical analysis program. To arrive at scientific inferences that convey generalized conclusions, researchers identified 24 sample projects and then selected 12 of those projects based on AADT, which ranged from 1,400 to 12,000 vpd. Since a single complete dataset that fits into the study purpose does not exist, researchers investigated several databases from which to extract necessary data fields by tracking individual projects with unique project IDs. The Roadway Inventory database was used to extract general project information, the Lonestar database was used for traffic data, and the Crash Records Information System (CRIS) database provided crash data for the study. The process to compile the information into a single database contained the following five steps:

1. Download and install the latest version of the TxDOT Roadway Inventory datasets.
2. Locate the file “TxDOT_Roadway_Inventory.txt” inside the datasets.

3. Devise R-based structured query language to communicate with datasets and to extract necessary data fields (Figure 32 provides an example).
4. Extract all entries identified as Super 2 corridor in the datasets (Figure 33).
5. Repeat the same procedures for the Lonestar and CRIS databases to extract necessary traffic and crash information.

Table 22 summarizes the key variables from the compiled dataset for selected sites.

```r
# load data
LoadData <- function (data_path, road_dat){
  setwd(data_path)
  dat.txDot <- read.delim(road_dat, header=T, sep = "|")
  df.txdot <- data.frame(dat.txDot)   # convert into dataframe
  return (df.txdot)
}

# 1. Load Data
# Set up working directory (the folder path where you put the data)
# copy the windows path of the folder here and change every "\" to "/"
data_path <- "D:/Study/III. TAMU/RAs/004-Preliminary Economic Valuation of Super 2/prelim/My data"
# Read TxDOT road inventory 2017
name.txDot <- "TxDOT_Roadway_Inventory.txt"
df.txDot = LoadData(data_path, name.txDot)
```

Figure 32. Coded R Scripts to Access the Roadway Inventory Database.

```r
# 2. Find Super 2
# fetch data rows by certain value 'attr_value' of certain attribute (column name 'attr_name') from a dataframe 'data'
FetchbyAttr <- function (attr_value, attr_name, data){
  col <- which(colnames(data) == attr_name)
  res <- data.frame(data[which(data[,col] == attr_value),])
  return (res)
}

FindSuper2 <- function (road_dat){
  # Find all super 2 lane segments from the data
  df.super2 = FetchbyAttr(2, "CLMB_PS_LANE", road_dat)
  hsys = lapply(df.super2$HSYS, as.character)
  # Extract relevant column and remove redundancy for Control Section
  sec_list = df.super2$C_SEC
  sec_unique = unique(sec_list)
  return(sec_unique)
}
my_dat = FindSuper2(df.txDot)
```

Figure 33. Coded R Scripts to Extract Super 2 Projects from the Roadway Inventory Database.

Table 22. Super 2 Site Dataset for Preliminary Economic Analysis.

Ctrl Sec	Hwy Sys	Hwy Num	AADT 2017	Truck %	Length (Mile)			Max Speed	Surf	RU	Dist
					Super 2	Total	Lane-Mile				
0133-01	US	82	1,444	22	11.99	19.71	39.43	75.0	4+10	1	CHS
0055-01	US	84	2,634	7	14.83	14.83	29.66	69.7	4+10	1	BWD
0245-19	SH	64	4,440	13	10.30	15.79	31.57	65.4	4	1	TYL
0079-03	US	67	4,943	19	15.40	15.42	30.84	73.0	4	1	BWD
0251-04	US	281	5,428	15	10.35	10.36	20.71	72.8	4+10	1	BWD
0251-05	US	281	6,476	14	15.31	16.15	32.29	73.0	4	1+2	BWD
0154-02	US	183	7,097	14	6.05	9.50	18.99	69.9	4	1	YKM
0291-01	SH	16	7,872	7	4.27	16.30	32.59	73.5	6+10	1	AUS
0762-01	FM	1960	8,599	13	3.31	8.40	16.80	64.8	4	1	BMT
0253-02	US	281	10,549	6	3.23	6.29	12.58	74.9	4+6	1	AUS
0253-01	US	281	11,060	6	0.64	12.61	25.21	74.0	4	1	AUS
0154-01	US	183	11,908	11	0.79	6.74	13.48	69.7	4	1	YKM

Where:
Ctrl Sec = Control section
Hwy Sys = Highway system
Hwy Num = Route number of the highway
Surf = Surface type:
1=Continuously reinforced concrete
2=Jointed reinforced concrete
3=Jointed plain concrete
4=Thick asphaltic concrete, over 5.5 inches
5=Medium asphaltic concrete, 2.5–5.5 inches
6=Thin asphaltic concrete, under 2.5 inches
7=Composite (asphalt surfaced concrete)
8=Widened composite pavement
9=Overlaid and widened asphaltic concrete pavement
10=Surface treatment pavement
11=Brick
12=Bladed
13=Gravel
99=Unknown

RU = Rural/urban code:
1=Rural (population < 5,000)
2=Small urban (population 5,000–49,999)
3=Urbanized (population 50,000–199,999)
4=Large urbanized (population 200,000+)
Dist = TxDOT district

Preliminary Quantification of Road User Cost

The RUC is not calculable, but when considering the concept of opportunity cost (i.e., the time that motorists could spend doing something else, such as recreation or work), its usefulness as a measure of time saved by completing a construction project early has become more important in recent years. The determination of RUC incorporates the concept of the demand-capacity model from the HCM. The four major factors to consider in the estimation of RUC are:

- Additional travel time (time lost due to construction lane closures).
- The average number of motorists per vehicle.
- The monetary value of time to motorists in the vehicle.
- The percentage of trucks in the traffic traveling through a construction work zone.

Agency efforts to quantify more accurate RUC have been furthered by use of innovative software analysis programs. A more recent tool arising from these efforts is a state-of-the-art tool called CA4PRS, which has come into use because of its ability to analyze schedules, RUC, and work zone traffic impacts together. The research team used CA4PRS in the preliminary analysis to directly estimate the total number of working days for individual projects, followed by computation of the impact of each project on the traveling public in terms of RUC and time spent in queue. To extract the needed project information for the study and to perform data stratification, regression, and statistical analyses, researchers used the programming language R using RStudio software as the main metadataset creation tool.

Input data originated mainly from the Roadway Inventory database with some additional data collected by the research team. Table 23 shows the results of the simulations that compare a Super 2 corridor option to a four-lane alignment alternative. These series of simulations conducted on 12 sample projects show the benefits of Super 2 corridors over four-lane alignments based on the number of closures, RUC, and maximum delay. Figure 34 reveals that Super 2 corridors provide added benefit at higher AADT over 7,000 vpd, compared to four-lane alignment options.

Table 23. Result of CA4PRS Schedule/RUC Simulations of Super 2 versus Four Lane.

	4-Lane Alignment					Super 2 Corridor				
	Number of Closures Needed to Complete		Road User Cost ($)		Max. Delay (min)	Number of Closures Needed to Complete		Road User Cost ($)		Max. Delay (min)
Ctrl Sec	Total	1 Dir.	Daily	Total		Total	1 Dir.	Daily	Total	
0133-01	118	59	1,150	678,278	5.8	36	36	760	136,747	3.6
0055-01	89	45	1,132	509,498	3.5	45	45	1,132	254,695	3.5
0245-19	94	47	1,728	812,251	2.8	31	31	1,269	196,752	1.9
0079-03	92	46	2,877	1,323,585	4.3	46	46	2,877	661,760	4.3
0251-04	62	31	2,215	686,828	2.9	31	31	2,214	343,120	2.9
0251-05	96	48	3,712	1,781,809	4.5	46	46	3,552	816,853	4.2
0154-02	57	29	2,384	691,464	2.3	18	18	1,758	158,250	1.5
0291-01	97	49	4,259	2,087,037	4.6	13	13	1,629	105,855	1.3
0762-01	50	25	2,062	515,554	1.5	10	10	1,270	63,511	0.6
0253-02	38	19	2,844	540,331	1.9	10	10	1,908	95,385	1.1
0253-01	75	38	4,863	1,848,125	3.6	2	2	1,159	11,590	0.3
0154-01	41	21	3,063	643,350	1.7	3	3	1,304	19,557	0.3

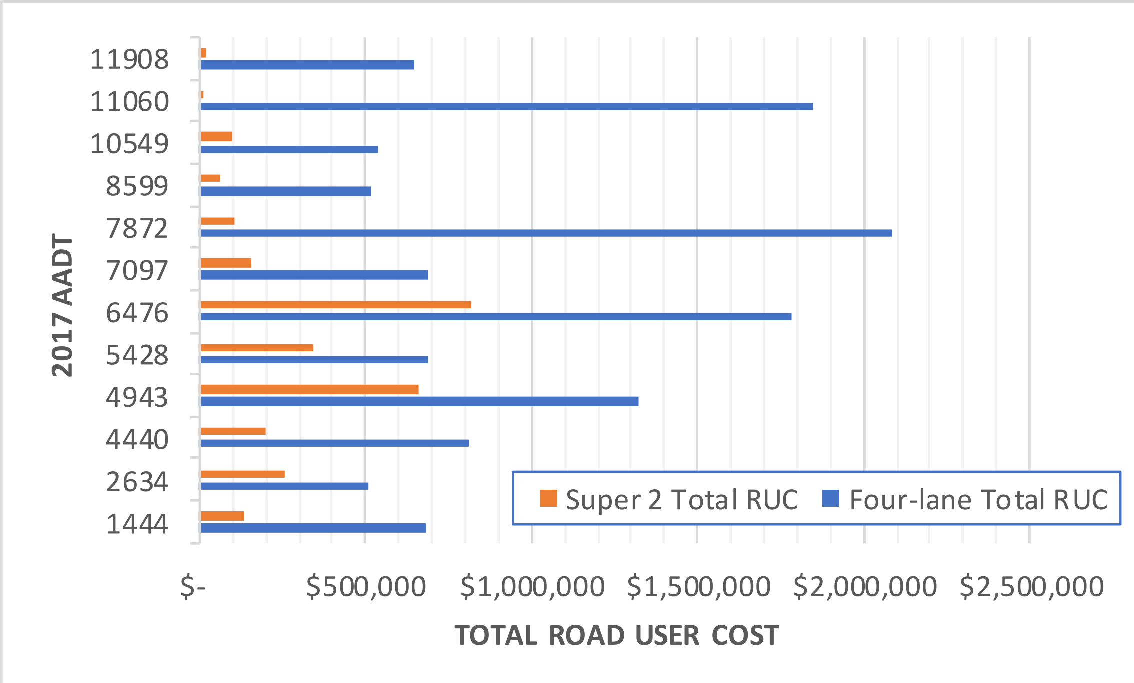


Figure 34. Comparison of Road User Costs by AADT for Super 2 versus Four Lane.

Knowing that the traffic volume described by AADT plays an instrumental role in the estimated benefit for RUC, researchers further investigated the effect of AADT specifically for the Super 2 option, in terms of RUC savings per vehicle-mile traveled (Table 24). Figure 35 shows that there is a negative linear relationship between AADT and RUC saving effect per vehicle-mile traveled. As AADT increases, the net RUC saving decreases for Super 2 corridors, which suggests that the four-lane capacity-added option would be preferable when AADT reaches a certain higher level.

Table 24. RUC Savings by Vehicle-Miles Traveled.

Ctrl Sec	Hwy Sys	Hwy Num	Length (Mile)			AADT 2017	Super 2 Savings in RUC ($)	Super 2 Savings in RUC per Vehicle-Mile Traveled (VMT)	
			Super 2	Total	Lane-Mile			VMT	Saved RUC per VMT ($)
0133-01	US	82	11.99	19.71	39.43	1,444	541,531	28,462	19.03
0055-01	US	84	14.83	14.83	29.66	2,634	254,803	39,065	6.52
0245-19	SH	64	10.30	15.79	31.57	4,440	615,499	70,093	8.78
0079-03	US	67	15.40	15.42	30.84	4,943	661,825	76,217	8.68
0251-04	US	281	10.35	10.36	20.71	5,428	343,708	56,223	6.11
0251-05	US	281	15.31	16.15	32.29	6,476	964,956	104,557	9.23
0154-02	US	183	6.05	9.50	18.99	7,097	533,214	67,391	7.91
0291-01	SH	16	4.27	16.30	32.59	7,872	1,981,182	128,289	15.44
0762-01	FM	1960	3.31	8.40	16.80	8,599	452,043	72,245	6.26
0253-02	US	281	3.23	6.29	12.58	10,549	444,946	66,352	6.71
0253-01	US	281	0.64	12.61	25.21	11,060	1,836,535	139,411	13.17
0154-01	US	183	0.79	6.74	13.48	11,908	623,793	80,248	7.77

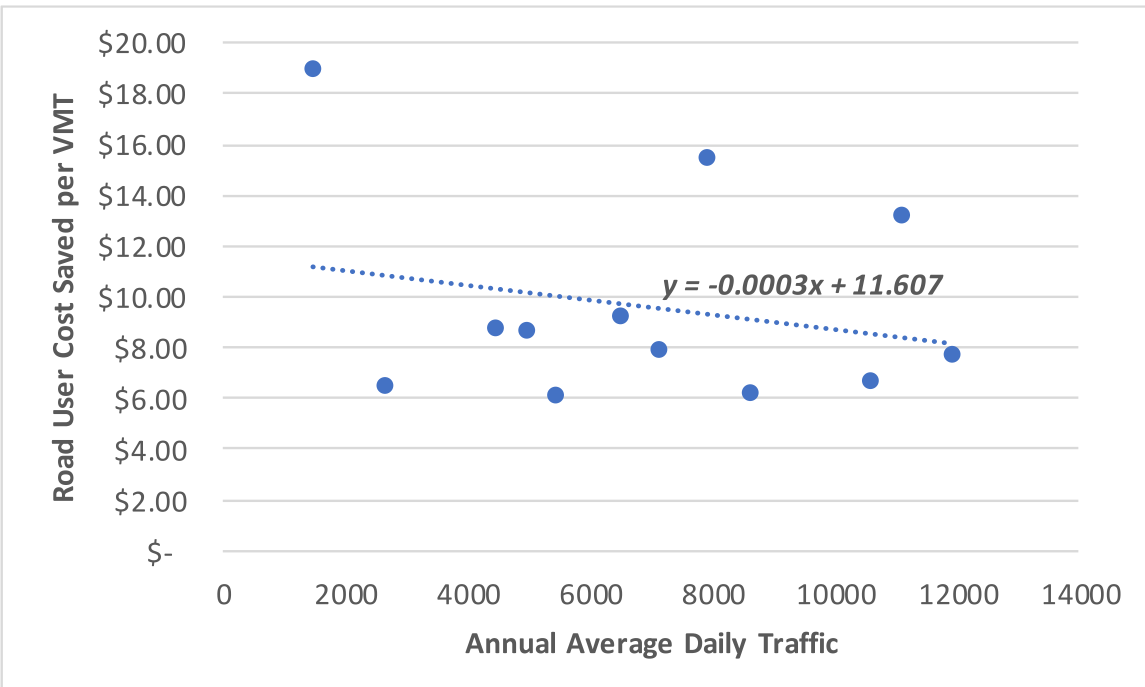


Figure 35. Super 2 RUC Savings per VMT versus AADT.

Preliminary Quantification of Crash Cost

Severe crashes on two-lane highways are commonly associated with cross-centerline passing maneuvers. Passing lanes are known to reduce crash risks by providing reliable passing opportunities without the need for the passing driver to use the lane normally reserved for opposing traffic, which breaks up traffic platoons for drivers and reduces the need for passing maneuvers downstream (*85*).

To measure the safety effectiveness of passing lanes, the most rigorous analysis technique is to conduct a B/A study that uses the EB method with a comparison group. To conduct an EB analysis on the safety effectiveness of Super 2 corridors, the following procedure was used on Project 0-6135 (*47*):

1. Define the reference group with road segments that have similar characteristics with the studied Super 2 corridors.
2. Develop safety performance functions for each reference group.
3. Compute the yearly correction factors.
4. Compute the EB estimates and their variances for the before period.
5. Predict the expected number of crashes and variances for the after period.
6. Compute the sum of the predicted crashes over all treated sites and its variances.
7. Compute the sum of the actual crashes over all treated sites.
8. Compute the unbiased estimate of the safety effectiveness of the treatment and its variances.

These steps provided insulation against effects from common statistical issues. A regression-to-the-mean bias is a good example and is a statistical phenomenon that occurs whenever a nonrandom sample is selected from a population (*58*, *107*), as well as many other factors like crash migration and long-term trends in the studied region.

To perform an EB analysis for the evaluation of added monetary benefit in terms of reduced crash risk, researchers gathered and analyzed the crash data from the CRIS database system through the following steps:

1. Accessed the CRIS Query system at https://cris.dot.state.tx.us/public/Query/app/public/welcome.
2. Located Super 2 corridors using geographic information system information and searched projects with appropriate queries to obtain raw crash data that covered projects completed from 2011 to 2018.
3. Searched two-lane reference group projects with appropriate queries to obtain raw crash data. This served as a filter of reference groups.

4. Downloaded the raw crash data in a tabular format that contained key crash data such as crash severity and its location.
5. Wrote scripts using R to access the downloaded crash data tables (Figure 36).
6. Formatted the data in a spreadsheet to display results (Figure 37).

```
# 3. Load Crash Data
# load data
LoadData <- function (data_path, crash_dat){
  setwd(data_path)
  dat.crash <- read.csv(crash_dat, skip=12)    # There are some meta data in the first 12 rows, ignore them here
  df.crash <- data.frame(dat.crash)    # convert into dataframe
  return (df.crash)
}

crash_data_path <- "D:/Study/III. TAMU/RAs/004-Preliminary Economic Valuation of Super 2/prelim/My data/Crash Data Graph"
name.crash <- "result=query_rural+2-lane+on_road+reference_district_.csv"
df.crash = LoadData(crash_data_path, name.crash)
```

Figure 36. R Script to Access the CRIS Crash Data.

Crash Yea	A - SUSPE	B - NON-I	C - POSSIE	K - KILLED	N - NOT IN	Total		ABC				99 - UNKNOWN
2011	2	7	4	0	23	37		13				1
2012	1	1	5	1	15	23		7				0
2013	2	1	3	1	17	24		6				0
2014	1	4	1	0	14	21		6				1
2015	2	7	4	0	21	34		13				0
2016	2	4	3	0	6	15		9				0
2017	3	4	3	1	22	33		10				0
2018	2	2	2	2	23	32		6				1
Total	15	30	25	5	141	219		70				3

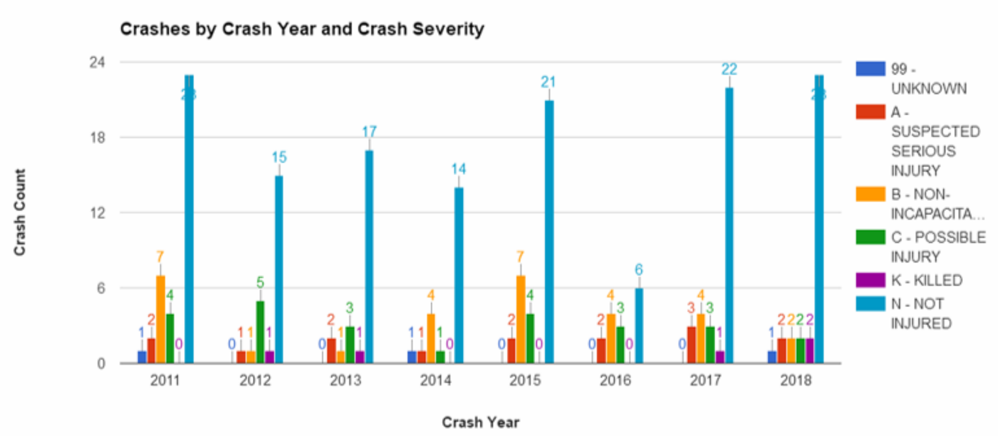


Figure 37. Sample of the Downloaded CRIS Crash Data for Crash Analysis of a Super 2 Corridor.

Researchers gathered, stratified, and analyzed crash data for both the Super 2 corridors and all reference groups such as two-lane and four-lane alignment options. The statewide crash rates data were obtained from the TxDOT FTP site, http://ftp.dot.state.tx.us/pub/txdot-info/trf/crash_statistics/2017/02.pdf, and statewide crash count data with severity information is downloadable at http://ftp.dot.state.tx.us/pub/txdot-info/trf/crash_statistics/2017/11.pdf.

For the effort in this preliminary analysis, with the complete set of crash data, the team performed a cross-sectional comparative analysis based on the actual crash counts gathered for Super 2, two-lane, and four-lane highways. The crash costs of each reference group were computed based on the total crash counts weighted by the level of crash severity, as guided by the National Highway Traffic Safety Administration (NHTSA) (*108*).

In this analysis, the two-lane highway crash counts, n_1, and four-lane highway crash counts, n_2, were estimated in comparison to crash counts on the individual Super 2 section that is represented by project ID. For this estimate, TTI adopted the 2017 TxDOT statewide rural two-lane highway crash risk (R_1) and statewide rural undivided four-lane highway crash risk (R_2), multiplied by the total VMT as section length (L) and $AADT$ of that section, as shown in the following equations:

$$n_1 = L \times AADT \times R_1 \qquad (2)$$

$$n_2 = L \times AADT \times R_2 \qquad (3)$$

To estimate the two-lane crash cost (C_1) and four-lane crash cost (C_2), a weighted Texas rural highway unit crash cost (λ) was used as an estimation of the total crash cost for each crash case. The unit cost was estimated using the following equation:

$$\lambda = \frac{\sum n_i \times D_i}{\sum n_i} \qquad (4)$$

where n_i is TxDOT 2017 crash statistics for all rural highway systems with the breakdown of different levels of crash severity such as K = fatal, A = severe injury, B = non-incapacitating injury, C = possible injury, and N = property damage only; D_i is the unit crash cost value of the corresponding crash severity level from NHTSA.

With the estimated unit crash cost λ, researchers computed the total crash cost for two-lane highways (C_1) and the total crash cost for four-lane highways (C_2), each of which corresponds to an individual Super 2 corridor section, as shown in the following equations:

$$C_1 = n_1 \times \lambda \qquad (5)$$

$$C_2 = n_2 \times \lambda \qquad (6)$$

Table 25 shows the results of this preliminary analysis and suggests mixed benefits of Super 2 compared to two-lane or four-lane cross-sections. However, this analysis was completed primarily to show the manner in which such an analysis could be conducted on a larger scale with a larger sample size and more rigorous methodology. This analysis has a small sample size and has potential bias effects from external factors, so these results should be considered preliminary. In addition, the control sections where the Super 2 crash costs are higher had one or more fatalities and/or serious injuries, greatly affecting the calculated cost. The final analysis, described in subsequent sections of this chapter, used a more streamlined method of calculating safety benefits that is less sensitive to small sample size.

Table 25. Preliminary Quantification of Monetary Benefit of Reduced Crash Risk.

		2-Lane Crashes		4-Lane Crashes		Super 2 Crashes			
Ctrl Sec	**AADT 2017**	**Count (n_1)**	**Cost (C_1)**	**Count (n_2)**	**Cost (C_2)**	**Count (n_0)**	**Cost (C_0)**	**Super 2 vs. 2 Lane (C_0-C_1)**	**Super 2 vs. 4 Lane (C_0-C_2)**
0133-01	1,444	11.75	789,058	12.491	838,859	3	1,406,640	617,582	567,781
0055-01	2,634	14.51	974,186	15.422	1,035,671	19	1,852,483	878,297	816,812
0245-19	4,440	29.62	1,989,334	31.491	2,114,889	35	2,158,759	169,425	43,870
0079-03	4,943	32.44	2,178,652	34.488	2,316,156	22	1,638,941	−539,711	−677,215
0251-04	5,428	20.72	1,391,285	22.024	1,479,095	8	963,041	−428,245	−516,055
0251-05	6,476	38.83	2,607,420	41.276	2,771,985	7	390,975	−2,216,445	−2,381,011
0154-02	7,097	27.10	1,819,958	28.810	1,934,823	15	421,871	−1,398,087	−1,512,953
0291-01	7,872	52.05	3,495,876	55.340	3,716,516	48	2,374,969	−1,120,907	−1,341,547
0762-01	8,599	24.50	1,645,268	26.045	1,749,108	31	4,549,368	2,904,100	2,800,260
0253-02	10,549	28.12	1,888,461	29.895	2,007,649	18	440,160	−1,448,301	−1,567,489
0253-01	11,060	54.86	3,684,110	58.320	3,916,630	25	4,076,694	392,583	160,063
0154-01	11,908	30.50	2,048,274	32.425	2,177,550	24	2,235,356	187,082	57,806

FINAL ANALYSIS

After completing Tasks 3 and 4 and obtaining the simulation results to provide a basis for operational analysis, the research team conducted a final analysis of the costs and benefits associated with choosing a particular cross-section. The final analysis used a different methodology than was used in the preliminary analysis; this refined methodology, described in this section, was better suited to process the data available. To obtain a representative sample of construction cost data, researchers requested data from the Project 0-6997 Project Monitoring Committee for completed projects in their districts, in addition to data that the research team had already obtained. Data for the 2U+LT cross-section was not available, but all other cross-sections evaluated in Task 4 were represented. Thus, researchers completed a benefit-cost analysis (BCA) for each of the seven cross-sections listed in Table 26.

Table 26. Cross-sections Analyzed in Benefit-Cost Analysis.

Cross-section	Identifier
Super 2 with 2-mile passing lanes × 3	2S-23
Super 2 with 3-mile passing lanes × 3	2S-33
Super 2 with 2-mile passing lanes × 6	2S-26
Super 2 with 3-mile passing lanes × 6	2S-36
4-lane undivided	4U
4-lane divided	4D
Base case: 2-lane undivided	2U

Each BCA was divided into two scenarios: the no-build (or base) scenario and the build (or project) scenario. The benefits were compared for the two scenarios assuming a 20-year operating period, a 40-mile project length, and a two-year construction period. The following outputs from Task 4 were used as inputs to the BCA model for each cross-section:

- Percent trucks.
- Total number of vehicles.
- ADT.
- Total delay in hours for passenger vehicles.
- Total delay in hours for trucks.

The present value of the benefits was calculated by subtracting the total travel costs of the project scenario from the total travel costs of the base scenario over the 20-year operating period. All outputs are presented in 2018 dollars to be consistent with default factors. Using a standard discount rate of 3 percent, researchers estimated the following benefits:

- Vehicle operating cost savings.
- Business and personal time cost savings.
- Safety benefits.
- Environmental benefits.

Vehicle operating costs include but are not limited to fuel, purchase payments, insurance premiums, tires, maintenance, and repairs. Business time cost savings are the business cost of labor for professional drivers and paid crew. Personal time cost savings are the valuation of the average passenger's time. Safety benefits are the monetized value associated with the reduction of crashes that result in a fatality or injury, and environmental factors include the cost savings of air pollution and greenhouse gases per vehicle-hour of travel.

The present value of costs was created by multiplying a cost per mile for each cross-section by the 40 miles used in the analysis. For uniformity, researchers obtained historical costs per mile for projects for each cross-section and converted them to 2018 dollars to produce an average for each cross-section. Similar to the benefits, researchers applied a 3 percent discount rate to those costs. The benefit/cost ratio (BCR) is simply the total benefits derived from the project divided by the total cost of the project. A BCR greater than 1.0 is positive, meaning that the benefits of the project outweigh the costs.

Development of Model and Scenarios for Analysis

The research team created a spreadsheet model to conduct the BCA. The user has the ability to select the cross-section (described in the model as the project type), the ADT (in 2,000-vehicle increments), and the percentage of trucks. Other default values that can be altered include:

- Traffic growth rate.
- Construction start year.
- Operation start year.
- Constant dollar year.
- Project length (miles).
- Project cost.

Table 27 depicts the model inputs for a sample 2S-26 project, as entered into the BCA spreadsheet model. The top three factors highlighted in yellow allow the user to select from a pull-down menu, while the project cost override factor, located at the bottom, allows the user to override the default project cost calculated by the model if more accurate project cost information is available. The remaining default factors highlighted in gray depict the values used for this analysis that can be altered if other data are available.

Table 27. BCA Model Inputs.

Inputs	
Please Select from Pull Down Menu	
Project Type	2S-26
ADT	11,000
Percent Trucks	40%
Traffic Growth Rate	2%
Construction Start Year	2021
Operation Start Year	2023
Constant Dollar Year	2020
Project Length (Miles)	40.0
Estimated Project Cost	$40,545,609
Known Project Cost Override	

Table 28 shows the outputs of the BCA model for the sample project. The total benefits over the 20-year period of operation are presented at the top (discounted at 3 percent), followed by the discounted project cost. The BCR and the net present value (NPV) are also presented. An explanation of each of the cost and benefit categories is provided in the following subsections.

Table 28. BCA Model Outputs.

Outputs	
Benefits and Costs	**Present Value (M 2018$)**
Vehicle Operating Cost Savings	$149.5
Business and Personal Time Cost Savings	$176.4
Safety Benefits	$230.0
Environmental Benefits	$1.3
Total Benefits	**$557**
Capital Costs	$38.8
Total Costs	**$39**
Benefit/Cost Ratio	**14.4**
Net Present Value (NPV)	**$518**
3% Discount Rate	

Vehicle Operating Cost Savings

The net change in vehicle operating costs is the change in operating costs from the project to the base scenario. Vehicle operating cost is the cost per hour of operating a passenger vehicle or commercial truck. The base operating cost includes maintenance, tires, mileage-based depreciation, and insurance.

The hourly fuel operating cost is also calculated using fuel prices per gallon obtained from the Energy Information Administration (EIA) and a vehicle-gallons-consumed-per-hour factor obtained from the Transportation Economic Development Impact System (TREDIS):

- Base operating cost (truck and passenger) = (hours of delay × vehicle operating cost per hour).
- Fuel operating cost (truck and passenger) = (hours of delay × gallons per hour) × fuel cost per gallon.

Default factors used to calculate these benefits are listed at the end of this chapter under "Sources."

Business and Personal Time Cost Savings

The value of time savings is the crew cost for trucks and the personal time cost for passenger vehicles saved due to a reduction in delay between the project scenario and the base scenario. Time savings are calculated by multiplying the number of crew or passengers per vehicle by the crew- or passenger-cost-per-hour factor for each crewmember or passenger, and then multiplying by the hours of delay in each scenario:

- Business time cost = (number of crew per truck × crew cost per hour per crew member) × truck hours of delay.
- Personal time cost = (passengers per vehicle × passenger cost per hour per passenger) × passenger vehicle-hours of delay.

USDOT-recommended values were used for crew and personal cost factors as well as the number of crew or passengers per vehicle.

Default factors used to calculate these benefits are listed at the end of this chapter under "Sources."

Safety Benefits

Safety benefits result from the reduction in the number of predicted annual crashes from the base scenario to the project scenario. First, the VMT was estimated annually using the selected ADT and the estimated 40-mile project length. A 2 percent annual growth rate was applied for the 20-year operational period. Fatalities and injuries for the base case were determined using a rate per 100 million VMT obtained from NHTSA. A CMF was applied to determine the reduction in fatalities and injuries between the two scenarios. Finally, the number of reduced fatalities and injuries was multiplied by the associated cost to determine the total safety cost reduction. Default factors used to calculate these benefits are listed at the end of this chapter under "Sources."

Environmental Benefits

The net change in environmental costs is the change in environmental costs from the project to the base scenario. This cost includes volatile organic compounds (VOCs), nitrogen oxides (NO_x), particulate matter (PM), sulfur dioxide (SO_2), and carbon dioxide (CO_2). The cost per ton of each of these emission types was obtained from USDOT, while emission rates were obtained from TREDIS. The environmental cost per hour for truck and for passenger vehicles was calculated by multiplying each hourly emission rate by the emission cost and then summing each type of emission cost per hour to calculate a total environmental cost per hour. This was then multiplied by the base case and project scenario hours of delay:

- Environmental cost per hour = hourly emission rate × emission cost.
- Environmental cost = hours of delay × environmental cost per hour.

Default factors used to calculate these benefits are listed at the end of this chapter under "Sources."

Results from Economic Analysis

This section presents the results from the scenarios considered in this analysis. Table 29 through Table 34 depict the individual benefits estimated for each project type. The results are shown for the low and high ADT as well as low and high percentage of trucks to provide a range of estimated outcomes. Values shown in red represent BCRs less than 1.0 and negative NPVs. All values are discounted at 3 percent.

Table 29. BCA Results for 2S-23 (3 Percent Discount).

2S-23	3,000 ADT		19,000 ADT	
	20% Trucks	40% Trucks	20% Trucks	40% Trucks
Benefits and Costs	Present Value (M 2018$)		Present Value (M 2018$)	
Vehicle Operating Cost Savings	$6.4	$9.0	$232.6	$1,079.4
Business and Personal Time Cost Savings	$12.1	$12.7	$384.4	$1,252.5
Safety Benefits	$62.7	$62.7	$397.3	$397.3
Environmental Benefits	$0.1	$0.1	$2.0	$9.7
Total Benefits	**$81**	**$84**	**$1,016**	**$2,739**
Capital Costs	$38.8	$38.8	$38.8	$38.8
Total Costs	**$39**	**$39**	**$39**	**$39**
Benefit/Cost Ratio	**2.1**	**2.2**	**26.2**	**70.6**
Net Present Value (NPV)	**$42**	**$46**	**$977**	**$2,700**

Table 30. BCA Results for 2S-33 (3 Percent Discount).

2S-33	3,000 ADT		19,000 ADT	
	20% Trucks	40% Trucks	20% Trucks	40% Trucks
Benefits and Costs	Present Value (M 2018$)		Present Value (M 2018$)	
Vehicle Operating Cost Savings	$7.4	$10.4	$267.9	$1,141.6
Business and Personal Time Cost Savings	$14.0	$14.5	$443.1	$1,314.4
Safety Benefits	$62.7	$62.7	$397.3	$397.3
Environmental Benefits	$0.1	$0.1	$2.3	$10.2
Total Benefits	**$84**	**$88**	**$1,111**	**$2,863**
Capital Costs	$38.8	$38.8	$38.8	$38.8
Total Costs	**$39**	**$39**	**$39**	**$39**
Benefit/Cost Ratio	**2.2**	**2.3**	**28.6**	**73.8**
Net Present Value (NPV)	**$45**	**$49**	**$1,072**	**$2,825**

Table 31. BCA Results for 2S-26 (3 Percent Discount).

2S-26	3,000 ADT		19,000 ADT	
	20% Trucks	40% Trucks	20% Trucks	40% Trucks
Benefits and Costs	Present Value (M 2018$)		Present Value (M 2018$)	
Vehicle Operating Cost Savings	$9.5	$13.2	$344.4	$1,267.4
Business and Personal Time Cost Savings	$18.2	$19.0	$571.0	$1,452.4
Safety Benefits	$62.7	$62.7	$397.3	$397.3
Environmental Benefits	$0.1	$0.1	$3.0	$11.4
Total Benefits	**$91**	**$95**	**$1,316**	**$3,128**
Capital Costs	$38.8	$38.8	$38.8	$38.8
Total Costs	**$39**	**$39**	**$39**	**$39**
Benefit/Cost Ratio	**2.3**	**2.5**	**33.9**	**80.6**
Net Present Value (NPV)	**$52**	**$56**	**$1,277**	**$3,090**

Table 32. BCA Results for 2S-36 (3 Percent Discount).

2S-36	3,000 ADT		19,000 ADT	
	20% Trucks	40% Trucks	20% Trucks	40% Trucks
Benefits and Costs	Present Value (M 2018$)		Present Value (M 2018$)	
Vehicle Operating Cost Savings	$10.5	$14.4	$436.5	$1,398.8
Business and Personal Time Cost Savings	$20.0	$20.8	$718.5	$1,594.3
Safety Benefits	$62.7	$62.7	$397.3	$397.3
Environmental Benefits	$0.1	$0.1	$3.8	$12.5
Total Benefits	**$93**	**$98**	**$1,556**	**$3,403**
Capital Costs	$38.8	$38.8	$38.8	$38.8
Total Costs	**$39**	**$39**	**$39**	**$39**
Benefit/Cost Ratio	**2.4**	**2.5**	**40.1**	**87.7**
Net Present Value (NPV)	**$55**	**$59**	**$1,517**	**$2,264**

Table 33. BCA Results for 4U (3 Percent Discount).

4U	3,000 ADT		19,000 ADT	
	20% Trucks	40% Trucks	20% Trucks	40% Trucks
Benefits and Costs	Present Value (M 2018$)		Present Value (M 2018$)	
Vehicle Operating Cost Savings	$12.3	$17.1	$520.5	$1,411.8
Business and Personal Time Cost Savings	$23.9	$24.9	$871.8	$1,763.3
Safety Benefits	$19.0	$19.0	$120.4	$120.4
Environmental Benefits	$0.1	$0.1	$4.5	$12.6
Total Benefits	**$55**	**$61**	**$1,517**	**$3,308**
Capital Costs	$246.1	$246.1	$246.1	$246.1
Total Costs	**$246**	**$246**	**$246**	**$246**
Benefit/Cost Ratio	**0.2**	**0.2**	**6.2**	**13.4**
Net Present Value (NPV)	**($191)**	**($185)**	**$1,271**	**$3,062**

Table 34. BCA Results for 4D (3 Percent Discount).

4D	3,000 ADT		19,000 ADT	
	20% Trucks	40% Trucks	20% Trucks	40% Trucks
Benefits and Costs	Present Value (M 2018$)		Present Value (M 2018$)	
Vehicle Operating Cost Savings	$12.2	$16.9	$21.1	$1,648.5
Business and Personal Time Cost Savings	$23.6	$24.7	$181.9	$1,947.6
Safety Benefits	$125.3	$125.3	$793.4	$793.4
Environmental Benefits	$0.1	$0.1	$0.1	$14.7
Total Benefits	**$161**	**$167**	**$996**	**$4,404**
Capital Costs	$167.9	$167.9	$167.9	$167.9
Total Costs	**$168**	**$168**	**$168**	**$168**
Benefit/Cost Ratio	**1.0**	**1.0**	**5.9**	**26.2**
Net Present Value (NPV)	**($7)**	**($1)**	**$829**	**$4,236**

Table 35 and Table 36 summarize the results for all project types from Table 29 through Table 34. The results are shown for the same low and high ADT values as well as low and high percentages of trucks to provide a range of estimated outcomes. Values shown in red represent BCRs less than 1.0 and negative NPVs. Values in Table 36 are in millions of 2018 dollars.

Table 35. Benefit-Cost Ratios (Discounted at 3 Percent).

Project Type	3,000 ADT		19,000 ADT	
	20% Trucks	40% Trucks	20% Trucks	40% Trucks
2S-23	2.1	2.2	26.2	70.6
2S-33	2.2	2.3	28.6	73.8
2S-26	2.3	2.5	33.9	80.6
2S-36	2.4	2.5	40.1	87.7
4U	0.2	0.2	6.2	13.4
4D	1.0	1.0	5.9	26.2

Table 36. Net Present Values (Discounted at 3 Percent).

Project Type	3,000 ADT		19,000 ADT	
	20% Trucks	40% Trucks	20% Trucks	40% Trucks
2S-23	$42	$46	$977	$2,700
2S-33	$45	$49	$1,072	$2,825
2S-26	$52	$56	$1,277	$3,090
2S-36	$55	$59	$1,517	$2,264
4U	($191)	($185)	$1,271	$3,062
4D	($7)	($1)	$829	$4,236

The results in Table 35 and Table 36 show that Super 2 corridors outperformed not only the 2U base case for all analyzed scenarios but also generally outperformed the 4U and 4D cross-sections. The 2S-36 produced the highest BCR, while the 2S-26 produced the highest NPV. Consistent with findings from the operational analysis, the 2S-26 scenario showed better results than the 2S-33, indicating that adding shorter passing lanes is more beneficial than providing fewer but longer passing lanes.

Not surprisingly, the four-lane cross-sections had negative NPVs and marginal BCRs at the lower ADT because that type of widening project typically is not necessary for volumes that low. The 4U cross-section had negative NPVs at the lower ADT levels because the project costs are high, and the safety benefits are less than those attributed to the Super 2 scenarios. The 4U BCRs at the higher ADT levels were positive but still lower than those of the Super 2 scenarios. However, at the higher ADT levels, the 4U NPV was greater than the Super 2 scenarios with three passing lanes in each direction. While the 4U scenario produced lower safety benefits, the

4U vehicle operating cost savings and value of time savings surpassed those of the other scenarios.

The 4D scenario outperformed the 4U scenario at the lowest volume level for both truck percentages and at the highest volume level with the highest truck percentage. The 4D scenario with highest ADT and percentage of trucks produced the greater NPV but not BCR compared to 4U. The difference between the 4D and 4U at the highest volume and lowest truck percentage was relatively small. The Super 2 scenarios had better BCR results in all four conditions compared to 4D. This underscores the general consideration when evaluating BCA results that BCR and NPV should be considered together when making decisions regarding benefits or ranking of one project type over another.

The results shown in Table 29 through Table 36 are based on the project data available to the research team at the time of analysis. The addition of more project cost data, including data on the 2U+LT cross-section, would allow for a more refined model that not only would be based on a broader sample of projects, but could also be more sensitive to ADT and/or truck percentage if the traffic data are available for the same projects as the cost data.

SOURCES

This section contains the sources of the values and assumptions used in developing the BCA tool and its calculations. Table 37 through Table 42 describe the various factors, values, and applicable notes associated with each category of calculations used in the BCA tool.

Table 37. Sources for Time/Value Calculations.

Time/Value Factors	2018$	Source/Notes
Crew Cost Factor ($/hr per Crew Member)	$29.50	USDOT BCA Guidance, January 2020
Passenger Cost Factor ($/hr per Occupant)	$16.60	
Crew per Truck	1.00	
Passengers per Vehicle	1.67	

Table 38. Sources for Per-Vehicle Cost Calculations.

Per-Vehicle Cost Factors	**2018$**	**Source/Notes**
Environmental Cost $/Hour (Truck)	$0.48	Based on TREDIS emission rates and USDOT BCA guidance emission costs
Environmental Cost $/Hour (Passenger)	$0.07	
Vehicle Operating Cost ($/hr) (Passenger)	$4.92	*AAA's Your Driving Cost* publication; includes maintenance, repair, and tires (@ 55mph)
Vehicle Operating Cost ($/hr) (Truck)	$24.11	American Transportation Research Institute hourly cost value less fuel costs, driver wages, and driver benefits for 2018 (2019 publication)
Truck Gallons per Hour	9.84	TREDIS; assumes average speed of 50 mph
Passenger Gallons per Hour	1.83	TREDIS; assumes average speed of 35 mph
Truck $ per Gallon	$2.81	EIA's Petroleum & Other Liquids: https://www.eia.gov/dnav/pet/pet_pri_gnd_a_epd2d_pte_dpgal_a.htm
Passenger $ per Gallon	$2.35	EIA's Petroleum & Other Liquids: https://www.eia.gov/dnav/pet/pet_pri_gnd_dcus_r30_a.htm
Fuel Cost/hr (Truck)	$27.65	
Fuel Cost/hr (Passenger)	$4.30	

Table 39. Sources for Emissions Rates Calculations.

Emissions Rates	**Value**	**Source/Notes**
VOC (Truck)	0.00000184	Passenger cars and light trucks, medium-duty trucks, heavy-duty trucks, and buses are based on the U.S. Department of Energy's (DOE's) AFLEET 2018 model. AFLEET 2018 provides state-specific emissions rates that are collapsed to national rates using registration data for each state as reported in Federal Highway Statistics 2017. AFLEET values are based on the most recent version of the U.S. Environmental Protection Agency's MOVES and analysis prepared by DOE. For cars and light trucks, fleet composition and emissions are assessed using survival rates and mileage-based exposure factors used by NHTSA in rulemaking documents and sales volumes from *Ward's Automotive Handbook*. For medium-duty trucks, the average model year (MY) 2018 vehicle is assessed based on its expected emissions after 5 years of use. For heavy-duty trucks and buses, the average MY 2018 vehicle is assessed based on its expected emissions after 10 years of use. These time frames represent roughly the average age of vehicles in these classes.
NO_x (Truck)	0.00000417	
SO_x (Truck)	0.00000004	
PM (Truck)	0.00000114	
VOC (Passenger)	0.00000112	
NO_x (Passenger)	0.00000093	
SO_x (Passenger)	0.00000000	
PM (Passenger)	0.00000016	

Table 40. Sources for Emission Cost Calculations.

Emission Costs	**2018$**	**Source/Notes**
VOC	$2,100	USDOT BCA Guidance, January 2020
NO_x	$8,600	
SO_x	$50,100	
PM	$387,300	
CO_2	$43	
Environmental Cost/hr (Truck)	$0.48	
Environmental Cost/hr (Passenger)	$0.07	

Table 41. Sources for Safety Cost Calculations.

<u>**Safety Costs**</u>	<u>**2018$**</u>	<u>**Source/Notes**</u>
Injury Crash	$250,600	USDOT BCA Guidance, January 2020
Fatal Crash	$10,636,600	
Fatalities per 100 Million VMT (2017)	1.16	NHTSA's Traffic Safety Facts Annual Report Tables: https://cdan.nhtsa.gov/tsftables/tsfar.htm#
Injured Persons per 100 Million VMT (National Rate 2017)	85	NHTSA's Traffic Safety Facts Annual Report Tables: https://cdan.nhtsa.gov/tsftables/tsfar.htm#

Table 42. Sources for Crash Modification Factor Calculations.

<u>**Crash Modification Factors**</u>	<u>**Value**</u>	<u>**Source/Notes**</u>		
Convert 2-Lane Roadway to 4-Lane Divided Roadway	0.34	4D	Ahmed et al (*109*)	Crash Modification Factors Clearinghouse (CMF ID 7566): http://www.cmfclearinghouse.org/index.cfm
Installation of Passing Relief Lane	0.67	2S	Bagdade et al (*110*)	Crash Modification Factors Clearinghouse (CMF ID 4858): http://www.cmfclearinghouse.org/index.cfm
2U to 4U Conversion	0.90	4U	*Safety Evaluation of Two-Lane to Four-Lane Conversions in Wisconsin:* https://minds.wisconsin.edu/bitstream/handle/1793/69510/MS_Thesis_AsareYeboah_Veronica.pdf?sequence=1&isAllowed=y	
Covert Injuries/Fatalities to Crashes	*FHWA Crash Costs for Highway Safety Analysis:* https://safety.fhwa.dot.gov/hsip/docs/fhwasa17071.pdf			

CHAPTER 6: FINDINGS AND CONCLUSIONS

This chapter summarizes the work completed throughout the project, as documented in the previous chapters of this report, and provides a listing of the researchers' key conclusions. This chapter also includes the researchers' recommendations for future action based on those conclusions.

FINDINGS FROM THE LITERATURE

During the course of this research project, researchers have reviewed relevant literature and research findings, as well as current policies in other states. Observations from those efforts led to several findings on the design and performance of Super 2 roadways:

- Texas policy on Super 2 design is discussed in Chapter 4, Section 6 of the TxDOT *Roadway Design Manual* (*2*), which provides guidance on lane width, shoulder width, passing lane length, taper dimensions, and other notes for practitioners.
- A number of other states have provisions in their respective roadway design guides describing the construction requirements for Super 2–type roadways or single passing lanes on two-lane, two-way highways, but many of them do not provide the level of detail on geometric design guidance found in the *Roadway Design Manual*.
- Internationally, similar roads are found in a number of countries, but they are usually built as a constant three-lane cross-section where the passing lane alternates from one direction of travel to the other. These are generally labeled as 2+1 roads and often have a median area and/or a median barrier, which restricts passing outside of the provided passing lanes. Design speeds and speed limits for international 2+1 roads are similar to those found in Texas, though they are often used at higher volumes than are typically found on two-lane roads in this state.
- Researchers reviewed studies that included a number of methods and tools for simulating traffic on passing lanes on rural two-lane highways. As of the time this project was conducted, VISSIM was determined to have the best ability to replicate the conditions desired to evaluate the cross-section alternatives.
- Analyses of crash data both within and outside Texas indicate reductions in crashes, injuries, and/or fatalities with the installation of passing lanes on rural two-lane

highways, ranging from 21 to 63 percent depending on the type of crash, type of injury, and inclusion of intersections in the analysis.

- A review of economic influences on Super 2 performance revealed that the total cost of a project with a particular purpose, scope, and length could vary widely depending on factors such as time, location, traffic, project contracting, special provisions, public outreach, acquisition of right-of-way, and accommodation of utilities. Cost estimates can change from one agency to another, as can the estimated value of a crash or the value of time. In a BCA, it is important to obtain as much data as possible from a source that most closely reflects the needs and practices of the agency and audience for which the analysis is intended.
- Similarly, a large number of potential economic influences could be included in a BCA, but the analysis should focus on those factors for which data can be obtained and which the agency or audience use. A very detailed analysis model can provide insights on the effects of many factors, but a simpler or streamlined model can also provide a reasonable estimate of the factors of interest with fewer steps and simpler input by the user.

SUMMARY OF DATA COLLECTION EFFORTS

Researchers used information already collected in previous efforts, along with information solicited from TxDOT district offices, for known locations of Super 2 corridors. This effort produced a database with 90 constructed sites and 58 planned sites. In their discussion of which of those sites to include as candidate study sites, researchers focused on identifying Super 2 corridors with relatively high and relatively low traffic volumes, to better identify locations that might be representative of locations in the state that are either likely to be expanded from two-lane to Super 2 highways or from Super 2 to four-lane highways based on traffic volume. Researchers also looked for sites with high truck percentages to help capture that effect in operations data to be collected and analyzed. Finally, researchers favored sites that were clustered relatively close together, to make data collection more efficient by enabling the collection of multiple sites on each data collection trip. Ultimately, researchers identified 15 candidate sites for study, which were narrowed to five sites where field data were collected:

- US-281 south of Blanco.
- US-183 north of Gonzales.
- US-59 west of Freer.
- US-67/US-90 east of Marfa.
- US-67 north of Alpine.

The objectives of the field data collection were to document highway operating conditions approaching, within, and departing each passing lane study site. The research team used two types of field data collection equipment: digital video recording equipment and road tube-based counter/classification equipment. Digital video was recorded at both the entry and exit from each of the passing lanes at the five study sites to document motorist behavior, vehicle classification, lane selection, and merge conflicts. In total, 240 hours of video documenting the passing lane activities of over 12,000 motorists were collected.

Counter/classifiers collected data before each passing lane, at the beginning and end of each passing lane, and after each passing lane to obtain information on traffic volume, speed, headway, and classification. The collected data resulted in vehicle volumes approximately ranging from 1,100 to 10,000 vpd and truck percentages from 5 to 25 percent. Speeds within passing lanes, as expected, tended to be somewhat higher than the speeds in adjacent through lanes, though not consistently higher than speeds upstream or downstream of the passing lane.

SUMMARY OF SIMULATION RESULTS

Data from the field study sites formed the basis of a VISSIM simulation of a 40-mile corridor with a variety of cross-section options. The length of the corridor was fixed, as was the location of access points (and their respective volumes) along the corridor. The cross-section, ADT, and truck percentage of the corridor were changed in various scenarios to evaluate relative operational performance of the corridor. Based on the results produced by the VISSIM simulation of 216 combinations of cross-sections, ADT, and truck percentages, the research team identified the following noteworthy trends:

- The 2U cross-section consistently had the lowest or second-lowest speeds (and highest delays) for every volume and truck percentage tested.
- The 2S-36 (i.e., Super 2 with passing lane length of 3 miles and 6 passing lanes in each direction), as expected, had the best performance of the Super 2 options. The

2S-26 outperformed the 2S-33 in every scenario, further supporting previous findings that more passing lanes (6 rather than 3 in this comparison) provide more operational benefit than longer passing lanes (2 miles rather than 3 miles in this comparison).

- The 4U cross-section had the highest speeds for all volumes up to 15,000 ADT, but its performance declined sharply above that level, even underperforming the 2U cross-section in some cases. A similar trend was found in the delay results, though not as pronounced. These trends support safety research that also concludes that alternatives that include Super 2 corridors or turning lanes are often preferable to the 4U cross-section.
- The 4D cross-section had performance measures that were similar to 4U at volumes of 13,000 vpd and below, but the 4D was more susceptible to the effects of trucks and turning vehicles at higher volumes, showing large differences in speed and delay results with each volume increment at 15,000 vpd and above.
- Performance of the 2U+LT cross-section was similar to that of the 2U for ADTs up to 15,000 but stabilized at higher volumes. This resulted in higher speeds than most, if not all, other options at 19,000 ADT, and lower delays at higher volumes as the truck percentage increased. Combined with the results for the 4U and 4D cross-sections, this suggests that as the volume and truck percentage increase, providing accommodation for turning vehicles outside the through lane, even for low volumes of turning vehicles, can produce more operational benefit than an additional through lane or a passing lane to process traffic near access points.
- The incremental changes in speed and delay performance for all cross-section options increased greatly above 15,000 ADT, compared to lower volume levels. The relative performance of each cross-section also changed at the highest volume levels, such that a reliable hierarchy of performance at 15,000 vpd or below did not result at higher volumes. These results indicate that when considering treatment options for one of these higher-volume conditions for an existing highway, the design process should particularly consider the presence of turning vehicles, rather than predominantly emphasize through vehicles traveling from one end of the corridor to the other. Providing turning lanes may be more beneficial in operations, as well as safety, than providing passing lanes, if a choice must be made between the two.

Based on the results produced by the BCA model, the research team identified the following noteworthy trends:

- The Super 2 scenarios had the highest BCRs in all ADT and truck percentage configurations. The 2S-36 produced the highest BCR, while the 2S-26 produced the highest NPV. Consistent with findings from the operational analysis, the 2S-26 scenario showed better results than the 2S-33, indicating that adding shorter passing lanes is more beneficial than providing fewer but longer passing lanes.
- The 4U had negative NPVs at the lower ADT levels because the project costs are high, and the safety benefits are less than those attributed to the Super 2 scenarios. The 4U BCRs at the higher ADT levels were positive but lower than those of the Super 2 scenarios. However, at the higher ADT levels, the 4U NPV was greater than the Super 2 scenarios with three passing lanes in each direction. While the 4U scenario produced lower safety benefits, the 4U vehicle operating cost savings and value of time savings surpassed those of the other scenarios.
- The 4D scenario outperformed the 4U scenario at the lowest volume level for both extremes of truck percentages and at the highest volume level with the highest truck percentage. The 4D scenario with highest ADT and percentage of trucks produced the greater NPV but not BCR compared to 4U. The difference between the 4D and 4U at the highest volume and lowest truck percentage was relatively small. The Super 2 scenarios had better BCR results in all four conditions compared to 4D; this was because the higher construction costs for a 4D cross-section outweighed the 4D's greater safety benefit.
- The availability of more cost data would allow for a more refined BCR and NPV. Currently, scenarios with ADT ranging from 3,000 to 19,000 are all applied with the same capital cost per mile for the specified project type.

SUGGESTIONS FOR FUTURE RESEARCH

This project considered a variety of detailed characteristics related to Super 2 corridors and their relative operational and economic performance compared to other cross-section alternatives. The findings from this project reinforce the conclusions and recommendations from previous projects related to the benefits of Super 2 corridors as improvements to traditional two-lane highways, and also provide insights into the relative performance of four-lane highways. During the course of the project, the research team identified items that would be beneficial to further describe the usefulness of Super 2 highways, provide more support and justification for their use across the state, and aid practitioners in their decisions to install them. Those items are presented as suggestions for future research, as follows:

- **Further development of the BCA tool with additional project data:** The BCA spreadsheet tool developed as part of this project provides useful insights into the expected economic performance of various cross-section alternatives. That tool is based in part on costs of previous TxDOT construction projects that include the cross-sections being considered; however, those cost data were limited to the construction projects available to the research team and the Project 0-6997 Project Monitoring Committee. As a result, no data on 2U+LT were available for use in developing the model for the spreadsheet tool. Expanding the source data used for construction costs in the model will not only allow the inclusion of 2U+LT as an alternative, but will also make the model for the other alternatives more robust.
- **Refine CMF for Super 2:** Some information on the crash reduction benefits of Super 2 highways does exist from previous projects in Texas and elsewhere; however, previous efforts have been somewhat constrained by either the limitations of the respective research projects or the number of Super 2 sites (and the amount of related crash data) available. The number of Super 2 corridors that have been built in the previous decade will provide a sizeable addition to the potential sample size that would be used to develop a CMF focused on Super 2 corridors in Texas. A formal CMF based on a rigorous review of crash data and corresponding statistical analysis would provide additional support for installing new Super 2 corridors around the state and would also provide additional refinement to the BCA tool.
- **Analysis of the 4D+LT cross-section:** The operational analysis revealed some unexpected results on performance measures of 4D cross-sections at higher volumes and truck percentages. The results indicated that the 4D may be more sensitive to turning vehicles at higher volumes than previously thought because with a four-lane cross-section, through vehicles are using both lanes in each direction, and a turning vehicle disrupts the flow of traffic in the left-hand through lane if an appropriate gap

is not available to complete the turn, even if a median provides a nominal amount of storage. The 2U+LT cross-section, though it has only one through lane, confines through traffic in that lane. Even though average speeds may be lower than with a 4D cross-section, the potential disruption and delay are also lower because through vehicles are not greatly affected by the turning vehicles that are waiting in the turning lanes. An expanded investigation into the characteristics of a 4D cross-section with turning lanes would help to better explain and quantify these effects of turning vehicles.

SUGGESTIONS FOR IMPLEMENTATION

This project developed a BCA tool for practitioners to use in making decisions on the type of cross-section to select for a given construction project. While a copy of the spreadsheet tool is provided as a deliverable for this project, along with discussion and instructions on its use, a series of virtual workshops to demonstrate the tool to practitioners may be useful in encouraging its widespread use. Practitioners may also provide valuable feedback on features of the tool that could be refined or expanded.

This project also developed a guidebook on Super 2 corridors (*111*) to provide a single-source reference for the principles related to the use of Super 2 passing lanes on the state's rural two-lane highways. Sharing this guidebook with practitioners both within and outside TxDOT will not only help publicize the existence of the guidebook but also promote its use and distribution, which will encourage consistent use of Super 2 corridors statewide and put into practice the findings from Project 0-6997 and previous TxDOT-sponsored research over the last two decades.

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