PASSING BEHAVIOR OF DRIVERS ON SUPER 2 HIGHWAYS IN TEXAS

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ABSTRACT
As traffic volumes increase in many jurisdictions, in both urban and rural areas, the demand on the highway network also increases. Specifically, as rural traffic volumes rise in Texas, the pressure on the state's network of two-lane highways rises accordingly. The increased volumes have an effect on congestion, air quality, and safety as traffic density increases, often approaching the limits of capacity for two-lane highways. High proportions of heavy vehicles compound the problem, contributing to a decrease in safety as impatient drivers attempt to pass slower vehicles in no-passing zones or pass trucks despite having diminished sight distance beyond such vehicles. Previous research in Texas demonstrated that periodic passing lanes can improve operations on two-lane highways with low to moderate volumes; these "Super 2" highways can provide many of the benefits of a four-lane alignment at lower cost. The current Texas Roadway Design Manual contains these guidelines for highways with Average Daily Traffic (ADT) lower than 5000. A current research project is expanding on that research to develop design guidelines for length and spacing of passing lanes on two-lane highways with higher volumes. That project will consider the effects of volume and terrain on traffic flow; in addition, the effects of varying proportions of heavy vehicles will also be considered. This paper will discuss the findings from an observation of passing maneuvers on existing Super 2 highway corridors in Texas, with an emphasis on where passing maneuvers occur within the passing lane and potential implications on congestion, crash reduction, and improved safety.

INTRODUCTION

As vehicular traffic in rural areas continues to increase, state departments of transportation are looking for ways to accommodate that traffic, even as demands on their budgets also increase. Specifically, as rural traffic volumes rise in Texas, the pressure on the state's network of two-lane highways rises accordingly. The increased volumes have an effect on congestion, air quality, and safety as traffic density increases, often approaching the limits of capacity for two-lane highways. High proportions of heavy vehicles compound the problem, contributing to a decrease in safety as impatient drivers attempt to pass slower vehicles in no-passing zones or pass trucks despite having diminished sight distance beyond such vehicles.

Traditionally, roadway agencies expand a two-lane highway to four lanes when certain criteria are met, such as daily traffic volumes, peak volumes, prevailing speeds, and/or crash history. As more rural highways approach conditions that meet these criteria, agencies are looking for alternatives to full four-lane expansion to provide a measure of operational benefits at lower cost. Previous research in Texas demonstrated that periodic passing lanes can improve operations on two-lane highway corridors with low to moderate volumes; called "Super 2" highways in Texas, these improved corridors can provide many of the benefits of a four-lane alignment at lower cost.

As traffic volumes increase on the state's two-lane roads, along with the volumes of heavy vehicles, the effects of limited passing sight distance are magnified, creating more locations where Super 2 highways can be effective. As a result, opportunities increase for longer passing lanes occurring at shorter spacing.

A current project is expanding on previous research to develop design guidelines for length and spacing of passing lanes on two-lane highways with higher volumes. That project will consider the effects of volume and terrain on traffic flow; in addition, the effects of varying proportions of heavy vehicles will also be considered. This paper will discuss findings from a field observation of two passing lane sites as part of the research from that project.

EXISTING CRITERIA

The Texas *Roadway Design Manual* (RDM) contains the current description of and guidance for the use of passing lanes on Super 2 highways in Texas. (*1*) It states that passing lane length and spacing are the critical elements to Super 2 highways, as the lanes must have sufficient length to allow drivers to complete the passing maneuver and they must be properly spaced to provide adequate passing opportunities. Guidance on passing lane length and spacing is based primarily on the ADT of the roadway, as shown in Table 4-6 of the *Roadway Design Manual*, reproduced here as TABLE 1.

TABLE 1 Super 2 Passing Lane Length and Spacing by ADT (*1*)

Two-Way ADT (vpd)	Recommended Passing Lane Length, mi (km)	Recommended Distance Between Passing Lanes, mi (km)
< 2000	1.0 (1.6)	5 - 9 (8.0 - 14.5)
2001 - 5000	1.5 - 2.0 (2.4 - 3.2)	4 - 9 (6.4 - 14.5)
> 5000	Conversion to four-lane highway should be considered	

The design criteria for passing lane sections are the same as the 3R design guidelines for other rural two-lane highways. These guidelines are also based on ADT, as shown in TABLE 2. The RDM adds that passing lanes should be located to best fit existing terrain and field conditions: "Uphill grades are preferred sites over downhill grades. Passing lanes on significant uphill grades should extend beyond the crest of the hill. Passing lane sections and transitions should be placed to avoid major intersections. If present, minor intersections that do not require deceleration lanes should be located near the midpoint of passing lane sections and also avoid transition areas to the extent practical." Other than these general statements, the guidelines do not account for effects of terrain, and they do not include adjustments for substantial proportions of heavy vehicles. The manual adds that providing a passing lane section downstream of a traffic signal for platoons leaving an urbanized area is particularly beneficial in dispersing the platoons and improving operations in rural areas.

TABLE 2 3R Design Guidelines for Rural Two-Lane Highways, US Customary Units (*1*)

Design Element [a]	Current Average Daily Traffic		
	0-400	400-1500	1500 or more
Design Speed [b]	30 mph	30 mph	40 mph
Shoulder Width (ft)	0	1	3
Lane Width (ft)	10	11	11
Surfaced Roadway (ft)	20	24	28
Turn Lane Width (ft) [c]	10	10	10
Horizontal Clearance (ft)	7	7	16
Bridges [d]: Width to be retained (ft)	20	24	24 [e]

NOTES:
(1 ft = 0.3048 m)
[a] These values are intended for use on rehabilitation projects. However, the designer may select higher values to provide consistency with adjoining roadway sections, to provide consistency with prevailing conditions on similar roadways in the area or to provide operational improvements at specific locations.
[b] Considerations in selecting design speeds for the project should include the roadway alignment characteristics as discussed in this chapter. 30 mph = 48 km/h; 40 mph = 64 km/h.
[c] For two-way left turn lanes, 11 ft - 14 ft usual.
[d] Where structures are to be modified, bridges should meet approach roadway width as a minimum. (Approach roadway width is the total width of the lanes and shoulders.) Greater bridge widths may be appropriate if the rehabilitation project increases roadway life significantly or if higher design values are selected for the remainder of the project. Existing structure widths less than those shown may be retained if the total lane width is not reduced across or in the vicinity of the structure.
[e] For current ADT exceeding 2000, minimum width of bridge to be retained is 28 ft.

The RDM says the purpose of Super 2 highways is to allow the passing of slower vehicles and the dispersal of traffic platoons, with the caveat that they should only be considered in rural areas. The Manual also addresses installations that approach four-lane alignments, saying that "significant lengths or segments of passing lanes are not encouraged. If traffic volumes are such that significant lengths or segments of passing lanes are necessary, then construction of another category of roadway should be considered." However, the manual adds that "a passing lane is appropriate for areas where passing sight distances are limited. The location of the proposed lane addition should offer adequate sight distances and lane taper. The location selection should also consider the presence of intersections and high volume driveways in order to minimize the volume of turning movements on a roadway section where passing is being encouraged." (*1*)

RECENT RESEARCH

Basis for Current Texas Guidelines

A previous research project in Texas produced recommendations for the current design guidelines for Super 2 highways in Texas. (*2*) Researchers on that project collected field data at existing Super 2 sections in Minnesota and Kansas, in order to gain firsthand knowledge of normal operations and to personally view installed designs with signing and marking details; they collected data on operating speeds, distribution of trucks, lane splits, and headways. The data provided them with a sample of real-world data on the passing maneuvers taking place on Super 2 sections and the conditions associated with those maneuvers. Additional field studies at passing lane transitions in Texas provided comparison data to the Minnesota and Kansas data. The research team also conducted a survey of Texas drivers to gather their input and gauge the then-current attitudes toward passing behavior. In addition, researchers created a test bed scenario for microscopic simulation, evaluating operating characteristics for a variety of passing lane lengths and spacing, traffic volumes, and heavy vehicle percentages. Based on the findings from analyzing those various data sets, researchers developed recommendations for passing lane length and spacing, lane and shoulder widths, signs, and pavement markings. Those recommendations, which were the basis for the current guidelines in the Texas *Roadway Design Manual*, are shown in TABLE 3, TABLE 4, and FIGURE 1.

TABLE 3 Recommended Values of Length and Spacing by ADT and Terrain (*2*)

ADT (vpd)		Recommended Passing Lane Length (mi)	Recommended Distance Between Passing Lanes (mi)
Level Terrain	Rolling Terrain		
≤ 1950	≤ 1650	0.8-1.1	9.0-11.0
2800	2350	0.8-1.1	4.0-5.0
3150	2650	1.2-1.5	3.8-4.5
3550	3000	1.5-2.0	3.5-4.0
Note: 1 mi = 1.6 km			

TABLE 4 Recommended Values for Lane and Shoulder Widths (*2*)

Lane Width	
12 ft (3.6 m) or Values in Table 3-8 of TxDOT's *Roadway Design Manual*	
Shoulder Width*	
Minimum (allowable only where traffic volumes are below 2000 ADT):	6 ft (1.8 m) if rumble strips are used 4 ft (1.2 m) if rumble strips are not used
Desirable:	Values in Table 3-8 of TxDOT's *Roadway Design Manual*
*Shoulders used in passing lane sections should be paved.	

The design elements recommended by that project are similar to those found in the Texas *Roadway Design Manual*, except that the RDM reduces the number of ADT categories and simplifies the length and spacing ranges. The RDM also refers the designer to existing lane and shoulder width guidelines rather than provide separate guidelines for passing lanes. The sign and marking layout, shown in FIGURE 1, identified two specific informational signs for the length and spacing and a skip-stripe marking to reinforce the preferred behavior that drivers should travel in the right lane except when passing.

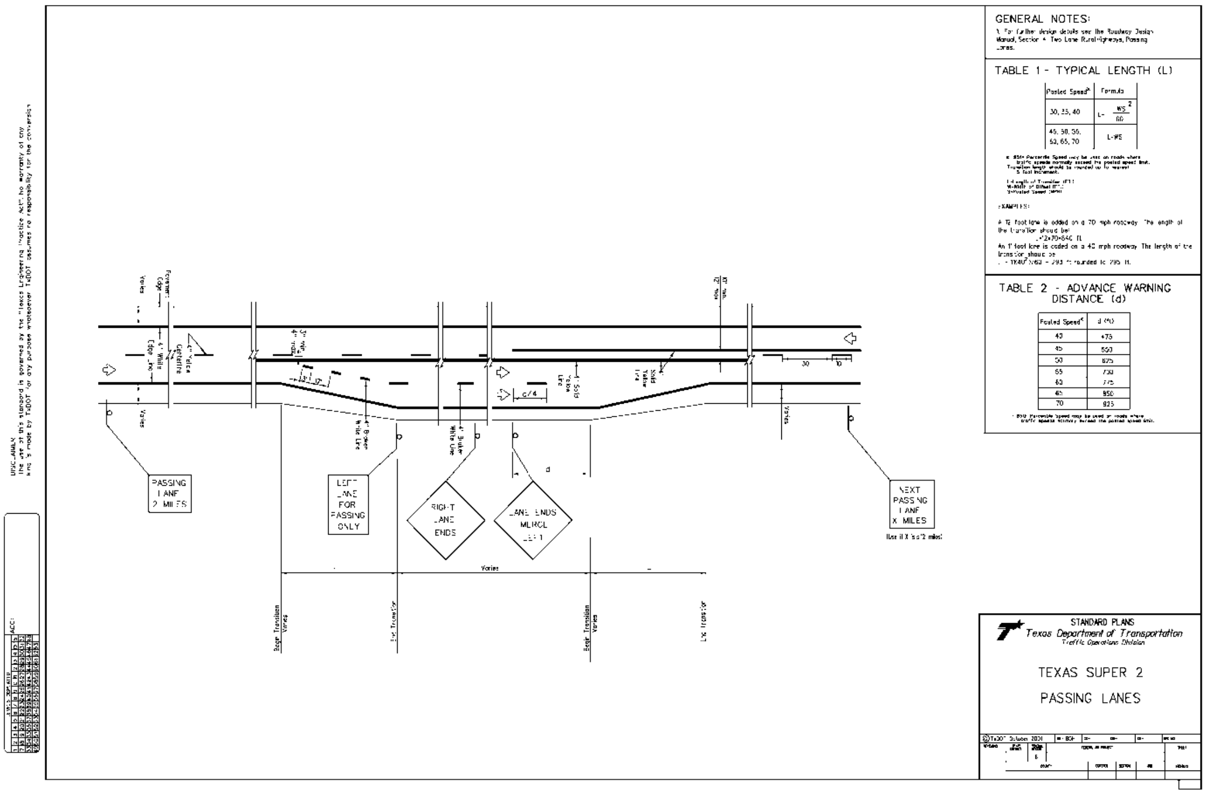


FIGURE 1 Super 2 signing and marking layout. (*2*)

Traffic Volumes

The Texas research project provided recommendations for passing lanes on highways with Average Daily Traffic (ADT) no more than 5000 vehicles per day (vpd), and current TxDOT *Roadway Design Manual* (RDM) guidelines limit Super 2 recommendations to highways with less than 3550 ADT, with the advice that a four-lane cross-section should be considered for higher volumes. However, recent studies have evaluated operations on higher-volume passing lane sections in other states.

In 2006, Gattis, Bhave, and Duncan reported on a study of passing lane operations, focusing on continuously alternating passing lane sections in Arkansas. (*3*) Their field study contained four sites with average flow rates between 164 and 445 vehicles per hour and maximum flow rates from 232 to 724 vehicles per hour. Their findings indicated that the passing lane sections reduced the percentage of vehicles in platoons by about 14 percent, with much of that reduction coming in the first 0.9 mi (1.4 km) of the passing lane. They also found that passing maneuvers increased as volume increased, inferring that higher-volume roads could use longer passing lanes. A broader review of the crash data at 19 passing lane sites showed that even though the average ADT of those sites (5,293 vpd) was almost three times the statewide average for rural two-lane undivided highways (1,857 vpd), the crash rates at 16 of those sites were lower than the statewide average of 1.4 crashes per million vehicle miles.

Potts and Harwood conducted an evaluation of the benefits and effectiveness of passing lanes in Missouri. (*4*) They analyzed three roadway sections comparing traffic operations before and after installation of passing lanes on rural two-lane highways. The three sites had ADTs ranging from 4,500 to 10,600 vpd, each with truck and recreational vehicle proportions of 10 and

5 percent, respectively. Analysis of the sections showed that the level of service improved noticeably at each site, based on the average travel speed and the percent time spent following; two of the three sites improved LOS by two letter levels. A review of accident data showed that the accident rates for two-lane highways with passing lanes were approximately 29 percent lower than the rates for traditional two-lane highways in the same districts.

Passing Lane Design Characteristics

Gattis, Bhave, and Duncan reported that the greatest benefits of passing lanes in their study of continuous three-lane cross sections (see FIGURE 2) were observed in the first 0.9 mi (1.4 km). (*3*) Between 0.9 and 1.9 mi (1.4 and 3.1 km), the benefits were less pronounced but were more likely to accrue as volumes increased. Where continuous three-lane cross sections with alternating passing lanes segments are present, they concluded, agencies should reexamine the need for any passing lane that continues beyond approximately 1.9 mi (3.1 km) in length. This study suggests that a rather high volume is needed before extra length produces any notable degree of extra benefits. It may be that the other direction of travel would benefit more from an earlier termination and a switch in the direction having the additional lane for passing.

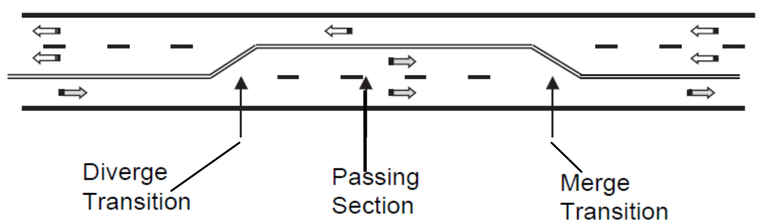


FIGURE 2 Schematic example of three-lane alternate passing design. (*3*)

EVALUATION OF EFFECTIVENESS

Existing Guidance on Evaluating Super 2 Performance

The *Highway Capacity Manual* (HCM) provides guidance on the evaluation and analysis of existing passing lane sections, based on microscopic simulation, field data, and theoretical concepts. (*5*) According to the HCM, the capacity of a two-lane highway is 1,700 passenger cars per hour (pc/h) for each direction of travel, with a combined capacity of 3,200 pc/h in both directions for extended lengths of highway. However, these theoretical capacities and the corresponding level of service are negatively affected by terrain, heavy vehicles, the peak hour factor, lane and shoulder widths, and other factors. Providing a passing lane on a two-lane highway in level or rolling terrain has a positive effect on the level of service in that direction of travel; this effect can be estimated by an operational analysis procedure.

The HCM analysis procedure provides a methodology for determining the appropriate section length for analysis, the percent time spent following, the average speed, and the level of service, among other metrics. However, the methodology is only intended for the analysis of a single passing lane section and its adjacent upstream and downstream two-lane sections. For analysis of the interactions between two or more passing lane sections (i.e., the support for appropriate passing lane spacing), the HCM recommends using simulation modeling and provides guidance on selected variables to consider in the simulation.

Platooning

Gattis et al. studied operations on selected passing lanes in northwest Arkansas. (*6*) Two of the passing lanes were shorter than 1400 ft, while the third was longer than 2500 ft. At all three sites, vehicles had traversed roadway sections with limited passing opportunities before they encountered passing sections on slight to moderate upgrades. By studying traffic at such sites, the researchers observed the behaviors of motorists who may have been restrained by slower traffic ahead, but who then encountered a relatively unconstrained environment that allowed them to pass if they became displeased or frustrated with the confinement they experienced in the traffic stream.

The number of vehicles in platoons per hour increased linearly with the total traffic volume. A regression analysis on the data yielded the following linear relationship: number of vehicles in platoons/hr = -151 + 1.22 × (total one-direction volume). The R^2 value for the regression analysis was 0.97, with the independent variable ranging from 325 to 525 vph. A slightly smaller proportion of vehicles attempted to pass on the short lanes than on the long lanes. This could have reflected driver judgment that there was insufficient distance in which to complete a pass on the short lane sections. In both data sets, passing success declined when headways were greater than 2.0 sec.

They also found that at both the short lane and the long lane sites, when headways were 3.0 sec or more and platoon speeds were 50 mph (80 km/h) or more, 85 percent of drivers exhibited little desire to pass. This suggests that many drivers may readily tolerate a slight level of congestion or platooning on two-lane rural roads. The findings from this research support the views of those who consider the 5.0-sec headway to be excessive when defining delay on two-lane rural highways. In the authors' opinion, a combination of both headway and platoon speed might more accurately define what the motorist considers to constitute delay.

FIELD STUDIES

Background

In the current Texas research project, Texas Department of Transportation (TxDOT) Districts were surveyed for locations where passing lanes currently exist. Sufficient detail was requested to differentiate locations where passing lanes were added to serve as climbing lanes from locations where passing lanes were added as Super 2 sections in level or gently rolling terrain. From all locations identified, two Super 2 locations, one in the Paris District and one in the Yoakum District, were selected for data collection.

The goal of the data collection effort was to document driver behavior and traffic conditions at the beginning and ending of the passing lanes and to collect real-world traffic volume, classification, speed, and headway data before, within and beyond each passing lane. These data will be used to calibrate the traffic simulation model (the Traffic Analysis Module – TAM – within the Federal Highway Administration's Interactive Highway Safety Design Model – IHSDM) used later in the research analysis and to develop estimates of passing lane impacts across ranges of traffic volumes found along two-lane roadways in Texas.

Description of Study Sites

Paris District

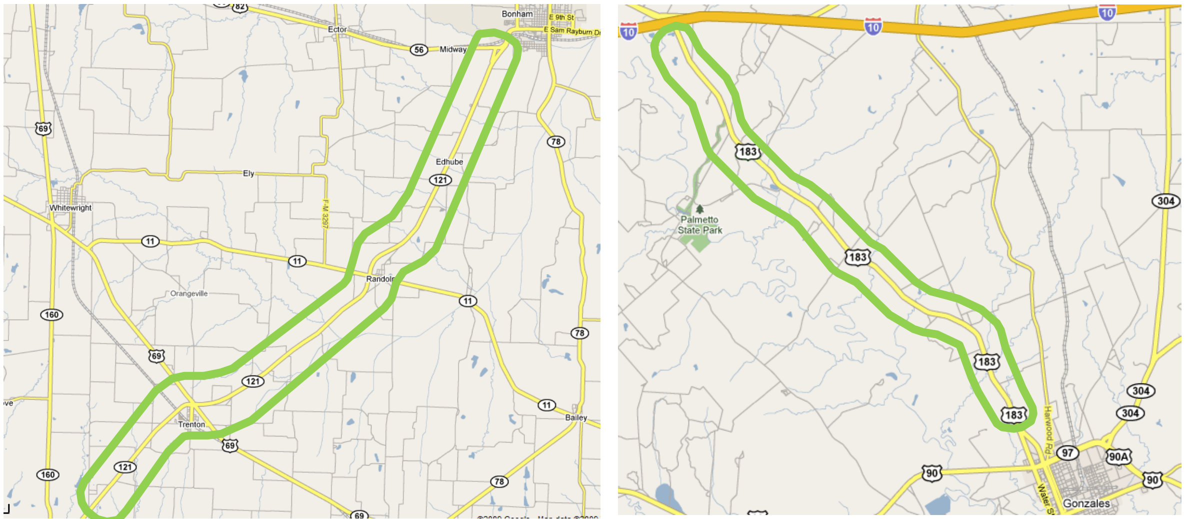
Passing lanes in the TxDOT Paris District were located along State Highway (SH) 121 between the Collin/Fannin County line and the SH 56 junction just west of the town of Bonham, Texas (FIGURE 3a). Within these boundaries, SH 121 is a two-lane rural roadway with a 70 mph speed limit. Between passing lanes the roadway is striped as a no-passing zone. SH 121 intersects several Farm-to-Market (FM) roads in this area, and all are at-grade intersections with two-way stop control on the FM roads. The corridor also has intersections with two major roadways, US 69 and SH 11, both of which are grade-separated and allow SH 121 traffic to remain uninterrupted. Right lane additions are present along both the SH 121 approaches to and departures from SH 11; the right lanes act simultaneously as passing lanes further from SH 11 and right-turn deceleration or acceleration lanes closer to the interchange.

For northbound SH 121, the passing lane section north of the Fannin County line was selected for data collection. The spacing between the end of this passing lane section and the beginning of the next downstream passing lane north of the US 69 interchange was approximately three miles. For southbound SH 121, researchers chose the passing lane section between SH 11 and US 69 for field data collection; the next passing lane section was located approximately 2.7 miles downstream, approaching the FM 814 intersection.

Yoakum District

Several passing lane sections are found along US 183 between Interstate 10 (I-10) and the city of Gonzales, Texas; FIGURE 3b shows an overview of the area. US 183 is a two-lane roadway with a 70 mph speed limit through the rural area between I-10 and northern Gonzales, but approaching the city it expands to a four-lane facility south of Business 183. Passing is allowed between passing lane sections in locations with adequate sight and passing distance, though mildly rolling terrain and horizontal curves limit the number of locations where passing is allowed. Several minor roadway intersections are found within the study boundaries, including Park Road 11 and FM 1586. All cross-street intersections with US 183 are two-way stop controlled with cross-street traffic stopping.

Two passing lanes are found in the southbound direction along US 183 within the study boundaries. The first passing lane is located just south of I-10, and the second passing lane begins roughly 4.5 miles downstream of the end of the first passing lane. With only two passing lanes present, researchers opted to study the upstream passing lane, which was about 3.1 miles long, and the roadway segment downstream of this passing lane to the start of the second passing lane section. In the northbound direction, there is only a single passing lane within the study bounds. This passing lane begins about 5.1 miles north of Business 183 in northern Gonzales and is two miles long. Whereas at all other data collection sites there is a length of roadway to study between passing lane sections, in this case there is no location where a second passing lane is added approaching the I-10 interchange. Accordingly, the data collection procedure at this site required the setup of traffic monitoring and counting equipment upstream of, rather than downstream of, the passing lane section.



(a) SH 121 **(b) US 183**

FIGURE 3 Study site boundaries.
(Source: Google® Maps, maps.google.com)

Field Data Collection

Two types of data collection equipment were employed for collecting passing lane data along SH 121 and US 183. A video trailer with a telescoping mast was used to capture driver behavior approaching each of the four passing lane sections studied. A second trailer was also used to collect driver merging behavior at the downstream end of each passing lane section. Two cameras with pan, tilt and zoom capability atop the mast allowed the field analysts to observe a field of view that included a short roadway segment preceding the passing lane, the expansion taper and an additional roughly one-quarter mile distance downstream at the beginning of each passing lane. At passing lane termini, a single camera was used and the field of view included the lanes approaching the reduction taper, the taper itself, and a short distance downstream. Digital video recording equipment was used to create a permanent 24-hour site visit video for passing lane beginning and ending points for each of the four passing lanes studied.

The second type of field data collection equipment analysts used for the passing lane field studies was portable traffic analyzers, or "plate counters." The sensor determines vehicle count, speed, and classification data using magnetic imaging technology and is able to record speed, classification and headway data for each individual vehicle passing over the sensor. Counter data were collected for each location before, within, and after each passing lane. Both types of data are described in the following sections, and summary values of each data type are presented.

DATA ANALYSIS

Passing Lane Entrance

Data collected from video at the beginning of the passing lane for each of the four study sites included lane selection and observed passing behavior. Analysts recorded motorist lane selection by vehicle type and whether vehicles entering the passing (left) lane were initiating a passing maneuver at the upstream end of the passing lane. Summaries of the data for each site are provided in TABLE 5.

TABLE 5 Passing Lane Entrance Data

Site	24-Hour Count of Vehicles	Vehicles Entering Left Lane		Trucks	
		Percent of 24-Hour Count	Percent Passing	Percent of 24-Hour Count	Percent Entering Right Lane
SH 121 NB*	2731	22.1	91.9	4.3	92.4
SH 121 SB*	2736	20.8	65.9	4.9	80.9
US 183 NB	2844	48.1	24.9	7.8	73.6
US 183 SB	2780	13.2	80.3	10.4	95.3

*These sites had inadequate lighting to reduce data during nighttime hours, so the vehicle counts shown are lower than the actual 24-hour count.

TABLE 5 shows that just over twenty percent of vehicles on SH 121 enter the left lane, and a large majority of the vehicles entering the left lane are passing vehicles. Nearly every vehicle entering the left lane was a passing vehicle on northbound SH 121, indicating better compliance with the Texas law requiring use of the left lane for passing only, but both directions show that there is a high level of motorist understanding and compliance with the passing lane. Heavy vehicles compose less than five percent of the traffic stream in both directions, and trucks consistently use the right lane as they enter the passing lane section. Counts on SH 121 were affected by the cameras' sensitivity to the contrast between vehicle headlights and the unlighted surroundings, which negated researchers' ability to conduct accurate counts during nighttime hours.

Passing lane operations along US 183 were in many ways similar to SH 121, but some significant differences were also noted. For US 183 in the southbound direction, 13 percent of vehicles entered the passing lane at its beginning and eighty percent of those vehicles are preparing to pass a slower moving vehicle. Truck percentage is approximately ten percent, and trucks consistently use the right lane when entering the passing lane section. However, for northbound US 183 almost fifty percent of vehicles entering the passing lane section do so in the left lane while only twenty-five percent of those vehicles are doing so to pass a slower-moving vehicle. Truck percentage in the northbound direction is just under eight percent, and roughly 75 percent of trucks enter the right lane of the passing lane section.

While discussing the differences in operations between SH 121 and US 183, it is meaningful to note that both the passing lane signing and markings and the level of enforcement were markedly different between the two corridors. The studied portion of SH 121 is striped for no passing along its entirety, with passing maneuvers only allowed in passing lane sections. US 183 is striped to allow passing in two-lane sections and for traffic in the direction opposing passing lane sections where sight distance and roadway geometry allow. Also, "left lane for passing only" signing was posted with greater frequency in the SH 121 corridor and diagonal striping across the left lane (directing vehicles to the right lane unless passing) found in the SH 121 corridor was not present at passing lanes on US 183; this supports the findings from the previous study (*2*) that generated the signing and marking recommendations for entrances to Super 2 sections. Finally, during the study period the SH 121 corridor was observed to be actively enforced while the US 183 corridor appeared to be more intermittently enforced.

Passing Lane Terminus

At the end of each passing lane, data were reduced from video to determine lane selection by vehicle classification and the presence and severity of merging conflicts between passing and passed vehicles (see TABLE 6). If analysts observed merging conflicts between vehicles at the end of the passing lane, they ranked the conflicts as follows:

- none -- vehicles merging had a headway less than roughly three seconds, but no merge conflict was observed),
- low – no braking,
- medium – some braking, or
- high level – both braking and swerving to avoid collision.

TABLE 6 Passing Lane Departure Data

Site	24-Hour Vehicle Count	Left Lane Vehicles		Trucks		Merge Conflict			
		Percent of 24-Hour Count	Percent Passing	Percent of 24-Hour Count	Percent in Right Lane	None	Low	Med	High
SH 121 NB	3495	27.5	66.2	6.9	66.8	63	37	17	0
SH 121 SB	3250	28.0	62.5	7.3	72.6	156	97	24	2
US 183 NB	2664	24.5	41.2	7.1	79.9	186	59	16	0
US 183 SB	2642	18.0	55.6	7.5	90.9	162	69	27	0

Driver behavior at the end of each passing lane is more consistent than driver behavior at the beginning of passing lanes for the sites under investigation. Drivers chose the left lane between 18 and 28 percent of the time on average, with some increases in left lane usage noted during higher-volume (peak) periods of the day. Passing percentages were slightly lower than those observed for the start of the passing lane, and vary on average between 41 and 66 percent; this suggests that perhaps many left-lane vehicles complete their passing maneuvers early in the passing lane section and do not change lanes prior to leaving the section. Truck utilization of the right lane remained high, but was also slightly lower than that observed at the start of the passing lanes. Truck utilization of the right lane, passing behavior and the percentage of vehicles using the left lane are all likely influenced by driver reactions to the passing lane terminus.

The rate of merging conflicts observed in the field was consistently low across the study sites. Merging events rated as medium or high occurred with greater frequency during higher-volume peak periods, but on average the number of moderate or high merging conflict events was less than one per hundred daily vehicles. The high frequency of low-level merging conflicts, or absence thereof, indicates that the merge design provides a relatively safe area for the traffic to return to single-lane operation.

Passing Lane Headway Data

Field data collection with plate counters supplied traffic count, speed, vehicle classification, and headway data for the model calibration and analysis of higher-volume two-lane roadways with passing lanes. Technicians programmed the counters so that the passing lane speed, class, and headway data for each individual vehicle passing over the traffic analyzer was collected. A summary of plate counter headway data is shown in TABLE 7; data are given for the stations upstream of the passing section, the left and right lanes near the midpoint of the passing section, and downstream of the passing section.

TABLE 7 Headway Data

Station	SH 121 NB	SH 121 SB	US 183 NB	US 183 SB
1 (Upstream)	26.3	28.0	32.9	56.9
2L (Midpoint Left Lane)	78.8	117.0	135.0	34.4
2R (Midpoint Right Lane)	120.0	35.8	43.4	43.2
3 (Downstream)	25.7	28.4	34.7	34.4
NOTE: Headway values are shown in seconds.				

Headway data for each study site and each station were calculated as the arrival time difference between following vehicles over each traffic analyzer device. Where following headways are shorter, which typically include locations just before passing lanes, the distribution of headways in a headway frequency diagram is shifted toward the left (i.e., the y-axis) and the proportion of headways less than 3 seconds is relatively high. Where volumes are low and following times between vehicles are greater, such as in the left lane of a passing lane section, the headway frequency distribution is "flatter" and the proportion of vehicles with short headways is low. Data from the SH 121 and US 183 field study sites consistently follow these general headway observation trends, an example of which is shown in FIGURE 4.

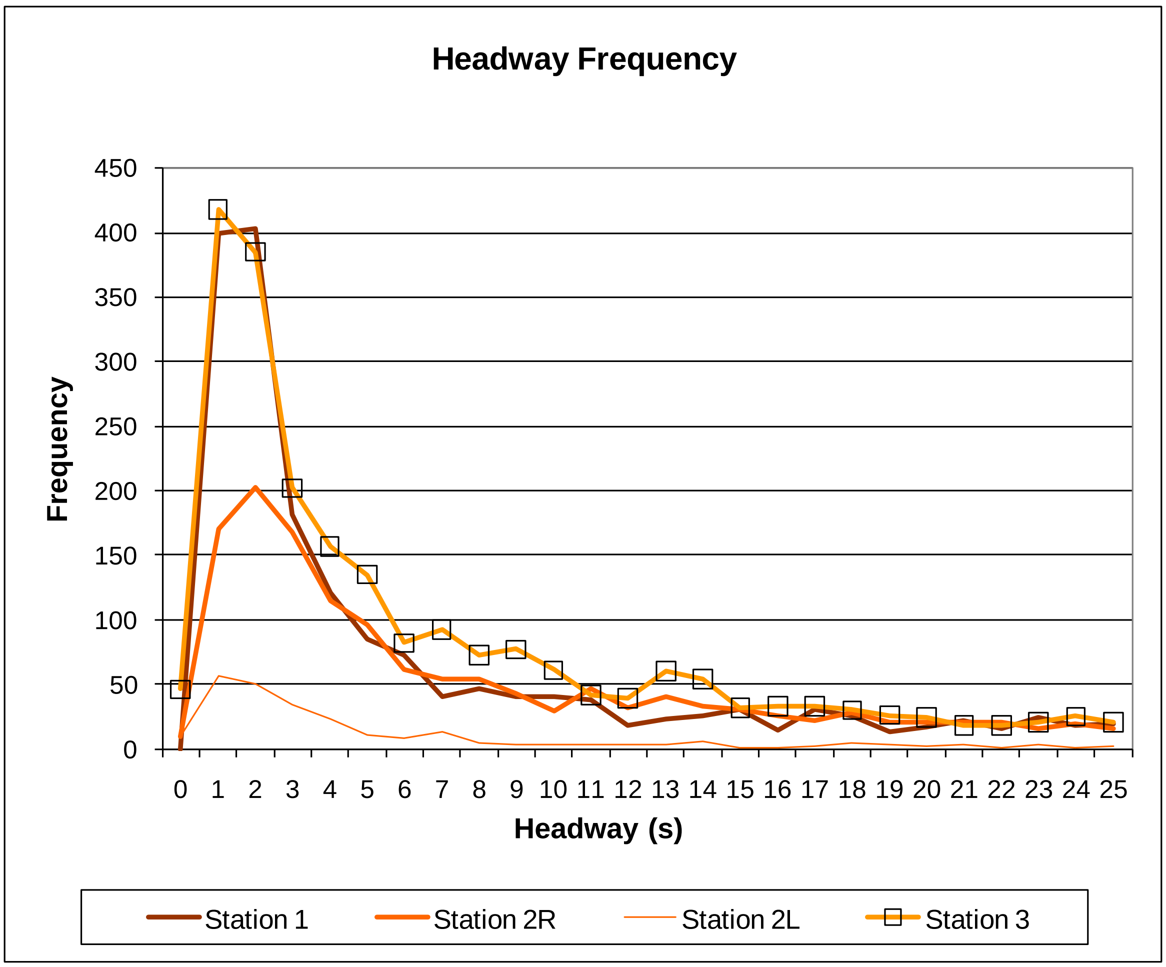


FIGURE 4 Headway frequency distribution for SH 121 northbound.

Data for the northbound SH 121 passing lane study is depicted in FIGURE 4. Upstream of the passing lane section – which is the first passing lane and passing opportunity for many miles – the headway distribution heavily favors headways of 1 and 2 seconds. In the passing lanes, however, the volume is split into the left and right lanes and the headway distribution represents longer headways present in each separate lane. The right lane, which has a much larger proportion of the volume that the left lane of the passing lane section, continues to have some shorter headways but the plot of the overall headway distribution is more rounded than upstream of the passing lane and is shifted away from the y axis. The left lane of the passing lane section shows the "flattest" distribution, emphasizing that vehicle following is minimized in this lane.

Station 3, which is immediately downstream of the passing lane section, has a headway distribution similar to Station 1. This finding would suggest that many of the passing lane benefits on congestion (e.g., increasing headway, reducing time spent following, and providing passing opportunities) are minimized downstream of passing lanes for roadways with volume and geometric circumstances similar to northbound SH 121. Statistical analysis of these data in later project phases will provide an improved estimate of the impacts of passing lanes on roadway segments immediately downstream for roadways similar to SH 121. The data will be used to calibrate a simulation model to estimate effects of various combinations of ADT, truck volume, terrain, and passing lane spacing.

CONCLUSIONS

Based on the field data collected at the Super 2 study sites, researchers drew the following conclusions:

- Results to date indicate agreement with previous research that Super 2 corridors improve operations on rural two-lane highways.
- Observation of lane selection at the entrance to the passing lane section indicates that large numbers of vehicles began passing maneuvers at the beginning of the section; however, not all vehicles in the left lane actually used the left lane for passing, contrary to Texas law. As many as 92 percent (and as low as 21 percent) of left-lane vehicles began a passing maneuver near the beginning of the section.
- Large trucks tended to utilize the right lane at the entrance to passing lane sections, allowing faster vehicles to pass. Truck compliance with the right lane was 74 percent or better at each site.
- While not a specific focus of this study, differences in traffic patterns at the two study sites suggest that pavement markings, signing, and enforcement may have measurable effects on lane choice at the entrance to the passing lane section, which supports findings from previous research that signing and marking are important elements in Super 2 design. A dedicated study with detailed analysis based on additional study sites could provide useful information on these effects.
- Between 40 and 66 percent of vehicles in the passing lane at the point of departure were engaged in a passing maneuver. Though there was a high level of non-compliance with the "left lane for passing only" law, it was more consistent at the departure than at the entrance, perhaps indicating that many vehicles complete their passing maneuvers early in the passing lane section and do not change lanes prior to leaving the section.
- Truck utilization of the right lane at departure was lower than at entrance, though it was still high overall, ranging from 67 to 91 percent.

- While traffic modeling will be used to analyze passing lane impacts under a variety of roadway volume and geometric conditions, the headway data collected for this project will be used to determine the impacts of passing lanes beyond their physical limits. The current state of analysis indicates that the downstream effects of passing lanes on congestion may be limited at higher volumes.

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