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16. Abstract

The use of periodic, short-term passing lanes is known in Texas as a “Super 2” design. The passing lanes may be alternating or side-by-side, but they are placed at regular intervals. Passing lanes are often constructed on two-lane roadways to improve overall traffic operations by breaking up traffic platoons and by reducing delays caused by inadequate passing opportunities over substantial lengths of roadway.

During the recent design of several “Super 2” projects, questions arose in three areas:

1) optimum passing lane length and spacing,
2) shoulder width requirements, and
3) optimum signing and driver information (pavement marking, etc.) strategies.

The objective of this project was to develop Super 2 design criteria in a format suitable for inclusion in the TxDOT *Roadway Design Manual*. Site evaluations were conducted in Texas, Kansas, and Minnesota, including before-and-after studies of driver behavior for variations in pavement markings. A hypothetical two-lane, two-way rural highway with varying length and spacing of passing lanes was simulated under a variety of traffic mixes and two-way traffic volumes. Additionally, laptop-based surveys were conducted to determine driver reaction to various passing lane spacings, wording on related signs, shoulder widths, and pavement markings entering a passing lane section. Recommendations for the TxDOT *Roadway Design Manual* were developed based upon these activities.

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DESIGN GUIDELINES FOR PASSING LANES ON TWO-LANE ROADWAYS (SUPER 2)

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DISCLAIMER

The contents of this report reflect the views of the authors, who are responsible for the opinions, findings, and conclusions presented herein. This project was conducted in cooperation with the U.S. Department of Transportation, Federal Highway Administration (FHWA). The contents do not necessarily reflect the official views or policies of the Federal Highway Administration or the Texas Department of Transportation (TxDOT). This report does not constitute a standard, specification, or regulation and is not intended for construction, bidding, or permit purposes. The engineer in charge of the project was Mark D. Wooldridge (TX-65791).

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CHAPTER 1

BACKGROUND

Many of Texas' highways are two-lane roadways and will remain so for the foreseeable future. As volumes increase, motorist satisfaction and traffic performance on those roadways will decrease. The traditional answer to these problems, provision of a four-lane roadway, appears to be out of reach for many of these facilities due to fiscal constraints.

An alternative approach is to provide lower-cost improvements on existing two-lane rural roads, thereby upgrading a larger number of roadways. Both United States and international research and experience have shown that the provision of passing lanes, turning lanes, localized alignment improvements, and other relatively low-cost measures can be highly cost effective in improving both traffic operations and safety on existing two-lane rural roads. These options are also most appropriate for roads with lower traffic volumes that may not warrant major improvement projects and on recreational or other routes with high seasonal demand *(1)*. Passing lanes are one of the most effective methods of improving the level of service on a two-lane roadway because they increase passing opportunities and provide smoother traffic operations with fewer vehicle-vehicle conflicts *(2)*. Passing lanes allow motorists the opportunity to safely and easily pass slower vehicles, improving traffic flow at a much lower cost than a traditional expansion to four lanes. Additionally, safety evaluations have shown that passing lanes and short four-lane sections reduce accident rates below the levels found on conventional two-lane highways *(3)*.

The distinction should be made between passing lanes and climbing lanes. Although the purpose of each is to reduce platooning of traffic behind slower moving vehicles, the design principles employed are inherently different from one another. The design objectives used in the construction of a climbing lane are different because there is a desire to eliminate platooning due to a significant change in grade: the size and length of the grade change directs the design. The design objectives for a passing lane are to disperse platoons and improve traffic operations through the provision of enhanced passing opportunities along a roadway corridor.

The location of an added lane should appear logical to the driver. The value of passing lanes is more obvious in locations where passing sight distance is short than in areas that may provide passing opportunities without passing lanes. When locating a passing lane, designers should recognize the need for adequate sight distance at the lane addition and lane drop tapers. The selection of an appropriate location also needs to consider the presence of intersections and high-volume driveways in order to minimize the volume of turning movements on a road section where passing is encouraged. Also, physical constraints such as bridges and culverts should be avoided if they restrict provision of a continuous shoulder *(4)*.

PROJECT GOAL AND ISSUES

The use of periodic, short-term passing lanes is known in Texas as a "Super 2" design. The passing lanes may be alternating or side by side but they occur at regular intervals. They are often constructed on two-lane roadways to improve overall traffic operations by breaking up traffic platoons and reducing delays caused by inadequate passing opportunities over substantial lengths of roadway. Passing lanes on a two-lane roadway are often much more cost effective for providing passing opportunities than continuous four-lane sections because locations with high construction costs (e.g., major earthwork, expensive structures) can be avoided *(1)*.

The goal of TxDOT Project 0-4064 was to develop reliable, appropriate, and defensible design guidelines that can be used to design Super 2 roadways, addressing the following design issues:

- optimum passing lane length and spacing,
- shoulder width requirements, and
- optimum signing and driver information (pavement marking, etc.) strategies.

Traffic characteristics such as volume, truck percentage, headway, and operating speed are important variables in addressing the preceding issues. However, it is also necessary to evaluate the driver's perception of and reaction to the potential changes in design. This is especially important when determining the proper signing and markings both at and in advance of the passing lane and at the entry and exit tapers.

Previous research and other trial projects have indicated that there are some general guidelines that can be used to establish an effective passing lane design. Researchers built upon those general guidelines to develop guidelines specific to Texas traffic patterns, laws, and driving behavior. Researchers used site visits, field studies, driver surveys, and literature reviews to develop these guidelines.

CHAPTER 2

SITE VISITS AND DATA COLLECTION

SITE SELECTION

Researchers visited existing passing lane sites in order to gain first-hand knowledge of how "Super 2" sections operate, to personally view installed designs with signing and marking details, and to collect data on operating speeds, distribution of trucks, lane splits, and headways.

Researchers chose sites in two states: Kansas and Minnesota. These states were chosen for several reasons. First, both states have done significant research on "Super 2 designs," and they had addressed some of the questions posed in this project. Second, department of transportation (DOT) personnel in these states provided extensive information and support for the project and were interested in cooperating with the researchers on their visits. Third, the DOT personnel were able to help identify the necessary number of appropriate sites to visit in a timely manner.

Researchers looked for several characteristics in selecting the study sites. There were a number of similarities between the sites: for example, sites in both states had a side-by-side design with a predominantly straight alignment over level terrain. However, there were some differences between the sites as well. Sites in Kansas tended to be more rural than sites in Minnesota, and the Kansas sites had a higher percentage of trucks in the traffic stream. Sites in both states were selected with a minimal number of driveways and intersections within the passing lane section, but sites in Minnesota had more access points than those in Kansas. The Kansas sites were relatively new, having been installed in the last few years, while the Minnesota sites had been in existence for much longer. Also, passing lane sections in Minnesota tended to be longer than those in Kansas.

DATA COLLECTION

After selecting the sites for field visits, researchers gathered as much information as possible about the layout and alignment of the site from maps and through contact with local DOT officials. At each site, researchers drove through the site several times to become acquainted with the terrain, roadside development, entry and exit taper configurations, signing, and striping. They chose positions beyond the edge of the roadway to observe traffic and record passing data. Researchers also obtained permission from landowners to be positioned at those locations where necessary.

At the beginning of each study day, researchers set out road tubes and traffic counters at four locations along a passing lane section: 500 ft upstream of the entry taper for the passing lane, 500 ft downstream of the entry taper for the passing lane, 500 ft downstream of the exit taper for the passing lane, and 1 mile downstream of the passing lane. These counters and tubes were used for a continuous six-hour period each day. A measuring wheel was used to measure necessary distances for sensor placement, section lengths, and lane and shoulder widths. The sensor tubes were fixed in place using fastener plates that were nailed into the pavement and reinforced by tape if necessary. The counters were then initialized and activated to record speed and headway data.

Two researchers positioned themselves off of the roadway to count the number of passes that occurred during the six-hour period while the counters were recording data. For the duration of the study period, these observers were sitting inside their respective vehicles, which were parked on a side road, a driveway, or a turnaround area. The vehicles were standard rental fleet vehicles, chosen to blend in with the local traffic stream and to avoid being mistaken for law enforcement vehicles. The vehicles were also parked as to appear to be either unoccupied or vehicles that were waiting to turn out onto the road being studied. The researchers were positioned so that the entire length of the passing lane section was within their view.

The researchers observed vehicles traveling through the passing lane section and recorded the number and type of passes that occurred within each 15-minute period of the six-hour study period. The type of pass was classified as follows: car passing car, car passing truck, truck passing car, and truck passing truck. A “car” was defined as a passenger vehicle, which included pickup trucks, sport utility vehicles, and minivans. A “truck” was generally defined as a cargo/freight vehicle, which included semi-trailer combinations, bread trucks, and shipping trucks. A “pass” was defined as a vehicle that begins the passing lane section behind another vehicle but concludes the section completely in front of the other vehicle.

At Minnesota sites, one researcher also set up a video camera to record the movements of vehicles entering the passing lane section. The video was also recorded for six hours, and tapes were viewed during data reduction to count the number of vehicles that entered each lane at the beginning of the passing lane section.

While two researchers observed traffic and recorded passing data, a third researcher completed the site characteristics data worksheet developed for this project. A sample worksheet is shown in Appendix A. Completion of the worksheet involved measuring length of entry and exit tapers, length of passing lanes, and width of lanes and shoulders; determining positions of signs and striping treatments within the section; counting access points (driveways and intersections) within the section; determining the roadside environment; and taking pictures of the site, signing, and striping. Researchers also made a drive-through video of each site, videotaping the driver's view of the site through the front windshield in each direction. The video also includes narration of mile-points, observation sites, and other significant features of the site.

At the end of the six-hour study period, the researchers stopped the counters and disconnected them from the sensor tubes. At sites where data collection occurred for two consecutive days, the sensor tubes were left attached to the pavement overnight, while the counters were stored and then reconnected the following day. When data collection was completed at a site, the sensor tubes were also removed from the pavement. The exposure time of personnel on the roadway was primarily limited to the installation and removal of road tubes and counters with some brief periods for taking measurements and pictures.

DATA REDUCTION

The data from the counters were stored in text files which were converted to spreadsheets for further reduction and analysis. The counters collected the following information on each vehicle: speed, headway, number of axles, direction, and time stamp. The counter also collected 15-minute vehicle counts. In raw format, headway was recorded in units of thousandths of a second, so headways were multiplied by 1000 to obtain whole seconds. Table 1 is a sample of counter data, converted to spreadsheet format.

Table 1. Sample of Formatted Counter Data.

DD/MM/YY	HH:MM:SS	Array	Flow	Veh No	Hdwy	Spd	Axles
28/11/00	10:14:33	1	+	44	4.985	68	2
28/11/00	10:14:48	1	+	45	15.000	68	2
28/11/00	10:15:12	1	+	1	24.011	63	5

After each set of data was formatted, a total vehicle count was made, and the minimum, maximum, average, and standard deviation of headway, speed, and axles was calculated for the entire set.

For the counters placed inside the passing lane section to collect data for two lanes, another step was necessary to format the data. In order to make calculations and analysis easier, the data from the two lanes had to be split into separate sets of columns within the spreadsheet. In the unformatted data, Lane 2 data were offset by one column, with a flow value of 2. All such data were then shifted within the spreadsheet to create two sets of data columns. Thus, the lane split format had the same columns as in Table 1, containing the data for Lane 1, but the last four columns were repeated to provide space for data from Lane 2. A sample of lane split data is shown in Table 2.

Table 2. Sample of Formatted Lane Split Data.

				Lane 1				Lane 2			
DD/MM/YY	HH:MM:SS	Array	Flow	Veh No	Hdwy	Spd	Axles	Veh No	Hdwy	Spd	Axles
28/11/00	10:13:04	1	+	40	7.988	64	5				
28/11/00	10:13:06	1	2	+				41	11.619	68	5
28/11/00	10:13:09	1	+	42	4.992	67	2				

As with the single lane data, a total vehicle count for each lane was made, and the minimum, maximum, average, and standard deviations of headway, speed, and axles in each lane were calculated.

The data were then reduced into platoons by comparing the headway values between vehicles. A vehicle was defined as being in a platoon if the headway between it and a preceding or succeeding vehicle in the same lane was 5 seconds or less. Blank rows were inserted into the spreadsheet between platoons to separate them visually. Then, for each platoon, the following values were calculated: average headway, speed, and number of axles for all trailing vehicles in the platoon; the number of trailing vehicles; the speed and number of axles for the lead vehicle; and the total headway, speed, and number of axles for all trailing vehicles. Based upon these values, it was possible to calculate the minimum, maximum, average, and standard deviation for the headway, speed, and number of axles of trailing vehicles; the number of vehicles in a platoon; and the speed and number of axles on the lead vehicles. Other calculations included: the count, average headway, average speed, and average axles for leading and isolated vehicles; the distribution of the number of trailing vehicles in each platoon; and the distribution of the number of axles for each trailing vehicle, and each vehicle in each lane.

The final step in data reduction was accounting for erroneous readings. Occasionally, the data files contained a reading for a single-axle vehicle or a headway of less than 0.01 second. These readings were primarily attributed to trailers that were recorded separately by the counter or vehicles that crossed only one sensor. These readings were either deleted or combined into the adjacent vehicle, depending on which was appropriate. After these corrections, the platoon data were re-checked for accuracy and updated if needed.

CHAPTER 3

DRIVER SURVEYS

One of the key tenets of transportation is that it should meet the needs of the user. To ensure that these needs are met, public meetings or hearings are held during the planning and design stages of major improvement projects to gather information regarding driver and community needs. In a similar spirit, researchers conducted a survey of Texas drivers to gather their input regarding the design of passing lanes on two-lane rural highways.

PREVIOUS SURVEYS

Researchers found two previous studies concerning views of the highway user regarding passing lanes. The first study was conducted in Canada for the Trans-Canada Highway in Banff National Park (*5*). The research performed in the study was limited to drivers of trucking companies and bus lines, Parks Canada employees, and Royal Canadian Mounted Police. The Canadian survey disseminated postcards to drivers on the potential passing lane routes between Banff and Lake Louise. The surveys, to be returned by mail, focused on delay, length, spacing, signing, and marking of passing lanes. Comments associated with the length and location of the passing lanes were positive, while negative responses were associated with reports of drivers disregarding the sign "KEEP RIGHT EXCEPT TO PASS."

In the second study, research was performed in Kansas for the Kansas Department of Transportation (*6*). This study focused on the specific locations where two passing lane sections were in the planning stage. These passing lanes were constructed along US 50 and US 54; a portion of the research included in this report was conducted at two US 50 sites.

The earlier Kansas survey consisted of five multiple choice questions and one open-ended question. While the researchers stated the desire to ask more open-ended questions, Mutabazi et al. felt that a survey of this type would maximize the response rate (*6*). Questions were associated with driver behavior, type of vehicle driven, characteristics and the need for passing lanes, the driver's state of residence, and a space for additional comments.

The overall response rate in the Kansas survey was approximately 40 percent, for a total of 406 out of 1000 possible responses. The results showed that approximately 85 percent of respondents said there was a need for more passing lane sections (*6*).

OBJECTIVES

The purpose of the survey for Project 0-4064 was to evaluate driver comprehension of the possible signing, marking, and design practices associated with the development of design criteria for Texas Super 2 roadways. The survey presented different signing and marking strategies to the survey participants to determine their understanding and acceptance of different signing, marking, and related geometric features associated with passing lanes.

SURVEY DEVELOPMENT AND ADMINISTRATION

TTI researchers conducted a laptop computer-based survey in the cities of Amarillo, Childress, San Antonio, San Angelo, and Odessa, Texas. Initially, a pilot study was conducted in College Station to fine-tune the design of the survey. The principal location for the administration of the survey was at Texas Department of Public Safety driver's license renewal offices. Each participant was presented with 18 questions related to signing and marking strategies associated with passing lanes.

The survey consisted of video clips, still photographs, text, and illustrations of different signs, providing a venue where the participants could visualize the aspects of the signing, marking, and geometric features of the roadway. This type of survey allowed the participant to easily understand the question being asked. The survey administrator recorded each participant's survey answer, ensuring that the participant fully understood each question and that the answer was correctly documented.

The use of this type of survey also facilitated the use of open-ended questions, permitting a better overall understanding of each participant's answers than could have been obtained with a traditional pencil and paper survey. The survey averaged approximately 11 minutes to complete, and no form of compensation was offered to the participants. A total of 134 participants were surveyed.

SUMMARY OF SURVEY QUESTIONS AND RESPONSES

The survey questions focused specifically on signing, markings, and geometric features associated with passing lanes on Super 2 roadways. Video clips and photographs used in the survey were taken on US 83 north of Eden, Texas, a site where further data were collected later during the field study.

This chapter contains the actual survey questions shown in bold face type. An explanation of why the questions were asked is included along with the results.

Questions 1-3. What does this sign mean to you?

Questions 1-3 included three signs that are currently in use in different areas of Texas and around the country where climbing or passing lanes presently exist.

The respondent's interpretation of the meaning of each sign was determined based upon their answer. This type of open-ended question provided a beneficial means of evaluating each participant's point of view without prompting. To eliminate any potential bias, their presentation order was randomized.

Currently, Texas law requires that the inside lane along four-lane rural highways is used exclusively for passing. The same interpretation of this law is made for two-lane rural highways with climbing or passing lanes. Survey participants were asked to explain what each sign shown in Figure 1 meant to them. The answers were then evaluated based on common responses.

Keep Right Except to Pass

Survey respondents typically responded to this sign as meaning "stay or keep to the right unless passing."

Slower Traffic Keep Right

Approximately 40 percent of the respondents associated this sign with vehicle speeds, and many even gave specific values for these speeds. A typical response in these instances was: "If you are driving 55 or less, stay in the right lane."

Figure 1. Signs for Questions 1-3.

Left Lane for Passing Only

Typically, many survey respondents said that this sign meant to "use the left lane only for passing" or "the left lane is to remain open for passing." Some participants in the survey were asked which of these signs they felt provided the strongest meaning associated with keeping the inside lane open for passing. Sixty-two of the 134 participants were asked which of the three signs had the strongest meaning. Seventy-one percent of these respondents felt that Left Lane for Passing Only carried the stronger meaning versus 29 percent for Keep Right Except to Pass.

Before question 4 was asked, respondents saw a video clip with the beginning as shown in Figure 2. The clip illustrates a vehicle just ahead, and was followed by this statement: "You are driving along this Texas two-lane highway. As shown in the video clip, you are following a slower vehicle." *(The 10-second video clip shows the slower vehicle traveling just ahead.)* Figure 3 depicts the sign shown to the survey participant for question 4.

Figure 2. Beginning of Video Clip for Question 4.

Figure 3. Sign for Question 4.

Question 4. While driving behind the slower vehicle, you see this sign. If the sign means that you will have a special lane to use for passing 2 miles ahead, would you wait until the passing lane to pass?

a. Yes
b. I would pass sooner if I had an opportunity

As shown in Figure 4, 61 percent of the respondents indicated that they would wait until the passing lane to pass the slower moving vehicle, while 39 percent said they would pass before the passing lane became available. Many respondents also indicated that this type of sign would be valuable to them in their decision on whether to initiate a passing maneuver. Answers to question 4 provided a basis on which to determine if the concept of passing lanes is seen as being beneficial from the driver's standpoint. It also offered an opportunity to evaluate response to the sign indicating advance notice of the passing lane.

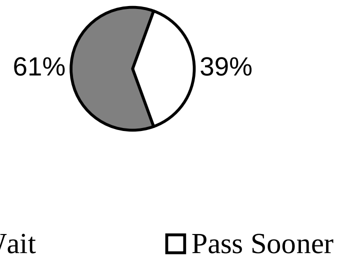

Figure 4. Results for Question 4.

Questions 5 and 6 were associated with the passing behavior of the driver when faced with current climbing and passing lane entrance markings versus a proposed new marking. The proposed new marking is a broken marking pattern delineating the passing lane from the right-hand, or outside, lane.

Positive results from the pilot survey indicated that further study was justified regarding the use of the broken marking pattern. The additional research involved a field study conducted at three Texas locations as described in Chapter 4.

Again, a scenario was created before questions 5 and 6 were asked. In this scenario, photographs and video clips, seen in Figures 5 and 6, were used in addition to text to illustrate a vehicle traveling just ahead and moving to the right-hand lane. In question 5, the participant is shown the entrance to the passing lane as typically constructed, while question 6 illustrates the closely spaced skip stripe pattern separating the passing lane from the right-hand lane.

Question 5. When you arrive at this point, which lane would you choose?

a. **Lane A: pass the slower moving vehicle**
b. **Lane B: follow the slower moving vehicle**
c. **I don't know**

Figure 5. Typical Passing Lane Entrance for Question 5.

Question 6. When you arrive at this point, which lane would you choose?

a. Lane A: pass the slower moving vehicle
b. Lane B: follow the slower moving vehicle
c. I don't know

Figure 6. Broken Marking Pattern for Question 6.

As shown in Figure 7, 96 percent of the respondents for question 5 indicated they would pass the slower vehicle using lane A. The remaining 4 percent were split equally, saying they would either follow the slower moving vehicle into lane B or that they didn't know.

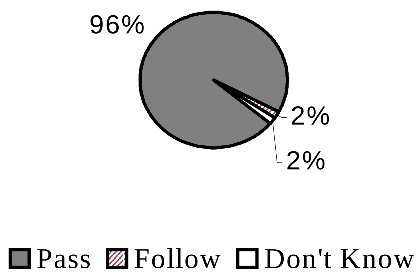

Figure 7. Results for Question 5.

As shown in Figure 8, 68 percent of the respondents for question 6 indicated that they would pass the slower vehicle using lane A, while 30 percent said they would follow the slower moving vehicle using lane B. The remaining 2 percent indicated that they did not know. A large number of the respondents who chose lane B also stated they would pass the slower vehicle after the transition to the passing lane.

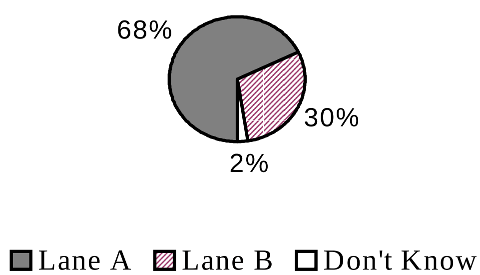

Figure 8. Results for Question 6.

Questions 7, 8, and 9 were related to which lane (A or B) the respondent would choose when approaching a passing lane with no other vehicles present. These questions were structured to indicate which lane the driver prefers when not in a platoon. They also provided a basis for comparison in later field studies on this issue.

Question 7. When you arrive at the point near the end of the video clip and you are not following or being followed by anyone, which would you choose?

a. Drive in Lane A
b. Drive in Lane B
c. I don't know

Figure 9 illustrates the end of the video clip associated with this question. (*The 10-second video clip shows the vehicle approaching the passing lane section typically marked in Texas and other areas around the country*.)

Figure 9. End of Video Clip for Question 7.

Figure 10 shows the results for question 7. As illustrated, 87 percent of the respondents indicated that when approaching a passing lane and not in the proximity of any other vehicles, they would choose lane B. The remaining 13 percent chose lane A. (These values are somewhat different than those produced by the field study conducted as part of this project. In that study, the number of vehicles choosing lane A was almost twice that indicated in the survey, with approximately 25 percent of drivers choosing lane A when not in the proximity of any other vehicles and not engaged in a passing maneuver. This is discussed in Chapter 6.)

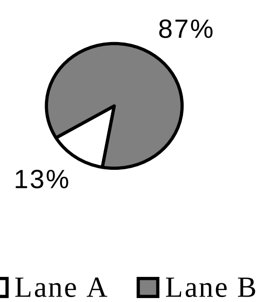

Figure 10. Results for Question 7.

In question 8, the participant was shown the photograph of an open section of a passing lane with no vehicles ahead, as shown in Figure 11. This question was asked to determine the lane preference of the driver in this situation.

Question 8. If no other vehicles are in Lane A or Lane B, would you:

a. Drive in Lane A
b. Drive in Lane B
c. I don't know

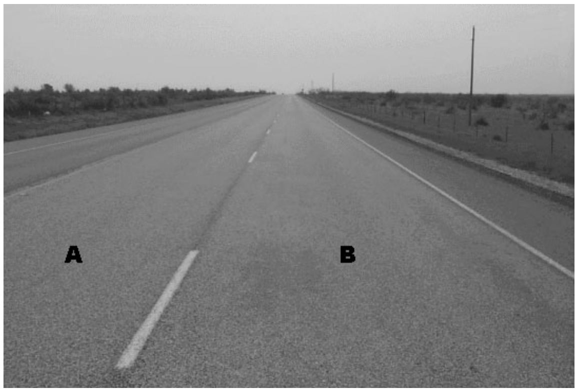

Figure 11. Photograph for Question 8.

As shown in Figure 12, 92 percent of the respondents stated that they would travel in lane B if no other vehicles were around them, while 7 percent said they would travel in lane A, and 1 percent did not know. (Again, while the field study was principally associated with the lane choice of the driver at the passing lane entrance, it can be concluded that the results of question 8 are different than driver performance in the field. The 7 percent of participants choosing lane A is well below the approximately 35 percent measured in the field 500 feet downstream of the end of the passing lane diverge taper, as discussed in Chapter 6.)

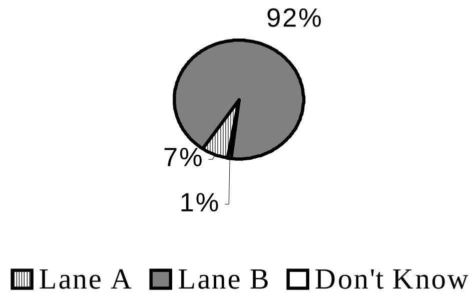

Figure 12. Results for Question 8.

In question 9, a video clip illustrated a vehicle traveling along the path to the right-hand lane, lane B, delineated by the broken marking pattern. A portion of this clip is shown in Figure 13. (*The 15-second video clip shows a vehicle following the path of the broken marking pattern*.) This question was asked to determine the effectiveness of the marking pattern in moving the driver to the outer lane. The placement of the driver in this location can result in increased safety by providing some degree of separation between vehicles traveling in opposing directions. It can also improve operational characteristics by moving drivers to the right-hand lane unless they are involved in a passing maneuver.

Question 9. Would you follow the path of this vehicle in this situation or would you cross the broken white stripes?

a. Drive in Lane A
b. Drive in Lane B
c. I don't know

Figure 13. Portion of Video Clip for Question 9.

As shown in Figure 14, 80 percent of the respondents indicated that they would move to the right-hand lane while 20 percent stated that they would cross the broken marking pattern. As shown in Figure 10 (the results for question 7), it appears that the broken marking pattern less effectively moves drivers to the outside lane with no marking across the entrance to the passing lane as typically found in Texas. (However, field study results indicate that the opposite is true; the marking is *more* effective in moving drivers to lane B when they are not engaged in passing and have headways greater than five seconds. This is discussed in Chapter 6.)

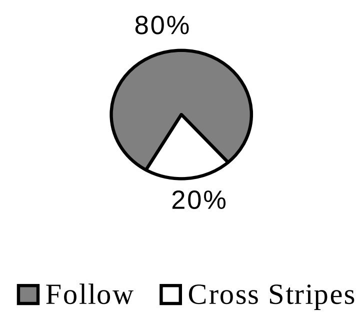

Figure 14. Results for Question 9.

Question 10 was included to determine driver understanding of no-passing zones associated with passing lanes. The still photograph presented in question 10 and shown in Figure 15 illustrates a no-passing zone along a passing lane section. The survey participant was asked to state if passing is legally permitted for traffic approaching in the oncoming direction.

Question 10. Are vehicles traveling in Lane X permitted to go into Lane A to pass provided there is no oncoming traffic?

a. Yes
b. No
c. I don't know

Figure 15. Photograph for Question 10.

Figure 16 illustrates the results for question 10. As seen in the figure, 94 percent of respondents recognized that they could not legally pass in this situation, while 6 percent indicated that they could legally pass provided there was no oncoming traffic.

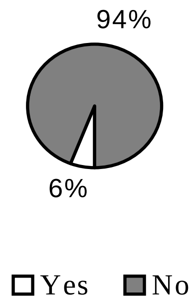

Figure 16. Results for Question 10.

Questions 11-13 relate to shoulder widths in passing lane sections and to the comfort level of the driver if stopping on the shoulder. These questions were asked to gain a better understanding of the width of shoulder that respondents recognized as acceptable for stopping on the shoulder in an emergency.

These questions were also randomized at survey locations to eliminate bias. However, for the purpose of this report, questions 11-13 are ordered to illustrate a vehicle parked along 10-ft, 6-ft, and 4-ft shoulders, respectively. The respondents did not know the widths of the shoulders; they saw only the photographs. Two still photographs were presented for each question in addition to the text.

Questions 11-13. Would you feel comfortable stopping on this shoulder if you had a flat tire?

a. Yes
b. No
c. I don't know

Figure 17 illustrates a vehicle parked on a 10-ft shoulder. This shoulder width is currently the maximum width of shoulders constructed in Texas.

Figure 17. Photograph for Question 11, 10-Ft Shoulder.

Figure 18 illustrates the results for question 11. As seen in Figure 18, 70 percent of the respondents indicated that they would feel comfortable stopping on the 10-ft shoulder, while the remaining 30 percent said they would not.

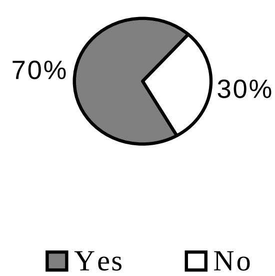

Figure 18. Results for Question 11.

Figure 19 illustrates the 6-ft shoulder presented to the survey participant in question 12. The roadway is similar to that used for the 10-ft shoulder except that it is in a passing lane section.

Figure 19. Photograph for Question 12, 6-Ft Shoulder.

Figure 20 shows the results for question 12. Approximately one half, or 49 percent, of the respondents stated that they would not feel comfortable stopping on the 6-ft shoulder when having a flat tire, and 6 percent said they were unsure. The remaining 45 percent indicated that they would feel comfortable stopping on the 6-ft shoulder illustrated in the photographs.

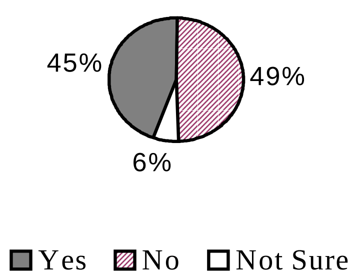

Figure 20. Results for Question 12.

As noted previously, question 13 was associated with the comfort level of the participant regarding stopping on a 4-ft shoulder due to a flat tire. Figure 21 illustrates the photographs shown to the participant. This shoulder is also in a passing lane section.

Figure 21. Photograph for Question 13, 4-Ft Shoulder.

Figure 22 illustrates the results for question 13. In this case, only 20 percent of the respondents said they would feel comfortable stopping on the 4-ft shoulder. Of the remaining 80 percent, 76 percent of respondents said they would not feel comfortable, and 4 percent were unsure.

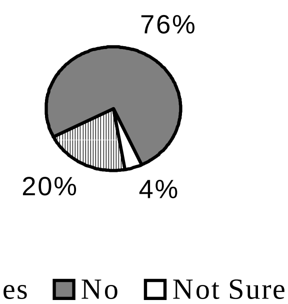

Figure 22. Results for Question 13.

The comfort level of the total number of respondents decreased along with the decrease in shoulder width. This downward trend toward the respondent feeling less comfortable with the narrower shoulder width presumably indicates the desire for the driver to be removed from traffic as much as possible when forced to stop along a shoulder in this situation.

Question 14 was asked to gain insight regarding the distance that a driver would be willing to wait for a passing lane when following behind a slower moving vehicle.

Question 14. Passing lanes can be used on long sections of two-lane rural roadways. The lanes are used to provide safer opportunities to pass when you are following a slower vehicle.

If you know that a passing lane is going to be provided ahead, what distance would you be willing to wait for the passing zone if you are behind a slower vehicle?

a. 2 miles or less
b. 3 miles
c. 4 miles
d. 5 miles
e. 6 miles or more
f. Other_____

The results for question 14, shown in Figure 23, illustrate that 55 percent of the respondents, were willing to wait 2 miles or less for a passing lane when following a slower vehicle. Nineteen percent of respondents were willing to wait 3 miles to pass, seven percent indicated that they would wait up to 4 miles, and 4 percent said they would wait up to 5 miles. The remaining 15 percent of respondents stated they would be willing to wait 6 miles or more to pass, and many of these respondents indicated that they simply did not pass or feel safe passing on two-lane rural highways.

The results of this question illustrate that the majority of respondents (55 percent) fall into the 2 miles or less category. The information gained from question 14 is helpful in determining the appropriate distance for the advance notice of the upcoming passing lane.

Question 15 was included in the survey to determine the willingness to move to the shoulder to allow a faster vehicle to pass. Although uncommon (and generally illegal) in other states, this practice is customary along rural two-lane Texas highways. *The same 10-second video clip shown in question 4 is used for question 15. However, in this scenario, the survey respondent is "driving" the vehicle in front.* A still image from the video clip is shown in Figure 24.

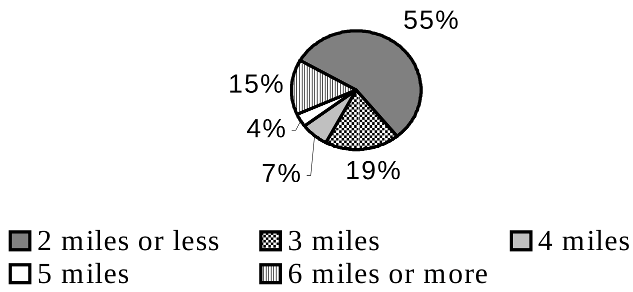

Figure 23. Results for Question 14.

Question 15. You are driving the vehicle shown *in front*. Another vehicle is following closely behind you. You see a sign that says a passing lane will be provided in 2 miles. Would you:

a. Move to the shoulder to allow the vehicle to pass
b. Wait for the passing lane to allow the vehicle to pass

Figure 24. Portion of Video Clip for Question 15.

Figure 25 illustrates the results for question 15. Fifty-three percent of the respondents indicated that they would move to the shoulder and allow the faster moving vehicle to pass. This result is important because, while it is apparent that approximately one half of vehicles will attempt to facilitate the passing of the faster vehicle, a significant number will maintain their lane position, leading to decreased operational benefits and increased safety.

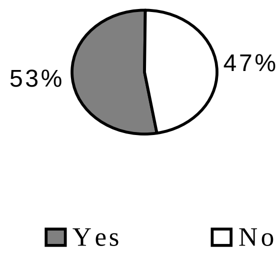

Figure 25. Results for Question 15.

Questions 16 and 17 were asked to further determine driver understanding of pavement markings in passing lane sections. While similar in nature to question 10, these questions were designed based on the assumption that passing lane sections, as opposed to climbing lane sections, will encompass a larger area where passing will be permitted in opposing directions due to available sight distance. They were also included to determine driver understanding of pavement markings.

Figure 26 illustrates a portion of the video clip presented with question 16. (*The 10-second video clip illustrates a slower moving vehicle just ahead with the passing lane in the opposing direction. There is a broken yellow line shown inside of a solid yellow in the direction of travel, permitting a legal pass*.)

Question 16. You are following the slower vehicle shown ahead. Can you legally pass this vehicle if desired?

a. Yes
b. No
c. I don't know

As shown in Figure 27, 79 percent stated correctly that passing the slower moving vehicle was legally permitted while 18 percent of the respondents indicated that a legal pass was not permitted, and 3 percent did not know. The results for question 16 indicate that approximately one out of five respondents incorrectly stated that passing the slower moving vehicle in this situation was not legally permitted. These results illustrate the level of misunderstanding presented by allowing passing in the opposing passing lane.

Figure 26. Portion of Video Clip for Question 16.

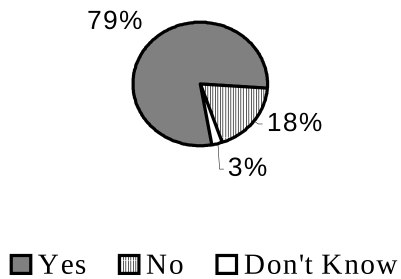

Figure 27. Results for Question 16.

Question 17 is the same as question 16 from the opposing direction, or traveling adjacent to the passing lane. Figure 28 shows a portion of the video clip presented with question 17. (*The 10-second video clip illustrates the slower moving vehicle just ahead, adjacent to the passing lane which is separated by a broken white marking*.)

Question 17. You are following the slower vehicle. Can you legally pass this vehicle if desired?

a. Yes
b. No
c. I don't know

Figure 28. Portion of Video Clip for Question 17.

The results for question 17 are illustrated in Figure 29. As seen in this figure, 95 percent of the respondents correctly recognized that passing was legally permitted in this situation. This result is in contrast to question 16, where only 79 percent of respondents indicated a legal passing maneuver could be made. The fact that the vast majority of respondents recognized that a passing maneuver is legal in this situation further underscores the recognition that a white broken marking is acceptable to cross during a passing maneuver or otherwise.

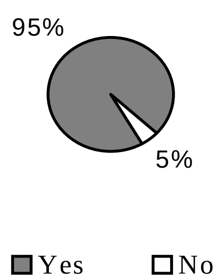

Figure 29. Results for Question 17.

Question 18 was asked to obtain relevant information on the subject of passing lanes. This open-ended question allowed respondents to communicate any ideas they had regarding the design and construction of passing lanes.

Question 18. Do you have any suggestions about passing lanes (signs, pavement markings, or distance between passing lane sections)?

Approximately 70 percent of the total number of participants made comments or suggestions. As shown in Figure 30, the results were centered around four key points: the length and frequency of passing lanes, better signing and markings, wider shoulders, and better education regarding passing lanes. For example, participants suggesting better education stated that some slower drivers do not readily move to the right-hand lane unless passing, forcing a passing maneuver to be made by the faster vehicle in that lane.

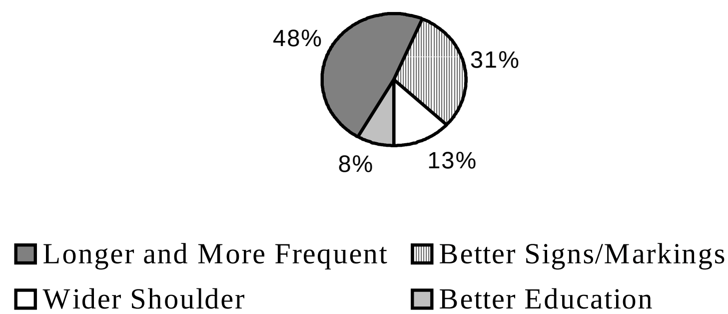

Figure 30. Results for Question 18.

As noted previously, some surveys were conducted in Childress, Texas, where several passing lane sections have recently been constructed. Almost all of the survey participants in Childress were familiar with these passing lanes. Their responses typically focused on the need for more passing lanes on other roadways in the area.

SUMMARY

This survey was associated with the critical design components and other passing lane issues including passing lane length and spacing, signing and marking strategies, lane and shoulder width, opinions and viewpoints from the user's perspective, and human factors issues. A comprehensive literature review and site visits where passing lane sections have been constructed were useful in providing information to develop the survey questions.

A considerable number of survey participants stated that they would be willing to wait 3 miles or less for a passing lane section. This type of information is not only helpful from the standpoint of driver expectancy between passing lane sections, but it also provides information on the satisfactory advance notice of upcoming passing lanes. Advance notice of upcoming or the end of passing lane sections is provided through appropriate signing. Information gathered in the survey was helpful in this area as well, providing insight about the user's perspective on signing associated with lane use in conformance with current Texas laws.

The survey was also constructive in providing information on signing and marking issues. Survey data indicated that one in five survey participants was unclear about whether it was legally permitted to pass in the opposing passing lane, even though markings clearly indicated it was legal to do so provided there was no oncoming traffic. This situation was in contrast to the large number of survey participants that readily responded to whether passing was permitted in a passing lane section and in a no-passing zone in a passing lane section.

Previous studies have indicated that a broken marking pattern delineating the passing lane is beneficial in channelizing traffic to the right-hand lane (*7*). This finding led to the formulation of questions regarding a version of this broken marking pattern for the survey. (A field study was also performed; see Chapter 6 for further information.) Results from the survey and later field study confirmed that this marking was useful in directing traffic to the appropriate lane position, allowing the passing lane section to be used more efficiently from an operational perspective.

The user's viewpoint was also helpful in recommending shoulder widths within passing lane sections. The comfort level associated with 4-, 6-, and 10-ft shoulders by the respondents yielded the driver's perspective regarding appropriate shoulder widths in passing lane sections. Again, the survey participants were only shown photographs depicting a vehicle stopped on a shoulder and were not informed of the actual shoulder width. This information was coupled with that gathered from the literature review and engineering judgment to develop shoulder width recommendations.

Suggestions from the survey participants provided key information about design components and related information that would be constructive to passing lane development in Texas. Many participants relayed the desire to see more frequent passing lane sections. They also recognized that many climbing lane sections in existence around the state are of insufficient length when passing more than one vehicle. Others noted the need for improved signing and marking associated with passing lanes. As previously noted, the advance notice of upcoming passing lane sections, as well as signage and markings designed to give the optimum amount of information to the user, provides an improved operational efficiency of passing lanes.

Some suggestions were associated with the need for better education, specifically regarding appropriate lane position in passing lane sections. The point was made that many times, passing of slower moving vehicles occurs in the right-hand lane due to the slower vehicles not moving over to clear the passing lane. In this case, even though the vast majority of survey respondents indicated the preference of lane B, the right-hand lane, even when other vehicles were not in close proximity, the field study provided results that showed the opposite was true in many instances. During the administration of the survey, it was concluded that a number of the younger participants were better educated regarding the laws, signing, markings, etc., than many older participants. This finding demonstrates the need for some form of educational materials to be made available to the public, perhaps by having brochures made available at driver's license renewal offices, distributed at public meetings or public hearings, or through radio and television advertisements.

The provision of the appropriate information regarding passing lanes was the primary goal in the development of the survey questions as well as the format and administration of the survey. The video clips and photographs provided a basis to ask questions that could be easily understood by the survey participants. The format was well received, and a number of participants commented that the nature of the survey was conducive to efficient two-way communication between the administrator and the participant.

Overall, the survey provided results that greatly increased the knowledge base used by the researchers to make the recommendations for passing lane design criteria.

CHAPTER 4

LENGTH AND SPACING OF PASSING LANES

Passing lanes on two-lane, two-way rural highways can improve the level of service (LOS) by providing passing opportunities to motorists traveling behind slower moving vehicles and dispersing platoons that may have formed behind the slower moving vehicle. Research indicates that passing lanes may be warranted for highways having average daily traffic (ADT) values between 1000 and 6200 in both directions, depending upon terrain, cost, and desired level-of-service *(8,9)*.

The functional effectiveness of passing lanes on two-lane, two-way rural highways depends on the length of the passing section and the spacing between the passing sections. It is desirable to have a passing lane section that is able to convert platoon flow at its upstream end to free-flowing single vehicles at its downstream end.

Also, the spacing between the passing lanes should be such that passing lanes function as a coordinated system and are able to disperse large platoons to decrease the percent travel time delay in the system *(9)*. The length and spacing of passing lanes are functionally dependent on the following factors: ADT, percent trucks, topography, and local needs. Therefore, a relationship between the ADT and the percent of trucks using the highway with the optimum length and spacing of the passing lanes needs to be established.

BACKGROUND

Three related research efforts have provided background on the length and spacing of passing lanes. These include research conducted by Texas Tech University, Kansas State University, and by Harwood and Hoban (*8*,*9*,*10*).

Capacity and Shoulder Use

It has been observed that the passing capacity of a two-lane rural highway decreases with increasing volume, which leads to an increase in platoon size *(11)*. Passing capacity approaches zero at an opposing volume of 700 passenger cars per hour per lane (pcphpl) on a two-lane, two-way rural highway having 100 percent passing zones *(12)*. Improving the roadway's geometry improves passing opportunities on a two-lane roadway. This could be achieved by either increasing the number of sections with adequate sight distance or by providing auxiliary lanes for passing.

Many research studies conducted in the past have recognized the ability of passing lanes to improve traffic opportunities by providing dependable passing opportunities in all volume conditions *(9)*. The following model developed by Harwood and St. John predicts the passing rate at a given passing lane section using a set of input values which are explained below *(1)*:

$$PR = 0.127FLOW - 9.64LEN + 1.35UPL;\ for\ 50vph \le FLOW \le 400vph \quad \left(R^2 = 0.83\right) \tag{1}$$

where

PR = passing rate in passes per mile per hour,

FLOW = flow in one direction in vph,

LEN = length of passing lane in miles,

UPL = percentage of vehicles platooned upstream, and

vph = vehicles per hour.

A regression analysis was conducted by Staba et al. to predict the number of passes in a passing lane as a function of the five-minute vehicle count. For the three climbing lanes and one passing lane section studied, the results indicated that the number of passes increased with addition of passing lanes as compared to a standard two-lane section *(7)*.

Romana and May (*12*) studied the effects of passing lanes by counting the number of passes that a test vehicle made in the passing lane sections by using a floating car technique. The test section in question was 9.3 miles (15 kilometers) long and had two passing lane sections in each direction. They observed that a larger number of passes occurred in the first of two passing lanes. However, they found that this was not true when the number of passes per unit length of passing lane was analyzed. They determined that the results of the experiment were inconclusive, but they believed that the number of passes depended on the following factors:

- length of the passing lane,
- speed of the vehicles,

- magnitude of the traffic volume,
- length of the platoon preceding the passing lane section, and
- position of the test vehicle in the queue as it enters the passing lane.

Gattis et al. studied the passing activity at both short passing lanes, less than 1400 feet and at long passing lanes, greater than 2500 feet (*13*). The number of vehicles that attempted to pass and the number of vehicles that successfully completed a pass were recorded. Results indicated that a slightly smaller proportion of vehicles attempted to pass on the short passing lanes than on the long passing lanes.

It has been observed that roadway sections with wide, paved shoulders are sometimes used as informal passing lanes where slower drivers pull to the shoulder to allow the faster vehicles to pass them *(9).* In a study conducted by Morrall and Plight in Alberta, Canada, it was observed that some slower drivers pulled to a 10-foot paved shoulder to allow faster vehicles to pass. However, they observed that this good gesture was usually limited to low-volume conditions. At higher volumes, drivers were reluctant to pull to the shoulder due to the problem of reentering the mainstream *(5).*

In another study, Harwood and St. John (*1*) observed that for highway sections having shoulders designated for slower moving vehicles, up to 8 percent of the total traffic and 40 percent of the platoon leaders used the shoulders. However, they concluded that shoulder use provides only minimal operational benefits at flow rates below 100 vph. They also observed that at flow rates above 100 vph, benefits from shoulder use are only 20 percent of that of a passing lane.

Shoulder usage for improving passing opportunities appears to be increasing in the United States. In 1985, the Transportation Research Board (TRB) quoted five states that allowed the use of shoulders for passing and 10 other states that allowed the use of shoulders under special conditions *(14).*

It can be concluded that passing lanes provide operational benefits on two-lane, two-way rural highways and the construction of the same should be carried out in a phased and methodical manner as explained in the latter part of this chapter.

MEASURES OF OPERATIONAL PERFORMANCE

Previous research studies have used various operational performance measures to evaluate the effectiveness of passing lanes. The most important factors used are percent time delay, speed, lane utilization, platoon structures, and time headway distribution *(9).*

Percent Time Delay and Percent of Vehicles in Platoon

The *Highway Capacity Manual* (*HCM*) defines percent travel time delay as the average percent of overall travel time that all vehicles traveling in platoons are delayed due to their inability to pass the slower moving vehicle at the head of the platoon *(14).* The *HCM* uses percent time delay as the primary measure of effectiveness in determining the LOS of a two-lane highway because it is reflective of both functions of a highway, namely mobility and accessibility *(9).*

Speed

The *HCM* defines the use of speed and capacity as secondary measures of LOS on a two-lane highway *(14).* The speed used in the above case is the average travel speed or the space mean speed, which is obtained by taking a length of highway and dividing it by the travel time of all vehicles traversing the segment in both directions of the highway segment under consideration.

Lane Utilization

In a highway section with a passing lane, the outer lane or shoulder is designated to be used by slower-moving vehicles, leaving the inner lane available for passing vehicles. A measure of the vehicles in the inner lane may reflect passing activities within that section. Therefore, lane utilization could be considered to be an indirect measure of passing rates subject to the assumption that motorists understand and follow the concept of lane assignment *(9).*

Platoon Structure

The platoon structures existing at the entrance and exit locations of a passing lane could be an indirect measure of the passing activities within a passing lane section *(9).* An ideal passing lane section would be one which is able to fully convert a platoon at the upstream location of the passing lane to free-flowing single vehicles at the downstream location of the passing lane.

Time Headway Distribution

Time headway is another measure of effectiveness of the operational efficiency of a passing lane. The time headways for a specific group of vehicles at the entrance and exit of a passing lane are compared to determine the effect of the passing lane on the group of vehicles.

DESIGN GUIDELINES

Guidelines published regarding the location and design of passing lane sections on two-way, two-lane rural highways are discussed in the following sections.

Guidelines

Research conducted by the Kansas Department of Transportation suggests that improvements to two-lane rural highways in the form of adding passing lanes should be accomplished in a two-level process: i.e., network and project levels *(9).*

The study recommends that, at the network level, two-lane rural highway segments operating below a predefined level-of-service should be identified for improvements. At the project level, highway segments identified at the network level should be ranked for the purpose of prioritization *(9).* The study also recommended minimum average annual daily traffic (AADT) values that warrant the addition of passing lanes at the network level, based on the *HCM* level-of-service procedures for rural two-lane highways *(9).* Table 3 presents these warrants.

Table 3. Suggested Minimum AADT Values for Rural Two-Lane Highways for Levels-of-Service B and C in Level Terrain–Justification for Passing Lanes.

		Projected Design Year AADT									
% Trucks		10		15		20		30		40	
LOS		B	C	B	C	B	C	B	C	B	C
% No Passing Zones	0 %	3900	6200	3700	5890	3520	5600	3210	5110	2950	4690
	20 %	3460	5630	3290	5340	3130	5080	2850	4630	2620	4260
	40 %	3030	5190	2880	4930	2740	4690	2500	4280	2290	3930
	60 %	2740	4900	2600	4660	2480	4430	2260	4040	2080	3710
	80 %	2450	4760	2330	4520	2220	4300	2020	3920	1860	3600
	100 %	2310	4620	2190	4380	2090	4180	1900	3800	1750	3490
Assumptions: K=0.15, directional split = 60/40, peak hour factor = 0.92, lane width ≥ 12 ft, shoulder width ≥ 6 ft.											

Length

The literature does not provide a specific definition for the length of a passing lane. Some studies consider the passing lane length to include tapers, while others exclude tapers from the definition of passing lane length. In this report, the length of a passing lane refers to the length of the two-lane passing section excluding the transition tapers.

Earlier research conducted by Harwood and Hoban suggested the optimal passing lane lengths for respective two-way volumes as shown in Table 4 (*10*). Subsequent research generally supported these recommendations (*8*,*9*). However, these studies were conducted during the period (1974-1996) when the national maximum speed limit was 55 mph.

Table 4. Optimum Lengths for Passing Lanes.

Two-Way Flow Rate (veh/hr)	Optimal Passing Lane Length (mi)
200	0.5
400	0.5-0.75
800	0.75-1.0
1400	1.0-2.0

Spacing

Spacing of passing lanes refers to the distance between successive passing lanes in the same direction of travel. The optimal spacing between passing lanes depends on a number of factors including traffic volumes, operational improvement desired, and cost constraints.

Harwood and Hoban (*10*) suggest that the Australian approach of long initial spacing of 10-15 miles should be followed for passing lane installations. If volumes continue to grow such that additional improvements are warranted, the spacing may be reduced to 3-5 miles by adding intermediate passing lanes.

A comparison of recommended design guidelines regarding length and spacing of passing lanes in Canada, Australia, and the United States is listed in Table 5 *(9)*.

Table 5. Comparison of Design Guidelines for Passing Lanes Among Canada, Australia and the United States (*2*).

Jurisdiction	Spacing (mi)	Length (mi)	Taper Length	
			Diverge	Merge
British Columbia	-	Minimum 0.5; desirable 0.65	20:1	25:1
Alberta	-	1.3	25:1	50:1
Canadian Parks Service	Determined from warrants	Trans-Canada 1.3; other highways minimum 0.3	100 m	200 m
Ontario	6.2-15.5	0.9-1.3	$\frac{V \times W}{1.6}$	$\frac{V \times W}{1.6}$
Federal Highway Administration (USA)	3.1-8.0	Minimum 0.2; 0.5-1.0 optimal	$\frac{2 \times V \times W}{3}$	$V \times W$
Australia	2.2-3.1 to 6.2-9.3	Depends on design speed; normal maximum length 0.75	$\frac{V \times W}{3}$	$\frac{V \times W}{2}$

V = 85th Percentile Speed.
W = Lane Width.
Length does not include transition tapers.

Configuration of Passing Lanes

Figure 31 shows nine different configurations of passing lanes (*9*). The isolated passing lane shown in Figure 31a is used to reduce delays occurring at a specific isolated bottleneck. The other configurations allow some interaction between consecutive passing lanes in opposite directions, and they are used when traffic improvements are needed in both directions of travel.

As per Harwood and Hoban (*10*), when two passing lanes are located in opposite directions at the same place on a high-volume highway, a tail-to-tail configuration is more effective. They claim that the tail-to-tail configuration is more effective than the head-to-head configuration because it creates a process of platoon break-up so that the vehicles are not in platoon as they leave the passing lane. They contend that for the head-to-head configuration, the breakup of the platoon takes place in the passing lane, but the vehicles may become re-platooned. The vehicles may leave the passing lane sections in platoons, thus reducing the efficiency of the passing lanes.

The alternating type passing lanes shown in Figures 31f and 31g can be used when sufficient width for passing lanes is available. Overlapping type passing lanes, shown in Figures 31h and 31i, can be used when a passing lane is located on a crest or sag vertical curve, respectively. Side-by-side passing lanes, shown in Figure 31j, could be used where the location of a passing lane is constrained by non-flexible factors. Those factors include (but are not limited to) obtaining right-of-way, when heavy traffic is the cause of platooning rather than no passing zones, and where the need for passing lanes exists in both directions *(9)*.

MICROSCOPIC SIMULATION

One objective of this research was to develop design guidelines for obtaining the optimal length and spacing of passing lanes for a given input value of two-way volumes. The simulation runs for this research were performed using TWOPAS. TWOPAS is a microscopic simulation software that simulates two-lane rural highways under a wide variety of conditions. TWOPAS has recently been developed for the Federal Highway Administration for Windows®-based personal computers.

The main advantages of performing simulations are that they can be performed in a short period of time and that the data can be easily reduced to obtain the desired results. TWOPAS has the ability to model two-lane, two-way rural highways with passing lanes. A user interface called UCBRURAL was recently added to TWOPAS, making it more user-friendly. TWOPAS is based on car-following logic, which assumes that a vehicle following another vehicle will always maintain a space headway relative to its lead vehicle that is linearly proportional to its speed.

A study conducted by Morales and Paniati showed that TWOPAS's simulation results compared favorably with those observed in the field with regards to measures of effectiveness (MOEs) (*15*). This study validated TWOPAS under a specific geometric and traffic condition and exposed the potential of the software to the transportation engineering community.

Subsequent evaluation of the software under a wide variety of traffic and geometric conditions in California has further validated the use of the software to replicate field conditions.

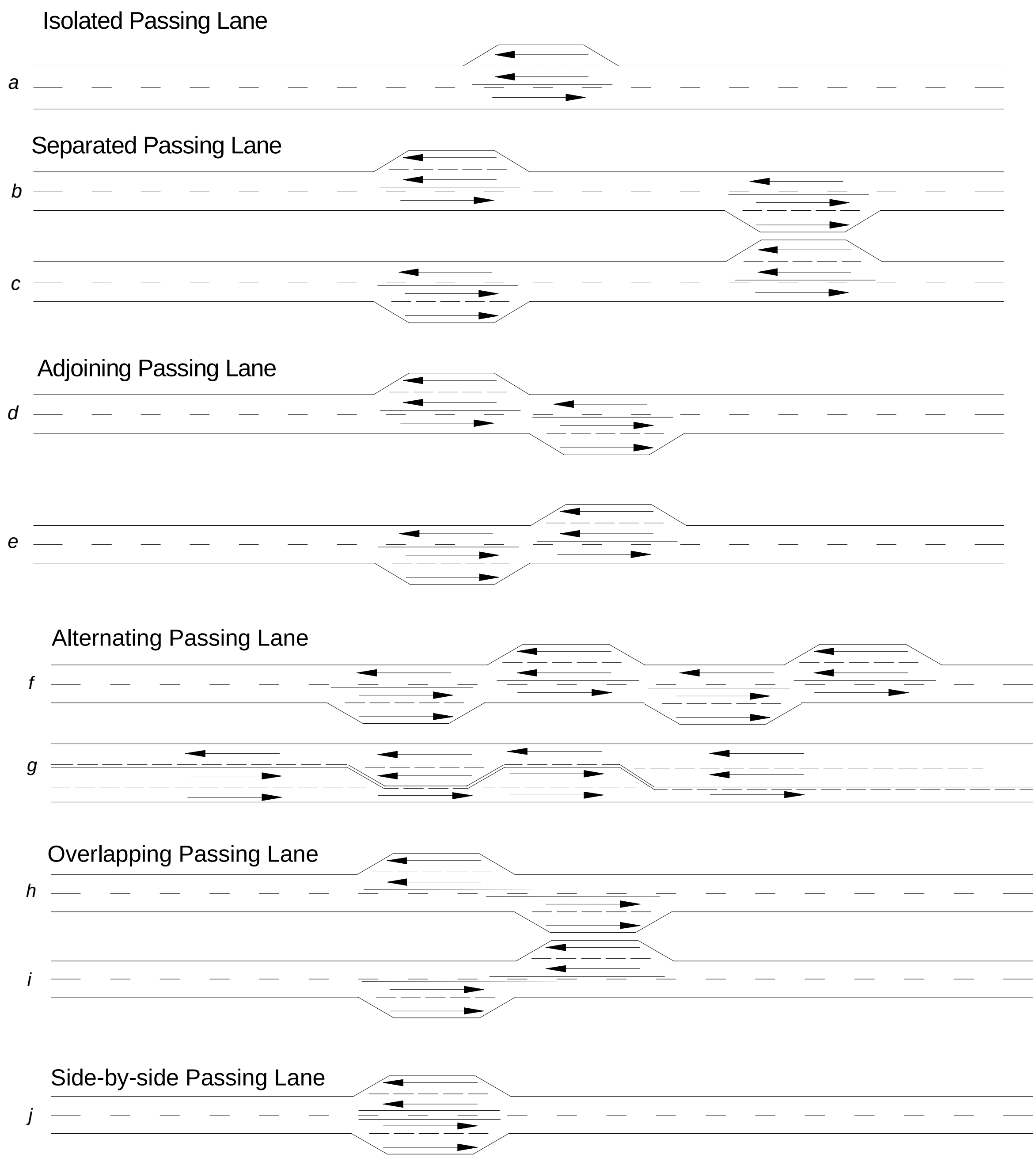

Figure 31. Passing Lane Configurations.

MEASURE OF OPERATIONAL PERFORMANCE SELECTED

Percent time delay was chosen as the measure of operational performance in this project, as the *HCM* uses percent time delay as the primary measure of effectiveness in determining the LOS of a two-lane highway. The level-of-service for a two-lane highway is related to the average percent time delay as shown in Table 6 (*14*).

Table 6. Level of Service and Corresponding Percent Time Delay *(11)*.

Level of Service	Percent Time Delay
A	30
B	45
C	60
D	75
E	> 75

EXPERIMENTAL SETUP

The following sections describe the various input parameters with regards to the experimental setup.

Highway Test Bed

A hypothetical two-lane, two-way rural highway with varying length and spacing of passing lanes was simulated under a variety of traffic mixes and two-way traffic volumes, equally proportioned in both directions. The spacing between the passing lanes was varied between 1.0 mile and 8.0 miles with a step size of 1.0 mile, and the length of the passing lanes was varied between 0.25 mile and 2.0 miles with a step size of 0.25 mile. The passing lane sections selected were side-by-side sections. The section upstream and downstream of the passing lane system was fixed at 1.0 mile in order to maintain uniformity in the setup and to obtain consistency with regard to the results of the simulation. The road was assumed to be on a level grade with opposed passing permitted in all sections except within the passing lanes. Figure 32 shows a sketch of the highway test bed used in this research.

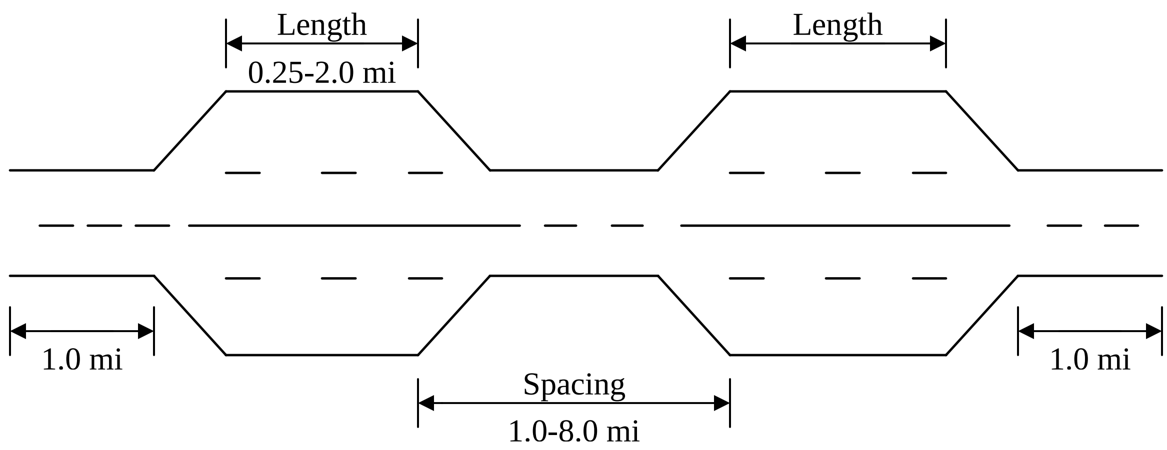

Figure 32. Section Used for TWOPAS Simulation Runs.

Traffic Volume

The range of two-way traffic volume used in this research was between 400 and 1000 vph, equally proportioned in both directions, with a step size of 200 vph. Keeping the volume equally proportioned in both directions leads to uniformity in the output. It also gives an average value of the operational performance measures simultaneously while taking into account the traffic movement in both directions of travel.

Percent Traffic by Vehicle Type

The percentage of trucks was varied from 0 to 40 percent, with a step size of 2 percent. The corresponding percentage of cars varied from 100 to 60 percent, respectively.

RESULTS

Variation of Percent Time Delay (PTD) with Two-Way Volume and AADT

The results of the TWOPAS simulation runs are discussed in the following sections. The variation of percent time delay with two-way volume and AADT, varying length and spacing of passing lanes, and percent trucks is shown in Figure 33. A level, straight two-lane highway with passing permitted was assumed as the base condition.

The plots indicate that the value of percent time delay for any given two-way volume decreases as the percentage of four-laned roadway increases. Thus, the higher the length of passing lanes for a given stretch of highway, the lower is the percent time delay value. When passing lanes are added, quality of flow is noted to improve by two levels of service for the higher volume cases. As a rule of thumb, increasing the percentage of four-laned roadway increases the design life by the same number of years. For example, a 20 percent increase in a four-laned section increases the design life by 20 years, assuming a nominal traffic growth of 2 percent per annum.

Variation of Percent Time Delay with Truck Percentage

The variation of the percent time delay with truck percentage for a two-way volume of 600 vph is shown in Figure 34. The figure indicates the percent time delay generally is insensitive to the percentage of trucks for two-lane highways having passing lanes. Percent time delay remains nearly a constant for increasing truck percentage, suggesting that the addition of passing lanes greatly improves the operational characteristics on these highways by increasing convenient passing opportunities and reducing traffic delays. This finding could be attributed to the fact that slow-moving vehicles are much easier to pass in the multi-lane passing section than on a conventional high-volume two-lane, two-way highway.

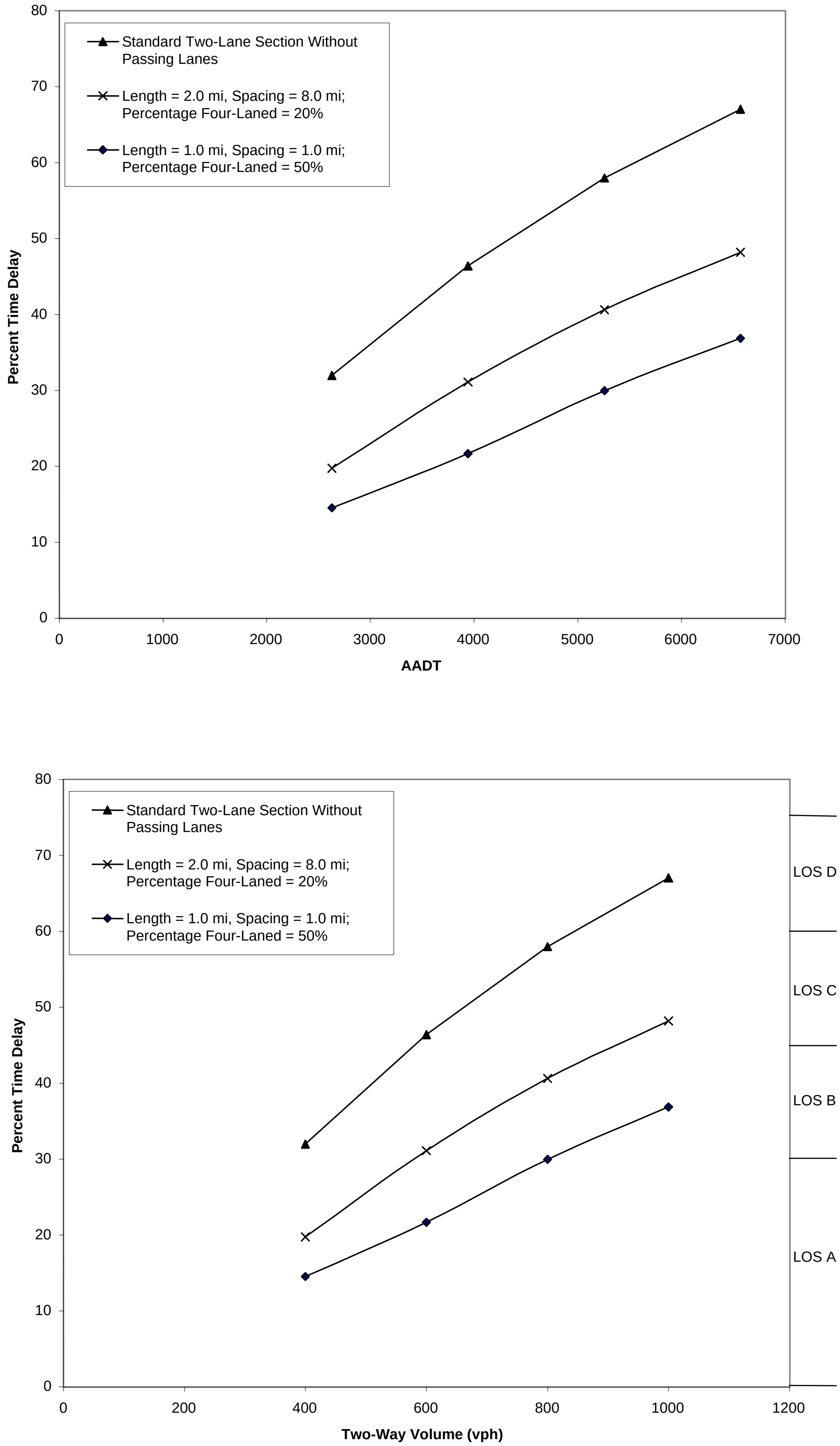

Figure 33. Variation of Percent Time Delay with Two-Way Volume and AADT for 10 Percent Trucks.

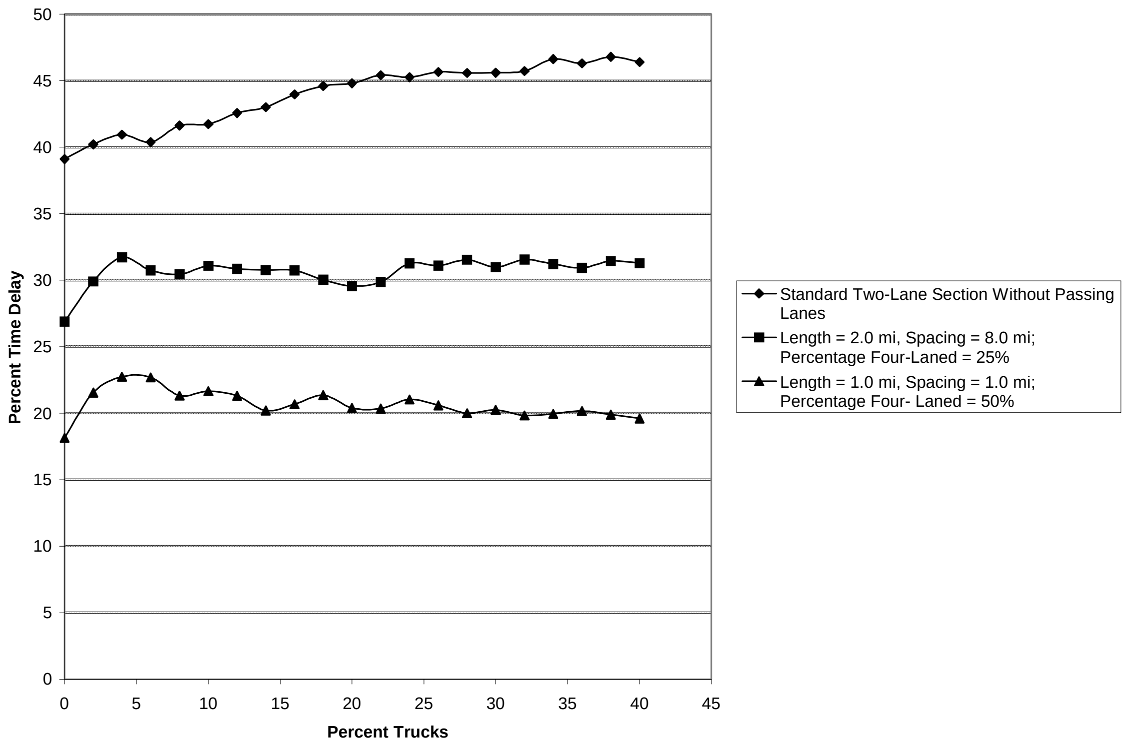

Figure 34. Variation of Percent Time Delay with Percent Trucks for a Two-Way Volume of 600 vph.

RECOMMENDATIONS

Recommended passing lane length and spacing values are shown in Table 7. The values were determined based on the premise of minimizing cost and percent time delay. These values are generally longer than those recommended by Harwood and Hoban (*10*), reflecting current higher speed limits for rural roads than the speed limits present during their research. Conversion of Super 2 roadways to four-lane highways should be considered when traffic volumes exceed 6000 ADT for level terrain and 5000 ADT in rolling terrain.

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 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, avoiding transition areas.

Table 7. Recommended Values of Length and Spacing by ADT and Terrain.

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

Traffic signals on highways in incorporated areas tend to build platoons. These platoons of through traffic leaving the last traffic signal in an incorporated area should be broken up before entering subsequent rural two-lane highway sections, if practical. The last signal should desirably feed into a continuation of the urban four-lane cross-section (if present in the city) or, alternatively, into a passing lane section. A one-half mile multi-lane section located immediately outbound of the last traffic signal is preferred; however, an outbound passing lane starting near the outskirts of the developed area is an alternative in more restrictive conditions.

CHAPTER 5

LANE AND SHOULDER WIDTHS

INTRODUCTION AND SAFETY ISSUES

Total roadway width is among the most important cross-section considerations in the safety performance of a two-lane highway. Generally, wider lanes or shoulders, or both, will result in fewer accidents. Additionally, safety evaluations have shown that passing lanes and short four-lane sections reduce accident rates below the levels found on conventional two-lane highways. Comparisons of the results of two before-and-after evaluations of passing lane installations are shown in Table 8. A California study at 23 sites in level, rolling, and mountainous terrain found accident rate reductions of 11 to 27 percent due to passing lane installation, depending on the road width (*3*). Accident rate reduction effectiveness at the 13 sites in level or rolling terrain was 42 percent. Another study of 22 sites in four states indicated a 9 percent accident rate reduction effectiveness for all accidents and a 17 percent accident rate reduction effectiveness for fatal and injury accidents. The combined data from both studies indicates that passing lane installation reduces accident rate effectiveness by 25 percent *(3).*

Table 8. Accident Reduction Effectiveness of Passing Lanes (adapted from *3*).

<table>
<tr><th rowspan="2"></th><th rowspan="2">Terrain Type</th><th rowspan="2">Total Roadway Width*</th><th rowspan="2">Number of Passing Lane Sites</th><th colspan="2">Percent Reduction</th></tr>
<tr><th>All Accidents</th><th>Fatal and Injury Accidents</th></tr>
<tr><td rowspan="4">Study 1 (Rinde)</td><td rowspan="3">Level, rolling, and mountainous</td><td>36</td><td>4</td><td>11</td><td>--</td></tr>
<tr><td>40</td><td>14</td><td>25</td><td>--</td></tr>
<tr><td>42-44</td><td>5</td><td>27</td><td>--</td></tr>
<tr><td>Level and rolling sites only</td><td>36-44</td><td>13</td><td>42</td><td>--</td></tr>
<tr><td>Study 2 (Harwood and St. John)</td><td>Level and rolling</td><td>40-48</td><td>22</td><td>9</td><td>17</td></tr>
<tr><td colspan="3">Combined Totals for Level and Rolling Terrain</td><td>35</td><td>25</td><td>--</td></tr>
<tr><td colspan="6">* Total roadway width includes both lane and shoulder widths.</td></tr>
</table>

Many Texans use the shoulder of the roadway to allow faster vehicles to pass. As reported by Fambro et al., the use of the shoulder as a turnout lane to facilitate passing was thought to improve safety and operations on the roadway (*16*). Since the shoulder is often used to allow vehicles to pass, providing a lane for passing seems to be a natural transition for Texas drivers. However, the answer to the question of what shoulder width should be provided *in addition to* the passing lane is unclear.

DRIVER SURVEYS

As described in Chapter 2, survey respondents were asked whether they would feel comfortable stopping to change a tire on various width shoulders (presented pictorially). Of the 134 drivers surveyed, 70 percent reported they would be comfortable stopping on 10-ft shoulders, 49 percent reported they would be comfortable stopping on 6-ft shoulders, and 20 percent reported they would feel comfortable about stopping on 4-ft shoulders.

EXISTING RECOMMENDATIONS FOR LANE AND SHOULDER WIDTHS

Researchers reviewed state design guidelines; national design guidelines; current literature; widths on existing passing lane sections in Kansas, Minnesota, and Texas; and available international design guidelines regarding lane and shoulder widths in passing lane sections. Several agencies have current recommendations for passing lane sections. These agencies include the American Association of State Highway and Transportation Officials (AASHTO); the states where field studies were conducted for this project—Kansas, Minnesota, and Texas; and other countries as noted in the literature.

AASHTO's recently updated version of the *Green Book (4)* includes a new section on passing lanes. The *Green Book* states that the width of an added lane should normally be the same as the lane widths of the two-lane highway. It also states that it is desirable for the adjoining shoulder to be at least 4 feet wide and that, whenever practical, the shoulder width in the added section should match that of the adjoining two-lane highway. However, the *Green Book* also states that a full shoulder width is not as needed on a passing lane section as on a conventional two-lane highway because: (1) the vehicles likely to stop are few, and (2) there is little difficulty passing a vehicle with only two wheels on the shoulder. Thus, if the normal shoulder width on the two-lane highway is 10 ft, a 6 to 8 ft widening of the roadbed on each side is all that may be needed. These recommendations are based upon the FHWA informational guide *Low Cost Methods for Improving Traffic Operations on Two-Lane Roads* by Harwood and Hoban *(10).*

Kansas State University completed a study entitled "*Review of the Effectiveness, Location, Design, and Safety of Passing Lanes in Kansas" (9).* This study recommends that passing lane widths should not be less than the width of the lanes in the adjoining sections but that reduced shoulder widths with a minimum of 4 feet may be used in the passing lane section. The study also recommends that the cross slope should stay the same as the adjacent lane.

The Minnesota Department of Transportation (Mn/DOT) specifies a desirable passing lane shoulder width of 8 feet with a 6-foot minimum, while the basic shoulder width of the adjoining lanes is 10 feet. MnDOT also specifies a passing lane width of 12 feet *(17).*

TxDOT does not currently have recommendations for passing lane sections. However, the current recommendations for climbing lane sections refer the designer to Table 3-8 of TxDOT's *Roadway Design Manual (18).* Based upon this table, required lane widths are 10 to 12 feet, and shoulder widths vary from 4 to 10 feet, depending upon the roadway classification (arterial or collector) and upon the roadway's ADT. Table 9 lists the information included in TxDOT's Table 3-8 with the information also converted to English units.

Other Recommendations

Recommendations for lane and shoulder widths in Australia, Ontario, British Columbia, Alberta, and Parks Canada are summarized in Table 10 along with the recommendations previously described (*19*). As shown in Table 10, the lane widths typically recommended were either 12 feet or widths that matched adjacent roadway sections. Shoulder width recommendations ranged from "minimum" values of 3 to 6 feet to "desirable" values that matched adjacent roadway sections.

Table 9. Portion of TxDOT's Table 3-8 for Lane and Shoulder Width Values (adapted from *18*).

Functional Class	Design Speed (mi/h)	Minimum Width [1,2] for future ADT of:			
		< 400	400-1500	1500-2000	> 2000
Arterial	**LANES (m)**				
	All	3.6 (12 ft)			
	SHOULDERS (m)				
	All	1.2[3] (4 ft)	1.2[3] or 2.4[3] (4 – 8 ft)	2.4[3] (8 ft)	2.4 - 3.0[3] (8 – 10 ft)
Collector	**LANES (m)**				
	50 (30 mph)	3.0 (10 ft)	3.0 (10 ft)	3.3 (11 ft)	3.6 (12 ft)
	60 (40 mph)	3.0 (10 ft)	3.0 (10 ft)	3.3 (11 ft)	3.6 (12 ft)
	70 (45 mph)	3.0 (10 ft)	3.0 (10 ft)	3.3 (11 ft)	3.6 (12 ft)
	80 (50 mph)	3.0 (10 ft)	3.0 (10 ft)	3.6 (12 ft)	3.6 (12 ft)
	90 (55 mph)	3.0 (10 ft)	3.0 (10 ft)	3.6 (12 ft)	3.6 (12 ft)
	100 (60 mph)	3.3 (11 ft)	3.3 (11 ft)	3.6 (12 ft)	3.6 (12 ft)
	110 (70 mph)	3.3 (11 ft)	3.3 (11 ft)	3.6 (12 ft)	3.6 (12 ft)
	SHOULDERS (m)				
	All	0.6[4,5] (2 ft)	1.2[5] (4 ft)	2.4[5] (8 ft)	2.4 - 3.0[5] (8 – 10 ft)

[1] Minimum surfacing width is 7.2 m for all on-system state highway routes.
[2] On high riprapped fills through reservoirs, a minimum of two 3.6 m lanes with 2.4 m shoulders should be provided for roadway sections. For arterials with 2000 or more ADT in reservoir areas, two 3.6 m lanes with 3.0 m shoulders should be used.
[3] On arterials, shoulders fully surfaced.
[4] On collectors, use minimum 1.2 m shoulder width at locations where roadside barrier is utilized.
[5] For collectors, shoulders fully surfaced for 1500 or more ADT. Shoulder surfacing not required but desirable even if partial width for collectors with lower volumes and all local roads.

Minimum width of new or widened structures should accommodate the approach roadway including shoulders.

Table 10. Summary of Existing Recommendations for Lane and Shoulder Widths on Passing Lanes.

	AASHTO (based on Harwood)	KDOT	Mn/DOT	TxDOT (for Climbing Lanes)	Ontario	British Columbia	Alberta	Parks Canada	Australia
Lane Width	Same as adjoining road or 12 ft	Not less than adjoining road	12 ft	10-12 ft	10.5 ft min; 11 ft desirable	12 ft	11.5 ft	12 ft	Normally 11.5 ft; not less than other lane width provided
Shoulder Width	4 ft min; match other shoulder when possible	4 ft min	6 ft min; 8 ft desirable	4-10 ft	3 ft min; equal to approach shoulder desirable	6 ft	5 ft	4 ft	3 ft

PROJECT RECOMMENDATIONS

Current lane width recommendations for passing sections range from 10 feet to 12 feet, a desirable width of 12 feet, or a minimum width to match that of the existing lanes on the two-lane roadway.

Recommendations for shoulder lane width are not as straightforward. Several items should be considered in determining the shoulder width for a passing lane section. Studies have indicated that the addition or widening of a shoulder greatly improves safety—shoulder widening can reduce related accidents by up to 49 percent with the addition of an 8-foot shoulder *(20)*. Therefore, it follows that the presence of a shoulder in a passing lane section increases the overall safety of the passing lane. The presence of a shoulder also increases the driver's comfort level. Additionally, driver expectancy may be violated when traveling from a two-lane section with a wide shoulder to a three-lane section with no shoulder or with a very narrow shoulder. However, as noted by Harwood (*2*), passing lane sections are short, and few vehicles are likely to stop in these sections. If vehicles do have to stop for an emergency, extra width for going around the vehicle is provided by the width of the additional lane.

Other user groups should also be considered in the provision of shoulders in passing lane sections. Pedestrians and bicyclists may also use the roadways with passing lane sections; if so, they may travel on the shoulder. Rumble strip installation also affects these users; if a rumble strip is placed in the center of the shoulder, usable space for pedestrians and bicyclists is limited. The Federal Highway Administration (FHWA) has developed a Draft Technical Advisory for rumble strip installation on non-freeways (*21*). These guidelines are summarized as follows:

1. Standard milled rumble strips, installed as close to the edgeline as practical, should be used when an 8-foot clear shoulder width remains available after installation of the rumble strip.
2. A modified design should be used when the remaining available clear shoulder width is less than 6 feet wide and the road is used by cyclists. The most recent studies indicate a milled depth of approximately 3/8 inch provides reasonable warning to motorists while not being unduly dangerous to cross on a bicycle when necessary. Some states have also used narrower strips (less than 16 inches) perpendicular to the direction of traffic successfully. Others have adopted a gap spacing to allow a cyclist to cross into the travel lane and back without having to cross directly over the rumble strips.
3. Rumble strips should not normally be used when their installation would leave a clear shoulder pathway less than 4 feet wide for bicycle use (*21*).

As shown in Table 10, current recommendations for minimum shoulder widths range from 3 to 6 feet. Other recommendations include making the shoulder as wide as the adjoining roadway section when possible. Based upon existing recommendations from other states and other countries, upon the considerations previously noted, and upon the survey results, researchers recommend the values in Table 11 for lane and shoulder widths in passing lane sections.

Table 11. Project Recommendations for Lane and Shoulder Widths.

Lane Width	
12 ft 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 if rumble strips are used 4 ft 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.	

CHAPTER 6
SIGNING AND MARKING

The primary means of communicating the designer's intentions for the use of a roadway is through its signs and pavement markings. Signs and markings explicitly inform the driver of permitted and required behavior such as passing or lane positioning. If drivers do not understand or agree with the intent of the designer, however, drivers may exhibit unpredictable or undesirable behavior.

The research team sought to develop a clear understanding of recommended signing and marking schemes and plans, seeking supporting research findings where available. As discussed in Chapter 3, a number of questions were examined through use of a survey of Texas drivers. In addition, a field study of a pavement marking pattern at the introduction of the passing lane was conducted.

SIGNS

Signing is intended to enhance the driver's understanding of the intended use of the roadway. Choosing a signing system that accomplishes this goal will enhance the operation of a passing lane by informing the driver of the intended use of the passing lane and the upcoming opportunities to pass. Signing associated with passing lanes is usually provided in six distinct areas along the passing lane section, as shown in Figure 35. These areas are:

1. in advance of the passing lane;
2. the transition area of the lane addition of the passing lane;
3. in advance of the termination of the passing lane;
4. the transition of the lane reduction of the passing lane;
5. the downstream area adjacent to the passing lane; and
6. in the opposing direction of the passing lane.

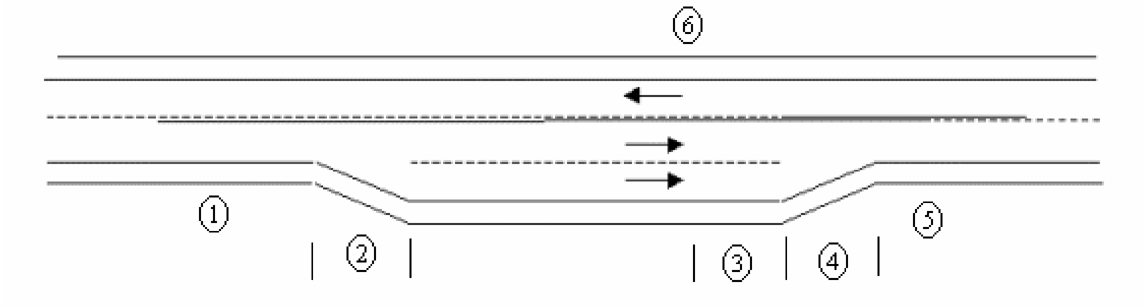

Figure 35. Passing Lane Signing Areas.

Advance Notice of the Passing Lane

Advance notice of passing lanes can reduce the likelihood of unsafe passes by informing the driver of the upcoming passing opportunity. The Kansas Department of Transportation (KDOT) uses a guide sign that gives advance notice of the upcoming passing lane 2 miles ahead, as shown in Figure 36. The Minnesota Department of Transportation uses a regulatory sign placed 2 miles upstream of the passing lane to provide advance notice of passing lanes, also shown in Figure 36.

Little guidance is available to determine whether the advance notice sign should be a guide or regulatory sign, although a case can be made for either. In the case of the guide sign, notice is given of a facility (in this case a passing lane) designed to assist travelers with information. In the case of the regulatory sign, the viewpoint is that the passing lane is a facility that has certain laws or regulations associated with its operation.

Figure 36. Advance Notice Signing in Kansas (left) and Minnesota (right).

The signing practice in Alberta, Canada is to provide advance notice of the upcoming passing lane in a similar manner to Mn/DOT, although the placement is 1.2 miles (2 km) upstream. Figure 37 illustrates the advance signing used in Canada's Ontario province (9). An interpretation of the symbolic sign's meaning is that the shorter arrow terminating at a point lower than the longer arrow represents slower moving vehicles. The meaning is then reinforced with another sign upon reaching the passing lane.

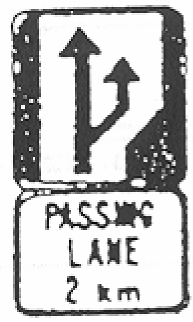

Figure 37. Advance Notice Signing in Ontario, Canada.

Transition Area of the Passing Lane Addition

The literature and current practice of signing associated with the addition of the passing lane focuses on three signs. These regulatory signs are KEEP RIGHT EXCEPT TO PASS, SLOWER TRAFFIC KEEP RIGHT, and LEFT LANE FOR PASSING ONLY as illustrated in Figure 38.

Figure 38. Typical Signing at the Passing Lane Addition.

Each of the signs in Figure 38 intends to convey the message that passing is to be carried out in the left lane. There is disagreement regarding which sign is more appropriate, although Hoban and Morral (*19*) report that SLOWER TRAFFIC KEEP RIGHT is being used in some areas of Canada in lieu of KEEP RIGHT EXCEPT TO PASS, with the belief that the sign conveyed a stronger meaning to drivers. These researchers also made the same observation in areas of Australia, with the exception of RIGHT being replaced by LEFT.

State law within Texas currently asserts that it is not legal to drive in the left lane unless passing another vehicle. In light of this fact, the sign conveying the strongest, clearest meaning would seem to be the most beneficial in instructing drivers to seek the outside lane unless involved in a passing maneuver along passing lane sections.

Advance Notice of Passing Lane Termination and Lane Reduction

Advance notice of the termination of the passing lane and subsequent lane reduction is required as per the *Manual on Uniform Traffic Control Devices* (*MUTCD*) (*22*). There are some agencies that use one sign in advance of the passing lane termination, while others use two. The sign in advance typically provides a distance to the termination of the passing lane, while the additional sign is placed at the point of termination or corresponding beginning of merge taper.

The spacing in advance of the merge taper to one lane is determined based upon the 85^{th} percentile speed of the roadway. The typical sign previously used in Texas and found in the literature has been the symbolic lane reduction sign shown in Figure 39. However, with the recent elimination of this sign in the *MUTCD* (*22*), a different sign must be utilized to merge traffic from the lane being dropped.

In order to provide advance notice of the upcoming merge, a RIGHT LANE ENDS sign with a plaque similar to the one shown in Figure 40 is used. As previously noted, the distance shown on the plaque varies according to the 85^{th} percentile speed of the roadway (*22*).

At or within close proximity of the beginning of the merge taper, a LANE ENDS MERGE LEFT SIGN as shown in Figure 41 is used. This sign provides the information that at this point, the roadway transitions from two lanes to one (*22*).

Figure 39. Obsolete Lane Reduction Sign.

Figure 40. Advance Notice of Passing Lane Termination.

Downstream Area

The downstream area adjacent to the passing lane section is an area where notification can be provided to drivers about upcoming passing lane sections, or that there are no upcoming passing lanes. This information is important because it allows drivers to have a better expectancy regarding forthcoming passing opportunities, thus enhancing the operation of the roadway.

Figure 41. Merge Transition Area Signing.

Opposing Traffic

Traffic flowing in the opposite direction of the passing lane must be provided information regarding whether they may cross into the lane to their left (i.e., the oncoming passing lane). This information can be provided through longitudinal pavement markings or a combination of both signs and pavement markings.

A no passing zone is typically provided at the merge transition area of the passing lane to reduce possible conflicts as drivers complete the merge maneuver. The addition of a NO PASSING ZONE sign similar to the one shown in Figure 42 can be used in addition to double yellow markings in order to provide more information to the driver if desired (*22*).

Figure 42. No Passing Sign.

For opposing traffic traveling adjacent to the passing lane, passing may or may not be permitted. Canada's Alberta Transportation and Ontario Ministry of Transportation use AADT as criteria for the restriction of passing. If the AADT is less than 4000 vpd, passing is permitted provided there is adequate sight distance (*19*). In these instances, Alberta uses the sign DO NOT PASS WHEN TRAFFIC ONCOMING spaced at approximately 1640 ft (500 m), while Ontario uses PASS ONLY WHEN CENTER LANE IS CLEAR spaced at approximately 2625 ft (800 m) (*9*).

While Australia has no criteria for determining a cutoff point for passing by the opposing traffic, they do use a sign with three arrows representing each lane's direction of travel. This sign is similar to the optional sign shown in Harwood and Hoban's recommended passing lane signing and marking configuration for passing lanes shown in Figure 43 (*9*, *19*).

One solution to alleviate passing by opposing traffic is simply to construct side-by-side passing lanes as illustrated in Figure 44. With the construction of passing lanes on either side of the centerline, the need for passing by opposing traffic in the passing lane is eliminated. The construction of side-by-side passing lanes may cause a decrease in operational efficiency but at a slightly increased level of safety. However, further study is necessary to fully confirm these speculations.

To review, a number of alternative signing layouts have been reported in the literature. Table 12 provides an overview of the signing schemes that have been used or recommended, along with their source. In examining the signing strategies shown in Table 12, it is clear that a majority of sources report use of the following signs as a part of a signing strategy for passing lanes: an advance sign notifying drivers of the presence of an upcoming passing lane and a sign stating that drivers should keep right except to pass.

Two signing elements form the basis for the defining characteristics of a passing lane: drivers should be notified that the passing lane is upcoming so that they are more willing to delay passes until the passing lane is reached, and they should be notified about the purpose of the additional lane so they move to the right lane unless they are passing a vehicle. Because Texas has a legal requirement that drivers use the outside lane unless they are passing, the second sign also informs them of their legal obligation.

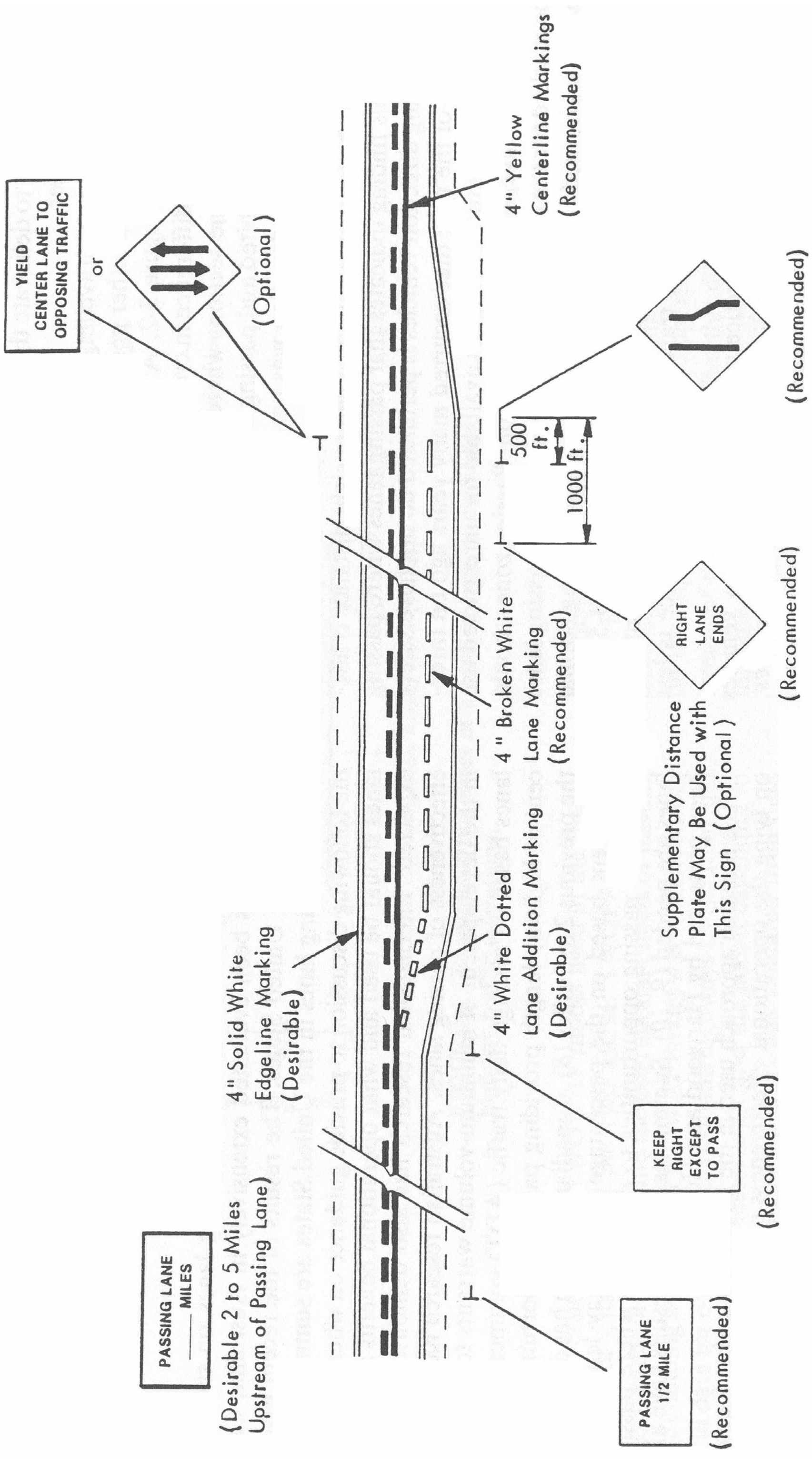

Figure 43. Harwood, Hoban, and Warren Passing Lane Signing and Marking (*23*).

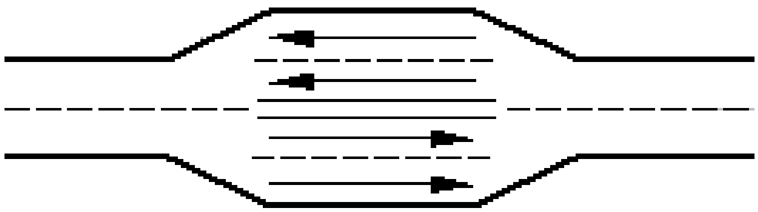

Figure 44. Side by Side Passing Lane Configuration.

Table 12. Comparison of Signing and Marking Strategies.

Signing and Marking Components	**Studies**						
	Ontario (1986) (*18*)	**Australia (1986) (*18*)**	**Alberta Transportation (1986) (*18*)**	**Harwood & Hoban (1987) (*23*)**	**Romana & May (1989) (*12*)**	**KDOT (1999) (*9*)**	**Gransberg et al. (1998) (*8*)**
Static Centerline	✓	✓	✓	✓		✓	✓
Advance Signing of Upcoming Passing Lane	✓	✓	✓	✓	✓	✓	✓
Keep Right Except to Pass	✓	✓	✓	✓		✓	
Slower Traffic Keep Right					✓		✓
Left Lane for Passing Only							
Staggered Passing Lane Design	✓	✓	✓	✓	✓		
Non-Staggered Passing Lane Design						✓	✓
Passing Permitted if Adequate Sight Distance	✓	✓	✓	✓	✓	✓	
Edgelines	✓	✓	✓	✓	✓	✓	✓
Arrows or Delineators at Merge					✓	✓	
Skip Stripe at Passing Lane Entrance	✓		✓	✓			✓

SURVEY FINDINGS

Several of the questions from the survey reported in Chapter 3 revolve around signing practices. Figure 1 provided three alternative wordings to inform drivers that they should stay in the right lane unless engaged in a passing maneuver. The wording of "KEEP RIGHT EXCEPT TO PASS," "SLOWER TRAFFIC KEEP RIGHT," AND "LEFT LANE FOR PASSING ONLY" was provided to drivers in the survey in open-ended questions requesting their interpretation of the signs' meanings.

Almost all of the survey respondents correctly interpreted that they should use the right lane unless passing another vehicle for the two signs stating "KEEP RIGHT EXCEPT TO PASS" and "LEFT LANE FOR PASSING ONLY," with "SLOWER TRAFFIC KEEP RIGHT" having a greatly reduced level of understanding. Based on the response to a follow-up question, most drivers felt that "LEFT LANE FOR PASSING ONLY" conveyed a stronger meaning (71 percent).

Sign Color

The Texas *MUTCD* provides the basis for signing in Texas, and was developed to ensure consistency and uniformity. A number of principles have been identified to determine appropriate sign characteristics (*24*):

- "Regulatory signs give notice of traffic laws or regulations." The signs are generally black legend on white background; an example is SPEED LIMIT 70 MPH.
- "Guide signs show route designations, destinations, directions, distances, services, points of interest, and other geographical, recreational, or cultural information." The signs are generally white legend on green background; examples include WEIGH STATION 1 MILE and PARK AND RIDE.
- "Warning signs call attention to conditions on, or adjacent to, a highway or street that are potentially hazardous to traffic operations." The signs are generally black legend on yellow background; an example is DIVIDED HIGHWAY ENDS.

Based on these principles, the signs recommended for the Texas Super 2 passing lane layout should have the following colors:

- PASSING LANE 2 MILES: white on green,
- LEFT LANE FOR PASSING ONLY: black on white,
- RIGHT LANE ENDS: black on yellow,
- LANE ENDS MERGE LEFT: black on yellow, and
- NEXT PASSING LANE X MILES: white on green.

MARKINGS

According to the Texas *MUTCD*, pavement markings may be used in conjunction with or independent of other devices such as traffic signs (*24*). Their independent use is hampered under certain conditions such as snow or wetness because of reduced visibility, although their use can still be very effective in communicating with the driver without diverting the driver's attention from the roadway.

Although other markings may be present (i.e., edgelines, centerlines, etc.), this review of pavement markings will focus specifically on those types and characteristics of markings associated with passing lanes. The two specific areas investigated include the provision and delineation of passing zone markings in the passing lane area and the use of markings at the entrance to the introduced passing lane. Table 12 provides an overview of various reported marking patterns, together with their source.

Passing Zone Markings

Passing zone demarcation has been treated in a number of different ways, depending on whether the markings are in the lane transition area, in the area of the fully developed passing lane, or in a location with specific traffic volume ranges.

Fully Developed Passing Lane

A variety of strategies have been used in setting passing zone markings in passing or climbing lane sections. Practices vary depending upon prior operational experience and with regard to tort liability concerns. The passing zone markings referred to are the markings that separate the directions of travel. In all of the cases discussed in the literature, crossing from the side of the roadway with a passing lane into the opposing direction of traffic is prohibited; the passing zone markings discussed either permit or prohibit traffic in the opposing lane from crossing into the passing lane (see Figure 45).

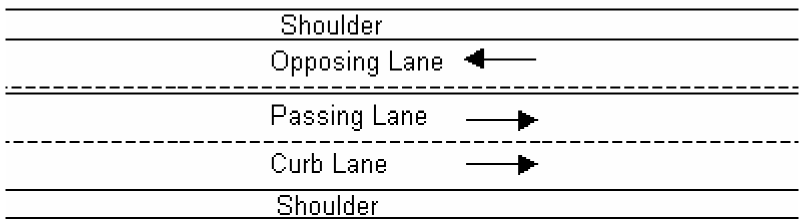

Figure 45. Passing Zone Markings.

Canadian practices vary considerably, depending upon the province or operating agency (*19*). In Ontario, passing is permitted across the centerline (from the opposing lane into the passing lane) unless sight distance restrictions are present. British Columbia has had a more varied practice. Prior to 1981, centerline striping practices were similar to Ontario, with passing permitted if adequate passing sight distance was available. A court decision in late 1980 regarding an accident led to a revised policy, however, with centerline no passing zones being marked on all passing lane roadway sections. This policy was revised in the mid-1980s, and passing permitted designations could be considered if traffic volumes were under 4000 vehicles per day. Centerline marking practices were also reported for Alberta. Similar to Ontario's revised practice, Alberta was reported as providing permitted passing for roadways with less than 4000 vehicles per day if sufficient sight distance was present. Hoban and Morrall also reported on Australian passing marking practices (*19*). In the designs reviewed, passing was permitted in areas that provided sufficient sight distance.

In a 1989 study of passing lanes, Romana and May provided an illustration of an example passing lane from the California *Traffic Manual* (*12*). The example permits passing in a similar manner to that depicted in Figure 45. The CalTrans *Traffic Manual Online* further dictates that two-direction no passing markings shall be used if average daily traffic exceeds 3000 vehicles per day.

The 1980 Texas *MUTCD* provides examples of three-lane roadways delineated to either permit or prevent passing from the opposing lane, depending on "inadequate sight distances or other special conditions" (*24*). In a study by Harwood and St. John, no difference in accident rate was found for sections that prohibited or permitted passing, provided that adequate passing sight distance was available (*25*).

Transition Areas

Passing across the roadway centerline is generally prohibited in the area of a passing lane transition (i.e., the area where the passing lane is introduced), although differing requirements and marking distances are reported.

Hoban and Morral report that Ontario prohibits passing from the opposing lane from a point 330 ft (100 m) upstream of the taper and extending through the taper (see Figure 46) (*19*). Both the national and Texas *MUTCD* (*23*, *24*) require that the length of the actual lane transition at the end of a passing lane is marked as no passing from both directions of travel.

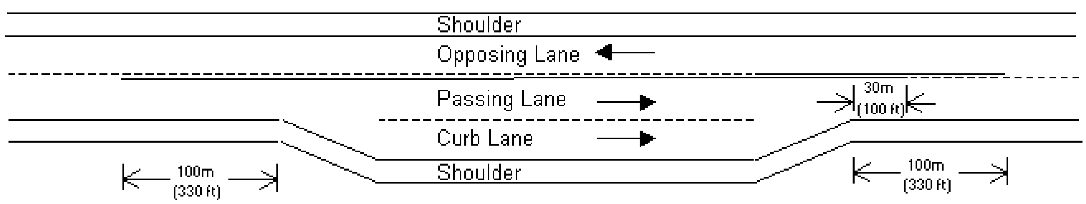

Figure 46. Example of End Transitions (*18*).

Lane Addition Markings

Several different lane transition marking patterns have been used to encourage motorists to stay in the outside (or curb, in Figure 46) lane of a passing lane section unless in a passing maneuver. One strategy used was to use a white dashed marking at the introduction of the passing lane, as shown in Figure 47. This type of marking is in use in Canada and Australia, although there is some variation among the various provinces and states (*19*). A similar pattern is recommended by Harwood and Hoban (*10*) for the United States.

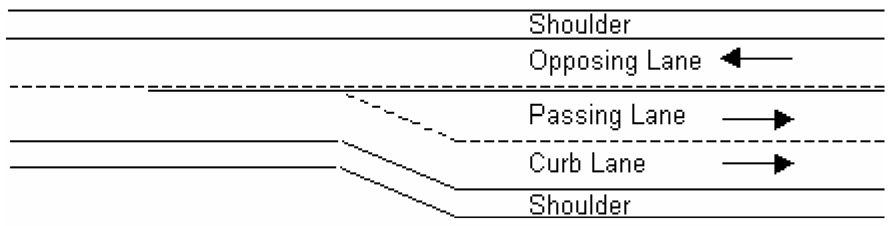

Figure 47. White Dashed Marking at Transition.

As noted by Harwood et al. the *MUTCD* does not provide a marking recommendation for the area of a lane addition (*22*, *23*). Harwood et al. recommend the use of white dashed line tapering across the opening to the passing lane (see Figure 47) to encourage drivers to go to the right or curb lane. Drivers engaged in a passing maneuver are permitted to cross the dashed marking. It is noted that several state agencies use this marking, although specifics are not provided by the authors.

Survey Findings

In the survey described in Chapter 3, motorists were asked questions regarding their behavior if they encountered the entrance to a passing lane with and without the supplementary marking. Of the surveyed drivers, 68 percent stated that they would cross the dashed markings to immediately enter the passing lane to pass a slower vehicle, while 96 percent said they would enter the passing lane in a similar situation if no supplementary markings were present. This difference of almost 30 percent indicated a substantial change in behavior that could produce a less efficient passing maneuver (i.e., the driver waits until further into the passing lane section before initiating a pass, thus requiring a longer passing lane).

Survey respondents who were asked which lane they would select if they were not close to another vehicle stated that they would enter the outside lane 87 percent of the time if markings were not present and 80 percent of the time if the markings were present. Because the additional transition markings were intended to encourage drivers to move to the outside lane, these findings were somewhat disconcerting. Further examinations of driver behavior were pursued in a field study.

Field Study

A field study of driver behavior was completed to examine lane selection for various entrance treatments for passing lane sections in Minnesota, Kansas, and Texas. Researchers analyzed the effect of different lane marking treatments on drivers' passing behavior. The time headway data were collected from several study sites in three states: Kansas, Minnesota, and Texas. All sites within each state had identical lane marking treatments: Kansas (Type A) no entrance skip striping (see Figure 48); Minnesota (Type B) gore channelizing all vehicles into the outside lane (see Figure 49); Texas (Type A for "before study,") similar to Figure 48; and Texas (Type C, entrance skip striping for "after study"), shown in Figure 50.

Data regarding lane selection were collected using classifiers that were connected to pneumatic tubes extending across the outside and inside lanes of the roadway. Data were collected at a point located 500 ft past the upstream transition from a single lane to the two-lane passing section. Researchers determined platoons and lane assignment by collecting vehicle headways, speeds, and volumes. Video data were also recorded in this section, allowing researchers to verify vehicle movements and check for erratic behavior.

Figure 48. Kansas and Texas "Before" Passing Lane Entrance Markings.

Figure 49. Minnesota Passing Lane Entrance Markings.

Figure 50. Texas “After” Passing Lane Entrance Markings.

Analysis

The data analysis was designed for two different data sets: (1) paired vehicles with headways less than 3 seconds, and (2) a single vehicle with a headway five or more seconds. For a pair of vehicles approaching a passing lane, four combinations of lane selection were possible:

- L-right, T-right: leading vehicle in *right* lane and trailing vehicle in *right* lane,
- L-right, T-left: leading vehicle in *right* lane and trailing vehicle in *left* lane,
- L-left, T-right: leading vehicle in *left* lane and trailing vehicle in *right* lane, and
- L-left, T-left: leading vehicle in *left* lane and trailing vehicle in *left* lane.

For a single vehicle, either the left or right lane is selected. The analysis was performed to investigate whether the three lane treatments have a significant effect on the driver’s passing behavior.

Table 13 summarizes the headway data collected over a six-hour period at each study site. Although the data collection periods were the same duration in each state, Texas had a smaller number of data points: roughly 20 percent of data from the other states.

Table 13. Summary of Data Collected.

State	Set	Name	Date	Hours	Type
Kansas	1	US 50 EB West of Emporia	11/28/00	6	A
	2	US 50 EB West of Emporia	11/29/00	6	
	3	US 50 EB West of Strong City	11/30/00	6	
Minnesota	1	US 12 EB East of Cokato	04/24/01	6	B
	2	US 12 EB East of Cokato	04/25/01	6	
	3	TH 371 NB North of Little Falls	04/26/01	6	
Texas Before	1	US 83 SB Childress	06/12/01	6	A
	2	US 83 SB Leakey	06/21/01	6	
	3	US 83 NB Eden	06/21/01	6	
Texas After	1	US 83 SB Childress	06/19/01	6	C
	2	US 83 SB Leakey	06/28/01	6	
	3	US 83 NB Eden	06/28/01	6	

The proportion of lane selection was calculated for pairs of vehicles entering the passing lane at each site, and the results are shown in Figures 51-54. In Kansas (Type A), nearly 70 percent of drivers followed the "L-right, T-left" pattern, and approximately 25 percent of drivers chose the "L-right, T-right" selection. In Minnesota, (Type B), the percentage of "L-right, T-right" was the highest, with a slightly higher percentage than "L-right, T-left." This is because the Type B treatment (double-yellow striped gore) explicitly encouraged vehicles to move to the right lane. Both Kansas (Type A) and Minnesota (Type B) showed little daily (or site) variability in percentages among the three data sets.

The proportions in Type C were similar to Kansas (Type A) in terms of overall trend. However, the data showed some site variability with different proportions at the Leakey study site. Within the Texas data, slightly different proportions were identified when comparing between Type A and Type C; Type A had a higher percentage of "L-left, T-right" and "L-left, T-left" vehicle pairs.

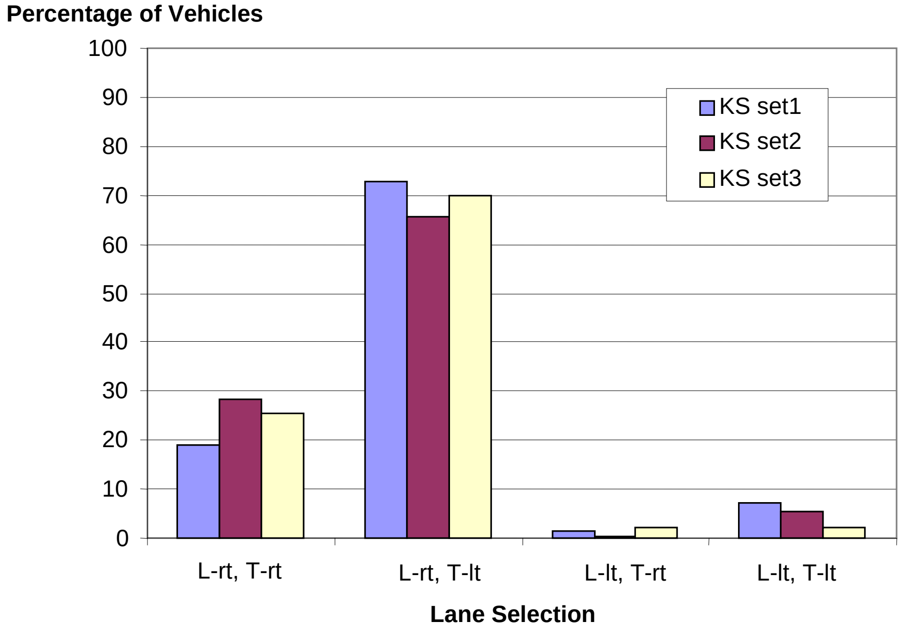

Figure 51. Proportion of Lane Selection for Kansas, Type A (Headway <3 sec).

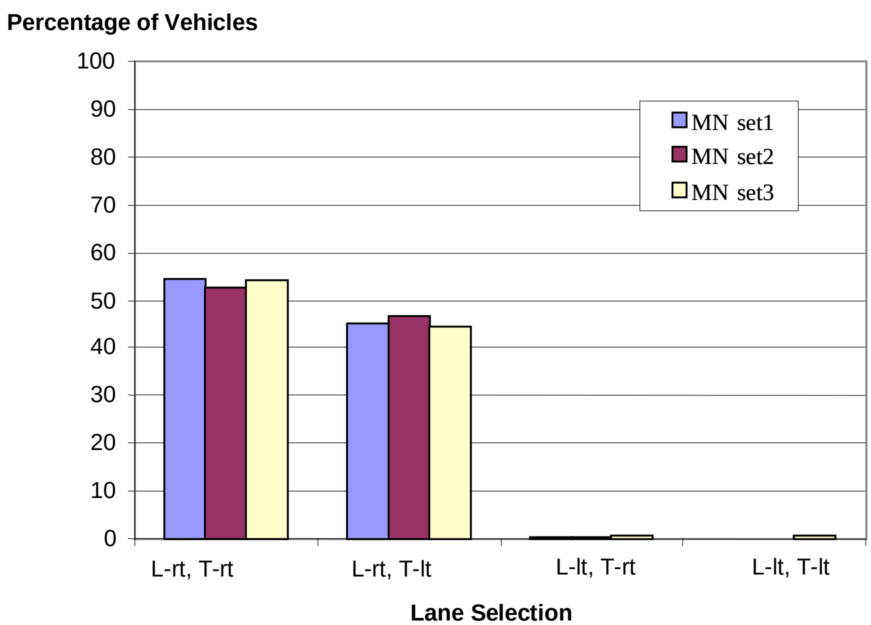

Figure 52. Proportion of Lane Selection for Minnesota, Type B (Headway <3 sec).

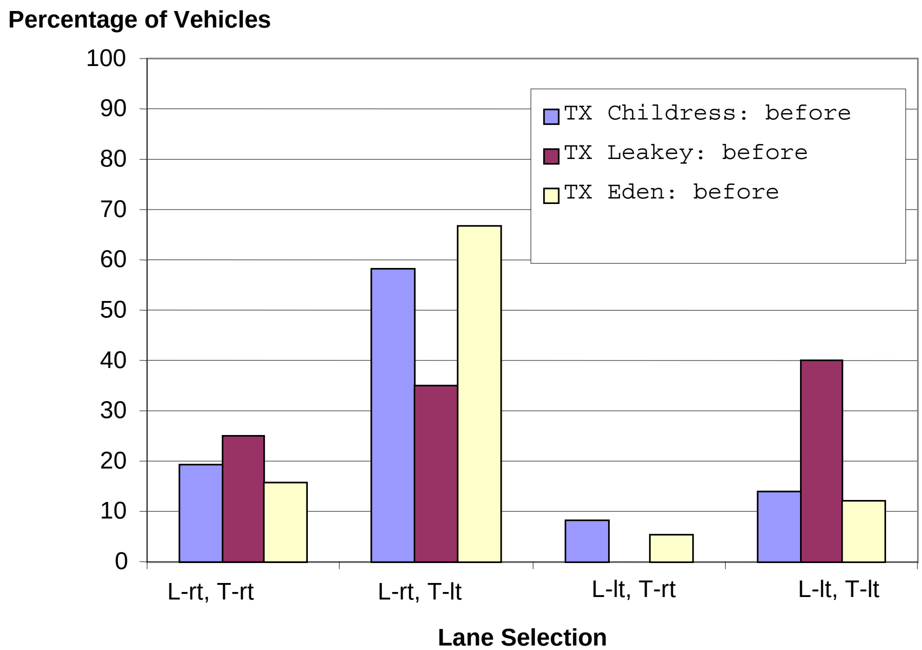

Figure 53. Proportion of Lane Selection for Texas "Before," Type A (Headway <3 sec).

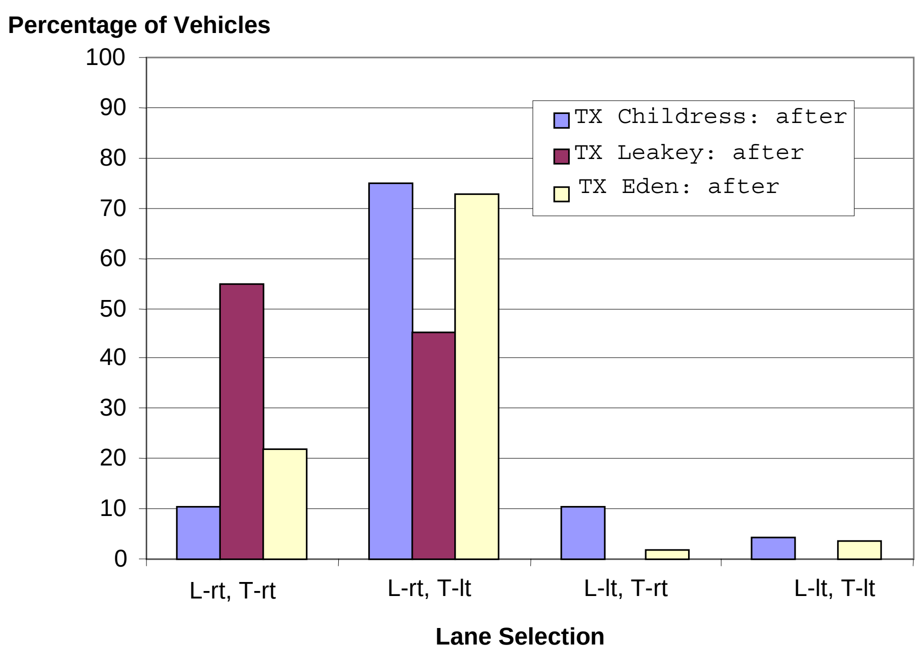

Figure 54. Proportion of Lane Selection for Texas "After," Type C (Headway <3 sec).

Looking at single vehicles, the percentage lane selection was calculated for vehicles having a headway greater than 5 seconds, and the results are illustrated in Figures 55-58. The percentage of vehicles in the right lane was higher than the percentage of vehicles in the left lane for all study sites. In particular, most vehicles (98 percent) selected the right lane in Type B. For Type A, both Kansas and Texas indicated a similar pattern, but the magnitude was different by 10 percent. However, the lane selection distributions indicated that the three treatment types might have three different types of performance effects on single vehicles.

Next, researchers performed a statistical analysis to investigate whether the differences in the proportion of each lane selection for the three treatments were statistically significant. The Chi-square test was selected for comparison of several binomial population proportions.

The test was performed with four different experimental designs. They are classified in terms of magnitude of the following headway and types of lane treatments:

1. Test the proportion difference of lane selections for three lane treatments when headway is less than 3 seconds for the four possible lane selection cases.
2. Perform a "before-and-after" study using Texas data only when headway is less than 3 seconds for the four possible lane selection cases.
3. Test the proportion difference of lane selection for three lane treatments when headway is greater than 5 seconds: two possible lane selection cases (left or right).
4. Perform a "before-and-after" study using Texas data only when headway is greater than 5 seconds: two possible lane selection cases (left or right).

The Chi-square test for differences in probabilities is described using an r×c contingency table: r = 3 (i.e., i = 3 treatments), c = 4 (i.e., j = 4-lane selection behaviors) (*26*). The expected number of observations in cell (i, j), E_{ij}, is defined as follows:

$$E_{ij} = \frac{n_i C_j}{N} \qquad (2)$$

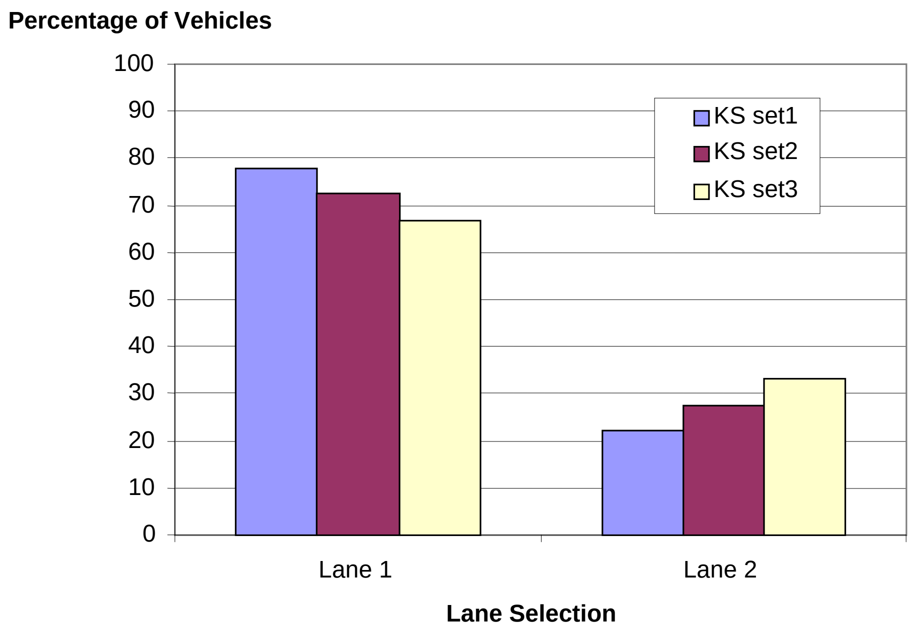

Figure 55. Proportion of Lane Selection for Kansas, Type A (Headway >5 sec).

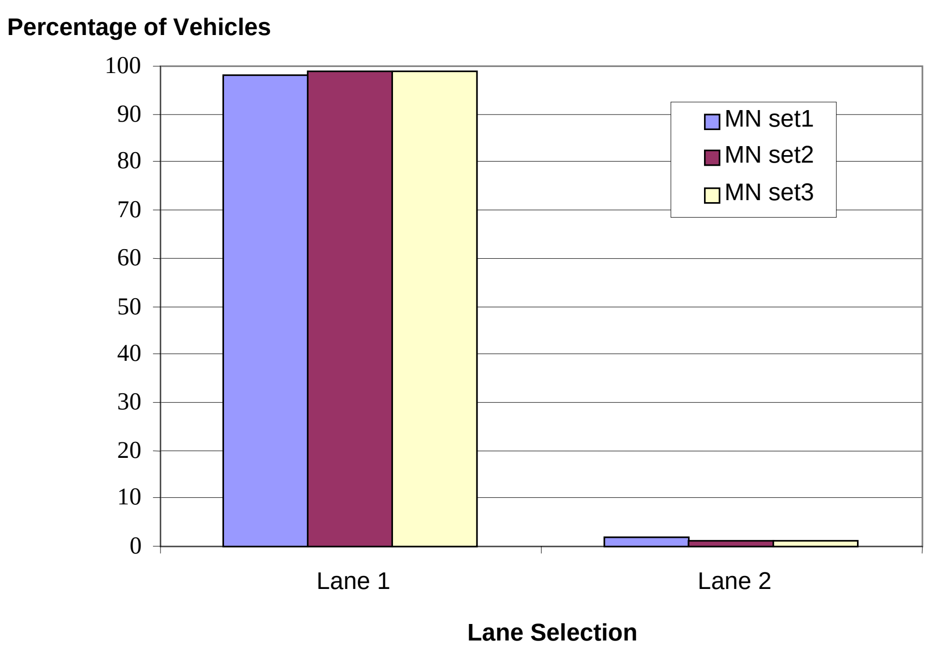

Figure 56. Proportion of Lane Selection for Minnesota, Type B (Headway >5 sec).

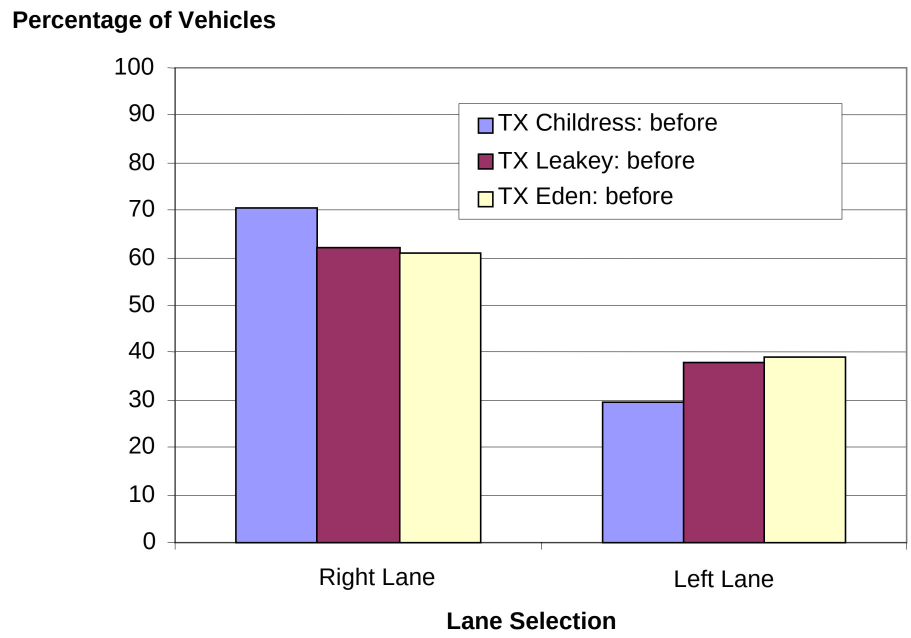

Figure 57. Proportion of Lane Selection for Texas, Type A (Headway >5 sec).

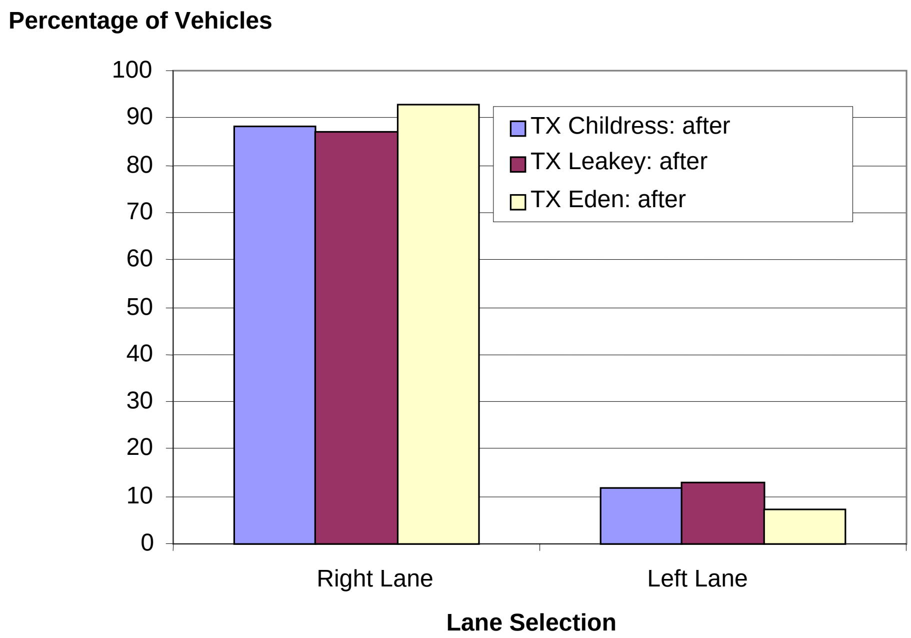

Figure 58. Proportion of Lane Selection for Texas, Type C (Headway >5 sec).

Test Hypotheses. The following hypotheses were used for the Chi-square test. H_o: $\Pi_{Aj} = \Pi_{Bj} = \Pi_{Cj}$, for all j (all of the probabilities in the same column are equal to each other), with H_1: At least two of the probabilities in the same column are not equal to each other.

The test statistic used is:

$$T = \sum_{i=1}^{r} \sum_{j=1}^{c} \frac{(O_{ij} - E_{ij})^2}{E_{ij}} \qquad (3)$$

The O_{ij} term represents the observed number in cell (i, j). If the test statistic is greater than χ^2_α, which is a Chi-square critical value corresponding to an upper-tail probability of α and degrees of freedom v=(c-1), then reject the null test hypothesis.

Cochran stated that "*If any E_{ij} is less than 1 or if more than 20 % of the E_{ij} are less than 5, the approximation **may** be poor*." If some E_{ij}s are too small, some categories may be combined to eliminate small E_{ij}s (*26*).

Test Results

The statistical analysis was performed in two steps. In the first step, the homogeneity of proportion within all data sets was tested to reduce the dimension of the test. In addition, the expected number of observations in cell (i, j), E_{ij}, was also checked to meet the previous recommendations for the reliable test. In the second step, a Chi-square test was performed against the four different experimental designs described earlier. The SAS ™ program was used to conduct the Chi-square test.

The test results of the homogeneity of proportion within all data sets are presented in Table 14. The results indicated that most states have homogeneous data sets; thus, they can be merged as a single data point with the exception of two cases. Type C in the Texas data with headway less than 3 seconds showed a small *p-value* (i.e., .0008), indicating the data sets were not homogenous. In addition, Kansas data with headway greater than 5 seconds also showed a *p-value* of .0051, leading to the same conclusions. Additional investigation of test results on the Kansas data indicated that sets 1 and 3 had homogeneity, but set 2 did not.

Table 14. Chi-Square Test Results for Homogeneity of Proportion.

State	Type	*p-value*	
		Headway < 3 seconds	**Headway > 5 seconds**
Kansas	A	.6654	.0051
Minnesota	B	.3795	.2975
Texas	A	.1649	.0886
Texas	C	.0008	.1554

The expected number of observations in cell (i, j), E_{ij}, was also calculated. It was found that the E_{ij} of "L-left, T-right" classification (with headway less than 3 seconds) was less than 5 for all study sites. Therefore, two lane selection types were combined into a single data point. That is, the counts of "L-left, T-right" and "L-left, T-left" were combined into a new value to meet the recommendations for the Chi-square test. In addition, the data of Type C in Texas data with headway less than 3 seconds were also combined due to a small expected number of cell observations. However, the Kansas data (with headway greater than five seconds) had a sufficient expected number of cell observations. Therefore, the Kansas data were divided into two different data sets (i.e., A1 = set1 + set3, A2 = set2), and they were used for the Chi-square test. The final test data are illustrated in Table 15.

The Chi-square test results are summarized in Table 16. Four tests were performed for the experimental design described. Test results showed that the differences in proportion from all experimental designs were statistically significant at the 5 percent significance level.

Conclusions

Researchers performed additional tests to identify the differences in proportion for each treatment type. The tests included several test hypotheses, and these results are also included in Table 16.

Table 15. Vehicle Count for Statistical Test.

Test	Type	L-right, T-right (Lane 1*)	L-right, T-left (Lane 2*)	L-left, T-right and L-left, T-left
I	A	120	348	34
	B	371	312	6
	C	28	85	10
II	A	21	66	26
	C	28	85	10
III	A1	616	205	n/a
	A2	211	105	n/a
	B	1582	22	n/a
	C	532	62	n/a
IV	A	351	186	n/a
	C	532	62	n/a
Note: * Notation for test III and IV.				

From the Test I result, the difference in proportion was significant between Type A and Type B as well as between Type B and Type C. However, no significant difference in proportion was observed between Type A and Type C (i.e., *p-value* = .8550). The experimental design of Test II is similar to Test I, except Test II included only Texas data. Results of Test II indicated that Types A and C could have different proportions. This conclusion is the opposite of the conclusion reached in Test I. This inconsistency might come from the variability within the Texas data sets and the small number of data points. It should be noted that the size of the data set of Type C in Texas was only about 20 percent of the sets in Kansas or Minnesota.

The results of Tests III and IV indicated that the difference in proportion was significant within each treatment at the significance level of 5 percent. Therefore, it could be concluded that when the vehicle's headway is less than 3 seconds (i.e., platooned vehicle), there is a significant difference between treatment Type B and the other two treatments. Whether the difference between Type A and Type C is significant is unclear from the tests performed on this data set. Testing using only the Texas "Before" and "After" data appears to indicate that the proposed marking treatment is effective in changing driver behavior in platoons, but the addition of data collected in Kansas resulted in a finding of no significant difference. Regional differences in driver behavior could account for this variation in response, but the results are uncertain. However, the marking treatment did have significant effects on lane selection when the vehicle headways are greater than 5 seconds (i.e., single vehicle).

Table 16. Chi-Square Test Results for Proportion Difference.

Test	H_o	*p-value*	Reject H_o
I	$\Pi_A = \Pi_B = \Pi_C$	.0001	Yes
	$\Pi_A = \Pi_B$	.0001	Yes
	$\Pi_A = \Pi_C$	.8550	No
	$\Pi_B = \Pi_C$	.0001	Yes
II	$\Pi_{before} = \Pi_{after}$	.0064	Yes
III	$\Pi_{A1} = \Pi_{A2} = \Pi_B = \Pi_C$	.0001	Yes
	$\Pi_{A1} = \Pi_B = \Pi_C$	.0001	Yes
	$\Pi_{A2} = \Pi_B = \Pi_C$	.0001	Yes
	$\Pi_{A1} = \Pi_B$	.0001	Yes
	$\Pi_{A1} = \Pi_C$	.0001	Yes
	$\Pi_{A2} = \Pi_B$	.0001	Yes
	$\Pi_{A2} = \Pi_C$	.0001	Yes
	$\Pi_B = \Pi_C$	.0001	Yes
IV	$\Pi_{before} = \Pi_{after}$	.0001	Yes

RECOMMENDATIONS

Based on available research and the studies performed by the research team, the following recommendations are made:

- Advance signing should be provided regarding the upcoming passing lane so that drivers are aware of its presence. The preferred sign (and associated sign placement) is that the passing lane is upcoming in 2 miles: PASSING LANE 2 MILES. This sign will permit drivers to delay passing maneuvers until they can be made more comfortably, although passing may still be permitted prior to the passing lane section.
- A sign should be provided just after the lane addition transition stating: LEFT LANE FOR PASSING ONLY. This wording is required because of current Texas State law (§ 544.011) rather than the more common KEEP RIGHT EXCEPT TO PASS.
- Standard RIGHT LANE ENDS and LANE ENDS MERGE LEFT signs should be used to indicate the end of the additional lane.

- A sign should be provided near the end of each passing lane section stating that in "X" distance another passing lane will be provided: NEXT PASSING LANE X MILES. This advance signing will inform the driver of the repetitive nature of the passing lane design, allowing the driver to understand the purpose and nature of the roadway's characteristics. This sign should be used if the distance to the next passing lane is less than or equal to 12 miles.
- A dashed white line in the transition area extending from near the highway centerline to the beginning of the white dashed line separating the passing lane from the right lane should be provided. Drivers were observed to be more likely to comply with state laws regarding driving in the right lane unless passing when this marking was used. Testing of Texas drivers also indicated better compliance in lane selection when driving in platoons, without unnecessarily delaying the initiation of passing maneuvers.
- Standard taper rates as defined in the Texas *MUTCD* should be used to add and drop lanes for the passing lane section.

CHAPTER 7

RECOMMENDATIONS

The design of a two-lane roadway that efficiently and effectively places passing lane sections is dependent upon the successful use of a number of defining characteristics. The two most basic criteria, length and spacing of the passing lanes, ensure that the roadway is neither over- nor under-designed to suit the projected traffic volumes. The next criteria, concerning the selection of appropriate lane and shoulder widths, ensure that safety is not compromised in the design of the roadway. Finally, the signing and roadway marking designs ensure that the designer's intent is adequately conveyed to the driver. The best design possible will perform poorly if drivers do not understand its purpose and drive accordingly.

LENGTH AND SPACING OF PASSING LANES

Based on the research conducted, recommendations for the following values of length and spacing of passing lanes are shown in Table 17. The values in the table were developed based on the premise of minimizing cost and percent time delay. These values are generally longer than those values of Harwood and Hoban, reflecting current higher speed limits for rural roads than the speed limits present during their research (*10*). Conversion of Super 2 roadways to four-lane highways should be considered when traffic volumes exceed 6000 ADT for level terrain and 5000 ADT in rolling terrain.

Table 17. Recommended Values of Length and Spacing by ADT and Terrain.

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

Passing lanes should be located to best fit existing terrain and field conditions. Uphill grades are preferred sites over downhill grades, and passing lanes on significant uphill grades should extend beyond the crest of the hill. Passing lane sections 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, avoiding transition areas.

Traffic signals on highways in incorporated areas tend to build platoons. These platoons of through traffic leaving the last traffic signal in an incorporated area should be broken up before entering subsequent rural two-lane highway sections, if practical. The last signal should desirably feed into a continuation of the urban four-lane cross-section (if present in the city) or, alternatively, into a passing lane section. A one-half mile multi-lane section located immediately outbound of the last traffic signal is preferred; however, an outbound passing lane starting near the outskirts of the developed area is an alternative in more restrictive conditions.

LANE AND SHOULDER WIDTHS

Based upon existing recommendations from other states and other countries and upon the considerations previously noted, researchers recommend the values in Table 18 for lane and shoulder widths in passing lane sections.

Table 18. Recommended Values for Lane and Shoulder Widths.

Lane Width	
12 ft 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 if rumble strips are used 4 ft if rumble strips are not used
Desirable:	Values in Table 3-8 of TxDOT's *Roadway Design Manual* (*18*)
*Shoulders used in passing lane sections should be paved.	

SIGNS AND PAVEMENT MARKINGS

Advance signing should be provided regarding the upcoming passing lane so that drivers are aware of its presence. The preferred sign (and associated sign placement) is that the passing lane is upcoming in 2 miles (PASSING LANE 2 MILES). This sign will permit drivers to delay passing maneuvers until they can be made more comfortably, although passing may still be permitted prior to the passing lane section. Figure 59 provides a layout of the recommended signing and marking detail drawing.

A sign should be provided near the end of each passing lane section stating that in "X" distance another passing lane will be provided (NEXT PASSING LANE X MILES). This advance signing will inform the driver of the repetitive nature of the passing lane design, allowing the driver to understand the purpose and nature of the roadway's characteristics. This sign should be used if the distance to the next passing lane is 12 miles or less.

A dashed white line in the transition area extending from near the highway centerline to the beginning of the white dashed line separating the passing lane from the right lane should be provided. Drivers complied with state laws regarding driving in the right lane unless passing more often if this marking was used. Testing of Texas drivers also indicated better compliance in lane selection when driving in platoons, without unnecessarily delaying the initiation of passing maneuvers.

Based on general recommendations in the Texas *MUTCD* (*24*), the signs recommended for the Texas Super 2 passing lane layout should have the following colors:

- PASSING LANE 2 MILES: white on green,
- LEFT LANE FOR PASSING ONLY: black on white,
- RIGHT LANE ENDS: black on yellow,
- LANE ENDS MERGE LEFT: black on yellow, and
- NEXT PASSING LANE X MILES: white on green.

Standard taper rates as defined in the Texas *MUTCD* (*24*) should be used to add and drop lanes for the passing lane section (see Figure 59).

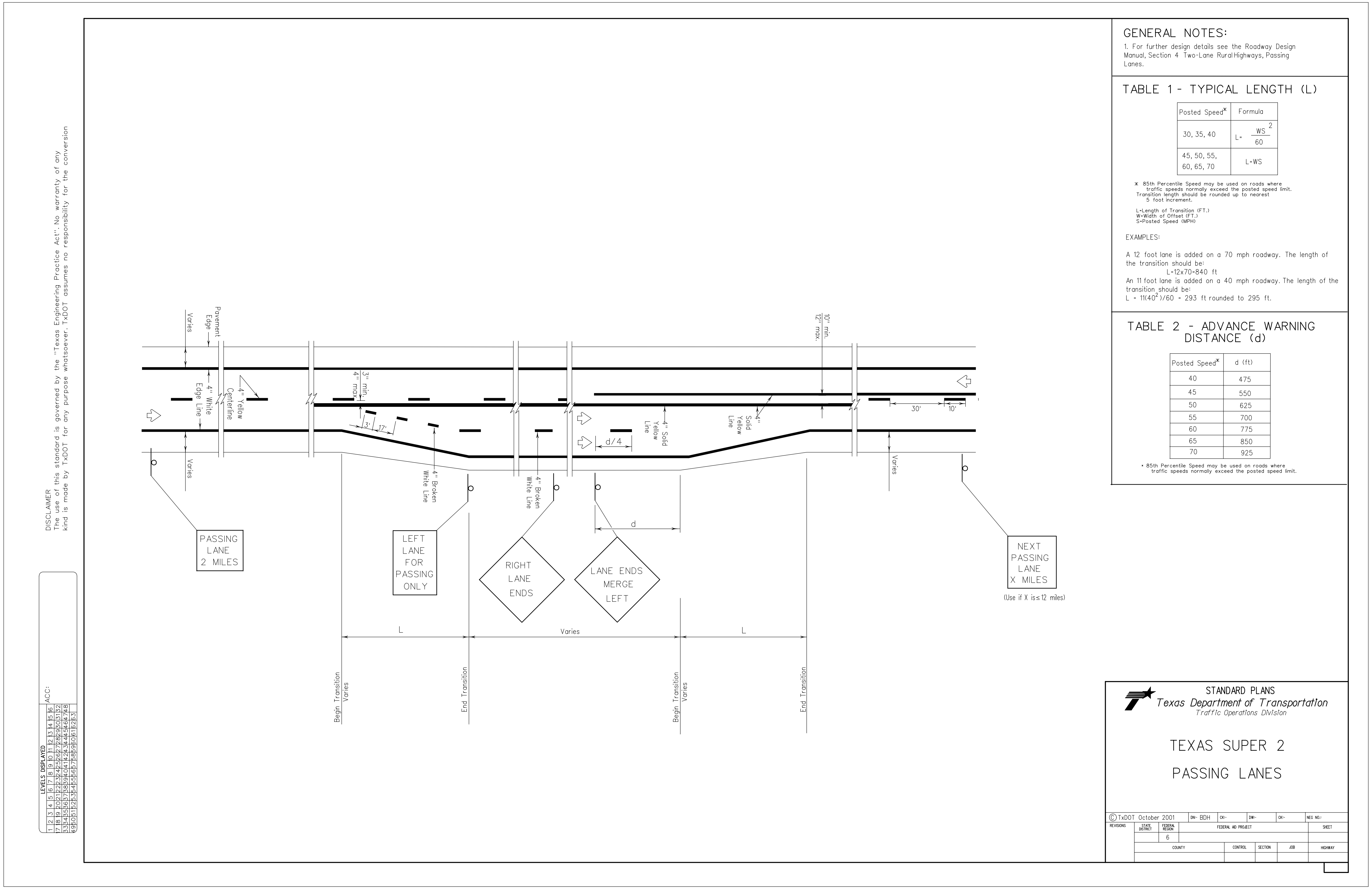

Figure 59. Signing and Marking Layout.

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APPENDIX

DATA WORKSHEETS

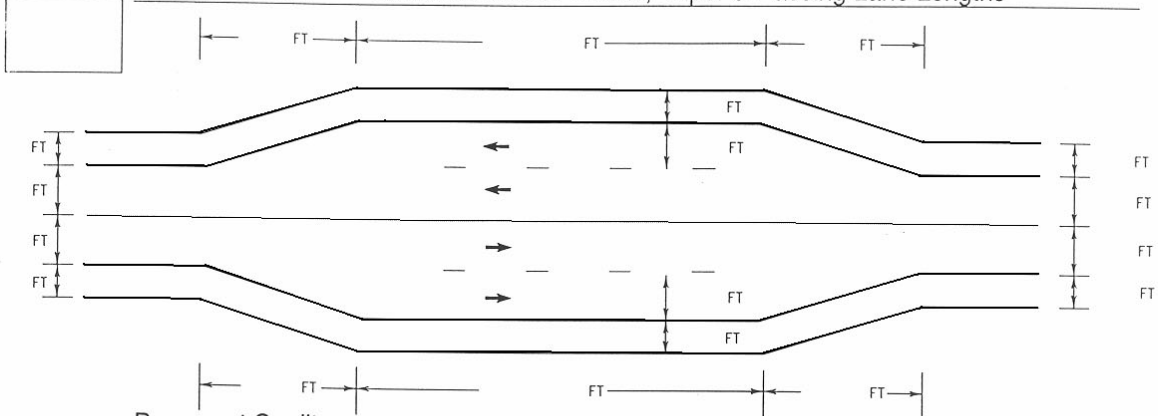
SITE CHARACTERISTIC DATA WORKSHEET - 4064

DATE:	CITY/LOCATION:	TIME:
HIGHWAY:	POSTED SPEED (mph):	WEATHER:

Functional Class: ☒ Rural ☐ Arterial ☐ Collector / ☐ Level ☐ Rolling

NORTH

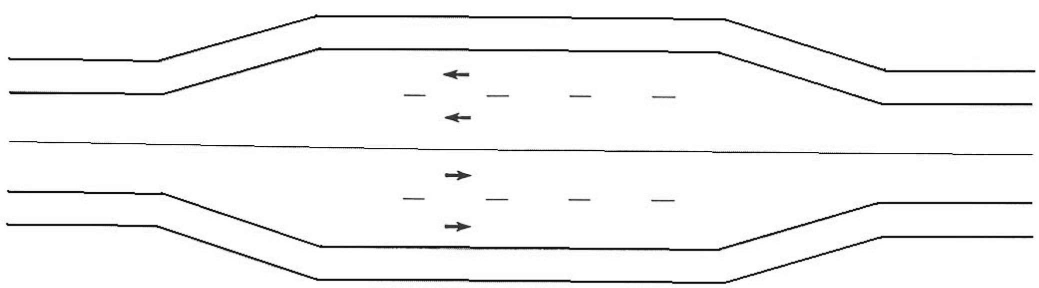
Cross Section: Lane & Shoulder Widths; Taper & Passing Lane Lengths



Pavement Quality:

☐ Good – Vehicle Speed Not Impacted ☐ Poor – Vehicle Speed Impacted

Signing & Marking:



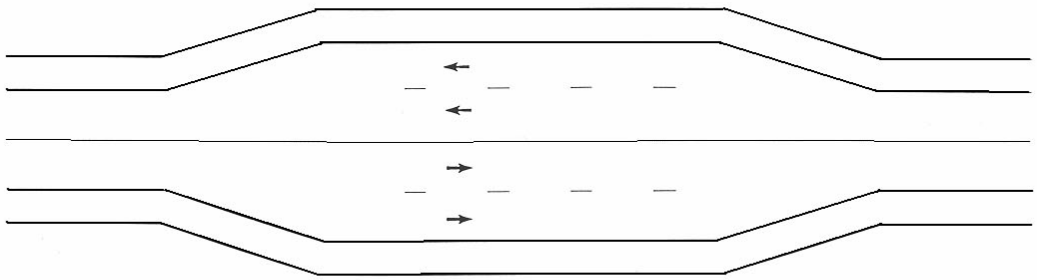
(sketch pavement marking/markers and signing configuration)

☐ 1. Advance Warning of Passing Lane ☐ 2. Passing Lane Ahead __ Mile
☐ 3. Keep Right Except to Pass ☐ 4. Slower Traffic Keep Right
☐ 5. Right Lane Ends ☐ 6. Lane Ends Merge Left ☐ 7. Symbol for Lane Reduction
☐ No Passing Zones ☐ Delineators ☐ Channelizing Stripe
Centerline: ☐ Opposing Passing Permitted ☐ Not Permitted
Edge Lines: ☐ Throughout Passing Lane ☐ Along Tapers Only

Access Density: ____ (Lt) Driveways (Rt) ____

Roadside Environment: Clear Zone ☐ 16 FT ☐ 30 FT

☐ clear with no fixed objects ☐ yielding objects only
☐ combination of yielding & rigid objects ☐ rigid objects only



(sketch driveways and roadside environment)

Traffic Distribution: Trucks ____% RV ____% PC ____%

Number of Passes

Minutes:	15	30	45	60	90	105	120
Car passing Car							
Car passing Truck							
Truck passing Car							
Truck passing Truck							

Notes: