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16. Abstract
This report documents the research activities completed during the second year of a two-year research project. The objective of the second year of the research project was to identify and evaluate new traffic control devices and practices that could be used to improve the safety of mobile and short duration operations.

Researchers conducted a synthesis of previous research, three focus groups, 241 motorist surveys, and a field study to assess motorists' comprehension and the operational effectiveness of current and innovative traffic control devices used to inform motorists about:

- the number of vehicles in a work convoy,
- the speed differential between the work convoy and traffic,
- passing a work convoy on two-lane, two-way roadways with unimproved shoulders,
- passing a work convoy on two-lane, two-way roadways with improved shoulders, and
- the LANE BLOCKED sign.

Based on the results of these activities, researchers recommended the use of several traffic control devices to improve the safety of mobile operations. In addition, based on existing TxDOT traffic control plans, field observations of mobile and short duration operations conducted during the first year of this research project, findings from the second year of this research project, and input from the advisory panel, researchers:

- recommended changes to the existing work duration definitions to help maintenance personnel distinguish between mobile and short duration operations,
- developed maintenance traffic control plans for select mobile and short duration operations,
- developed guidance for the use of trail and shadow vehicles for selected operations based on the roadway volume and posted speed, and
- developed quick reference tables that direct maintenance personnel to the appropriate mobile and short duration practice(s).

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TRAFFIC CONTROL DEVICES AND PRACTICES TO IMPROVE THE SAFETY OF MOBILE AND SHORT DURATION MAINTENANCE OPERATIONS

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DISCLAIMER

The contents of this report reflect the views of the authors, who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official view or policies of the Federal Highway Administration (FHWA) or the Texas Department of Transportation (TxDOT). This report does not constitute a standard, specification, or regulation, nor is it intended for construction, bidding, or permit purposes. The engineer in charge of the project was Melisa D. Finley, P.E. (TX-90937).

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CHAPTER 1:
INTRODUCTION

Maintenance work is often accomplished using mobile or short duration work zones. Mobile operations typically consist of one or more vehicles that move along the road intermittently or continuously at very slow speeds relative to the normal traffic stream. Short duration operations involve work that occupies a location for up to one hour. Both types of operations present a challenge due to the impracticality of installing traffic control devices since it takes longer to set up the traffic control devices than to perform the work activity. Research was needed to identify and evaluate new traffic control devices and practices that could be used to improve the safety of mobile and short duration maintenance operations.

SUMMARY OF FIRST YEAR FINDINGS

The first year of research focused on identifying hazards encountered by both workers and motorists in mobile and short duration maintenance operations. To accomplish this objective, researchers conducted a survey of state transportation agencies, discussion groups with Texas Department of Transportation (TxDOT) field and supervisory personnel, and field observations of mobile and short duration operations. Research Report 4174-1 (*1*) documents the findings from these tasks.

The primary hazards identified were apparent motorist misunderstanding of traffic control devices, vehicles entering the work convoy, speed differential between traffic and work convoy, and passing maneuvers around the work convoy on two-lane, two-way roadways. Researchers concluded that many of these concerns could be addressed by providing motorists with more specific information regarding upcoming conditions and/or the appropriate driving action to take.

In addition, the information gathered during the first year of the research highlighted the fact that the definitions of mobile and short duration operations, as well as the classification of specific operations as either mobile or short duration, were not consistent. Also, it is difficult for maintenance personnel (who are not engineers) to make decisions about which traffic control devices are needed for mobile and short duration maintenance operations on a day to day basis. Thus, researchers concluded that there was a need for:

- a clearer distinction between mobile and short duration operations,
- guidance in applying standards to specific types of operations, and
- an enhancement of the guidelines to provide direction related to roadway conditions (e.g., traffic volume, roadway speed, etc.).

SUMMARY OF SECOND YEAR ACTIVITIES

The objective of the second year of the research project was to identify and evaluate new technologies and practices that could be used to improve the safety of mobile and short duration operations. Thus during the second year of the research project, researchers evaluated the

potential of new traffic control devices to address the informational needs of motorists with respect to the following situations:

- motorist awareness of multiple work vehicles in a convoy,
- motorist awareness of the speed differential between the work convoy and traffic, and
- passing a mobile work convoy on two-lane, two-way roadways.

In addition, researchers worked with the TxDOT project director, TxDOT project panel, and an advisory panel to:

- examine the terminology used to define mobile and short duration operations and determine if changes would help distinguish between these types of operations,
- develop maintenance traffic control plans for select mobile and short duration operations,
- develop guidance for the use of "optional" devices based on roadway conditions, and
- develop a process that directs maintenance personnel to the appropriate practice(s).

REPORT ORGANIZATION

This report documents the research activities completed by the Texas Transportation Institute (TTI) during the second year of a two-year research project for TxDOT. The activities completed, as well as the report organization, are described below.

- *Chapter 2: Identification of Potential Devices* – Researchers reviewed previous research and the results of the state survey conducted during the first year of this research project to identify potential devices that could be used to improve the safety of mobile and short duration operations.
- *Chapter 3: Focus Groups* – Researchers conducted three focus groups to assess motorist understanding of current and innovative work zone traffic control devices. In addition, researchers used the focus groups to gather input from motorists with respect to alternative messages or devices that would provide them with more specific information regarding upcoming conditions and/or the appropriate driving action to take.
- *Chapter 4: Motorist Surveys* – Researchers administered 241 motorist surveys to further assess motorist comprehension of current and innovative work zone devices.
- *Chapter 5: Field Study* – In Texas, when mobile operations work on the centerline of two-way, two-lane roadways with improved shoulders, traffic is directed to pass the work convoy to the right on the improved shoulder. Researchers conducted a field study to determine if an experimental changeable message sign message improved motorist compliance.
- *Chapter 6: LANE BLOCKED Sign* – Researchers compiled a synthesis of previous and current research that evaluated motorist understanding and the operational effectiveness of the LANE BLOCKED sign and portable changeable message signs.
- *Chapter 7: Practices to Improve the Safety of Mobile and Short Duration Operations* – Researchers examined the terminology used to define mobile and short duration operations and recommended changes to help maintenance personnel distinguish between these two types of operations. Researchers also developed maintenance traffic control

plans for select mobile and short duration operations, guidance for the use of "optional" devices based on the roadway volume and posted speed, and quick reference tables that direct maintenance personnel to the appropriate practice(s).

- *Chapter 8: Summary and Recommendations* – Based on the results of the research project, researchers made recommendations regarding traffic control devices and practices that should be used to improve the safety of mobile and short duration maintenance operations.

CHAPTER 2:
IDENTIFICATION OF POTENTIAL DEVICES

Researchers reviewed previous research and the results of the state survey conducted during the first year of this research project in order to identify potential devices that could be used to improve the safety of mobile and short duration operations. This chapter summarizes the findings with respect to the following situations:

- motorist awareness of multiple work vehicles in a convoy,
- motorist awareness of the speed differential between the work convoy and traffic, and
- passing a mobile work convoy on two-lane, two-way roadways.

NUMBER OF VEHICLES IN A WORK CONVOY

Based on the findings from the first year of this research project, researchers speculated that motorists might not understand that the term "convoy" means more than one work vehicle. From the state survey, researchers identified the following alternatives:

- ROAD MACHINERY AHEAD (Texas and Indiana departments of transportation [DOT]s),
- MACHINERY IN ROAD (North Carolina DOT), and
- 3 VEHICLE CONVOY (Wisconsin DOT).

SPEED DIFFERENTIAL BETWEEN THE WORK CONVOY AND TRAFFIC

For activities where mobile operations are working in a lane and moving at a significantly lower speed than the normal flow of traffic, a major concern and hazard is the inability of motorists to recognize the speed differential between the convoy and their vehicle. According to research conducted by Hanscom and Pain (*2*), the speed of the work vehicle has the most impact on driver perception of the work vehicle's speed and closure rate. In addition, the perception error that the work vehicle is going faster than its actual speed is most severe at very low work vehicle speeds (0 to 8 mph). Major countermeasures to this phenomenon are drawing the motorist's attention to the operation as soon as possible and then optimizing the information provided to the motorist.

Currently, the TxDOT San Angelo District uses a mobile speed display attached to the rear of the trail vehicle (i.e., the last work vehicle in a mobile operation, which is the first vehicle motorists encounter) to inform motorists about their approach speed (Figure 1). As shown in Figure 1, the display shows the speed of oncoming vehicles and contains the words YOUR SPEED in white letters. Although the maintenance crew perceived that the speed display slowed traffic, during the first year of this research project researchers observed several vehicles making last minute erratic maneuvers to avoid a collision with the trail vehicle.

In 2001, the Wisconsin Department of Transportation in conjunction with Marquette University (3) evaluated the ease of installation and removal, device reliability, device accuracy and visibility, and operational impacts of a mobile speed display. Figure 2 shows the mobile speed

display mounted on a maintenance vehicle. The left display indicates the speed of oncoming vehicles and contains the words YOU in yellow letters. The right display indicates the speed of the maintenance vehicle on which it is mounted and contains the words ME in white letters.

Figure 1. Mobile Speed Display Used by the San Angelo District.

In order to determine the operational impacts of the mobile speed display, researchers measured the speed of oncoming vehicles when the speed display was used and when the speed display was not used. The average distance upstream of the display at which the speeds were measured was approximately 330 ft. The speed limit was 55 mph. It should be noted that during data collection, the maintenance vehicle was parked on the shoulder of a two-lane roadway and thus the ME display was blank.

The findings indicate that the 85th percentile speed was reduced by 4 mph when the speed display was used. In addition, the speeds measured by the YOU display were within 1 mph of the speeds measured with a laser gun. The legibility distance of the displays, as assessed by two of the researchers, was approximately 700 ft.

In addition to the mobile speed displays, researchers identified the following uses of the term "slow" on static or dynamic signs to describe the speed of the work convoy:

- SLOW MOVING TRUCKS AHEAD (Connecticut DOT),
- SLOW MOVING TRAFFIC (North Carolina and Wisconsin DOTs),
- SLOW MOVING OPERATION (North Carolina DOT), and
- SLOW MOVING VEHICLES (Washington DOT).

Figure 2. Mobile Speed Display Evaluated by the Wisconsin DOT (*3*).

PASSING A WORK CONVOY ON TWO-LANE, TWO-WAY ROADWAYS

During the first year of this research project, researchers observed mobile maintenance operations on two-lane, two-way roadways with unimproved (i.e., not paved) and improved (i.e., paved) shoulders. On the roadways with unimproved shoulders, some motorists remained behind the work convoy even though they were allowed to pass the convoy (i.e., the work zone traffic control and existing pavement markings did not prohibit passing and there was no oncoming traffic). On the roadways with improved shoulders, the maintenance work was on the centerline, so the traffic control directed motorists to pass the work convoy to the right on the improved shoulder. While most motorists passed the work convoy on the shoulder, some motorists hesitated before correctly passing the work convoy (in some cases coming to an abrupt stop behind the trail vehicle), passed the work convoy to the left into oncoming traffic, or followed the work convoy. Based on the reactions of the motorists, it would appear that the traffic control in both situations (unimproved and improved shoulders) did not provide motorists with the necessary information to understand how to pass the convoy.

From the state survey and literature review, researchers identified the following signs that could potentially be used to improve the passing information provided to motorists:

- LANE BLOCKED AHEAD PASS WITH CARE (*2*),
- PASS WITH CARE → (Illinois DOT),
- KEEP → RIGHT (North Carolina DOT),
- PASS → (Wisconsin DOT),
- BEGIN SHOULDER LANE (*4*),
- END SHOULDER LANE (*4*),
- SHOULDER USE OK (*4*),
- BEGIN SHOULDER USE (Maryland DOT), and
- END SHOULDER USE (Maryland DOT).

CHAPTER 3:
FOCUS GROUPS

The focus group method is a research tool that facilitates an open discussion between researchers and a group of motorists. Researchers used this method to assess motorists' understanding of:

- the WORK CONVOY sign (CW21-10),
- how to pass a work convoy on two-lane, two-way roadways with and without improved shoulders,
- the speed differential between the work convoy and traffic, and
- the LANE BLOCKED sign (FCW20-6).

In addition, researchers gathered input from motorists with respect to alternative messages or devices that would provide them with more specific information regarding upcoming conditions and/or the appropriate action to take. It should be noted that the evaluation of the LANE BLOCKED sign was added to the focus group protocol after the initial focus group was conducted. Thus, only two of the three focus groups included discussions regarding the LANE BLOCKED sign.

PARTICIPANTS

Researchers held focus groups in Bryan/College Station, Houston, and San Antonio. A total of 29 licensed drivers (10 in Bryan/College Station, nine in Houston, and 10 in San Antonio) participated in the focus groups. The participants recruited represented a range of ages, driving experience, and educational background. In addition, both males and females were included. Table 1 contains a summary of the participants' demographic information.

Table 1. Focus Group Participant Demographics.

	Age Category			Education Category				Driving Experience		
	18 to 39	**40 to 64**	**65+**	**NHS**	**HS**	**SC**	**C**	**0 to 19**	**20 to 39**	**40+**
Number of Participants	9	18	2	1	12	10	6	6	12	11
Average	46							33		
Range	18 to 72							3 to 50		

NHS – No high school diploma or equivalent; HS – High school diploma or equivalent;
SC – Some college; C – College degree

RESULTS

The results presented in the following sections are based on the data collected at all three locations. However, when pertinent, differences between locations are noted.

WORK CONVOY Sign

Prior to the start of each focus group, the participants completed an information sheet that included two questions concerning the meaning of the WORK CONVOY sign and their interpretation of the word "convoy." In general, the participants considered the WORK CONVOY sign to mean there was a work zone ahead that included workers and equipment/vehicles. A majority of the participants indicated that the word "convoy" meant a group of vehicles.

During the focus group discussion, participants viewed a picture of a WORK CONVOY sign (Figure 3). Participants stated that this sign implied there was more than one vehicle involved in the work zone. More specifically, most of the participants agreed that the work activity included three or more vehicles.

Figure 3. WORK CONVOY Sign (CW21-10).

Participants felt that the work vehicles could be moving or stopped. If moving, all the participants agreed that the vehicles would be traveling slower than the normal flow of traffic, with the most common response being between 5 mph and 20 mph. In addition, all of the participants agreed that their reaction would be to slow down as they approached the work vehicles.

Several participants stated that the sign implied there were workers on foot. However, there was no agreement among the participants, since most of them were unsure whether workers were present on the roadway based on the sign alone.

Some of the participants stated that they would like to know the exact number of vehicles involved in the work activity (e.g., 3 VEHICLE CONVOY). However, most of the participants thought the exact number of vehicles was unnecessary since the word "convoy" implies more than one vehicle. Others pointed out the difficulty involved with changing out the number on the

sign, especially if vehicles come and go from the convoy. Other suggestions preferred by the participants included the use of:

- a WORK VEHICLES sign,
- a CONSTRUCTION VEHICLES AHEAD sign,
- a MAINTENANCE TRUCKS AHEAD sign, and
- a symbol sign showing several trucks in a row.

However, the majority of the participants stated that they liked the WORK CONVOY sign better than any of the alternative suggestions.

Passing Maneuvers on a Two-Lane, Two-Way Road with Unimproved Shoulders

Before discussing the following two scenarios, participants were shown a picture of a two-lane, two-way (TLTW) roadway with unimproved shoulders and asked to imagine themselves driving on this roadway.

WORK CONVOY Sign on Work Vehicle

Participants were then shown a picture of a shadow vehicle that contained only a WORK CONVOY sign (Figure 4). All of the participants stated that they would slow down; however, the responses with respect to being able to pass the work vehicle were mixed. Approximately half of the participants agreed that they could pass the vehicle on the left when it was safe and legal to complete the maneuver. In contrast, the other half of the participants were not confident that they could pass and thus would remain behind the work vehicle. In addition, participants were not certain where the work activity was being conducted (e.g., in the roadway or off the roadway on the unimproved shoulder).

WORK CONVOY Sign and Four-Corner Caution Arrow Panel Display on Work Vehicle

Next, an arrow panel displaying the four-corner caution mode was added to the work vehicle (Figure 5). Similar to the previous situation, all of the participants stated that they would slow down as they approached the work vehicle. The majority of the participants felt that the addition of the four-corner caution arrow panel was confusing. Even though some participants thought that the arrow panel display might help alert motorists, the majority did not think it improved the meaning of the sign or helped inform motorists as to what driving action to take.

Figure 4. WORK CONVOY Sign on Work Vehicle (TLTW Roadway with Unimproved Shoulders).

Figure 5. WORK CONVOY Sign and Four-Corner Caution Arrow Panel Display on Work Vehicle (TLTW Roadway with Unimproved Shoulders).

Suggested Changes to the Information Provided

Researchers asked participants to suggest additional information that would aid them in making their driving decisions, as well as how to display this information. During the discussion, the participants provided many suggestions; however, they preferred the following (listed in no particular order):

- use of a changeable message sign (CMS) instead of an arrow panel display,
- the number of vehicles to be passed,
- a NO PASSING or PASS WITH CARE sign, and
- the addition of the word "slow" (e.g., WORK CONVOY – SLOW or SLOW MOVING OPERATION).

In addition, a few of the participants stated that they were unsure whether work was being performed or whether the vehicles were just traveling to a work area. Suggestions included the addition of a WORK IN PROGRESS sign or a WORKERS AHEAD sign to convey to motorists that work is being performed.

Passing Maneuvers on a Two-Lane, Two-Way Road with Improved Shoulders

Before discussing the following two scenarios, participants were shown a picture of a two-lane, two-way roadway with improved shoulders and asked to imagine themselves driving on this roadway.

WORK CONVOY Sign on Work Vehicle

As with the previous set of scenarios, participants then viewed a picture of a shadow vehicle that contained only a WORK CONVOY sign (Figure 6). All of the participants stated that they would slow down; however, responses with respect to being able to pass the work vehicle were again mixed. Most of the participants agreed that they would pass the work vehicle on the left when it was safe and legal to complete the maneuver. However, several of the participants were not confident they could pass or were unsure on which side to pass. In addition, participants were uncertain as to the location of the work activity (e.g., in the roadway or on the improved shoulder).

WORK CONVOY Sign and Flashing Right Arrow Panel Display on Work Vehicle

Next, an arrow panel displaying a right flashing arrow was added to the work vehicle (Figure 7). All of the Houston participants were confident they should pass the work vehicle on the right (i.e., on the improved shoulder). Similarly, in Bryan/College Station the majority of the participants stated they would pass on the right; however, they were not confident in their decision. The San Antonio participants provided mixed responses with no one being confident in their decision. The Bryan/College Station and San Antonio participants attributed their indecision to the possibility that the work was being performed on the shoulder and that it is illegal to pass a vehicle on the shoulder. Overall, the majority of the participants felt that the addition of the right flashing arrow display was confusing.

Figure 6. WORK CONVOY Sign on Work Vehicle (TLTW Roadway with Improved Shoulders).

Figure 7. WORK CONVOY Sign and Four-Corner Caution Arrow Panel Display on Work Vehicle (TLTW Roadway with Improved Shoulders).

Suggested Changes to the Information Provided

Researchers explained that the correct driving action was to pass the work vehicle on the right (i.e., on the improved shoulder). Participants were then asked to suggest additional information that would aid them in making their driving decisions, as well as how to display this information. During the discussion, the participants offered many suggestions; however, they preferred the following devices (listed in no particular order):

- use of a CMS instead of an arrow panel display,
- a USE SHOULDER FOR PASSING sign,
- a PASS ON RIGHT or PASS ON SHOULDER sign,
- a PASS sign on top of the arrow panel, and
- a USE CAUTION WHILE PASSING ON RIGHT sign.

In addition, a few of the participants noted that it would be helpful to know the exact number of work vehicles in the convoy so they would know how many vehicles they needed to pass on the right. However, most of the participants thought the exact number of vehicles was unnecessary since the word "convoy" implies more than one vehicle.

Speed Differential between the Work Convoy and Traffic

Information Used to Portray Speeds

In this section, participants were asked to consider the previously discussed scenarios and to identify what information they thought should be provided to motorists to help them understand that the work vehicles are moving slower than normal traffic. Suggestions included the following:

- a SLOW MOVING sign,
- a CAUTION – SLOW VEHICLES AHEAD sign,
- a PROCEED WITH CAUTION sign,
- a BE PREPARED TO STOP sign,
- a sign that states how fast the convoy is going,
- use of the vehicles' hazard lights, and
- the addition of more flashing lights.

YOUR SPEED Dynamic Speed Display

Next, the participants viewed a picture of a YOUR SPEED dynamic speed display attached to the rear of a work vehicle (Figure 8). All of the participants understood that the speed displayed was the speed they were traveling. In addition, the majority of the participants agreed that the work vehicles were moving slowly, but the exact speed of the work vehicles varied among the participants (ranged from 5 mph to 25 mph). Overall, most of the participants did not think the YOUR SPEED display helped inform motorists of the speed differential between the work vehicles and the traveling public. Suggestions included:

- a MY SPEED sign showing how fast the work vehicle is going and
- use of a CMS stating WORKERS AHEAD – DRIVE SLOW or SLOW TO "#" MPH.

Figure 8. YOUR SPEED Display.

YOU/ME Dynamic Speed Display

The participants then viewed a picture of a YOU/ME dynamic speed display attached to the rear of a work vehicle (Figure 9). All of the participants understood that the YOU speed (i.e., 58) was the speed they were traveling and the ME speed (i.e., 8) was the speed of the work vehicle. All of the participants preferred the YOU/ME display to the YOUR SPEED display.

Overall Assessment

Based on the group discussion, the participants preferred the use of signs (either static or dynamic) over the speed displays to convey information about speed. Sign messages suggested include:

- SLOW WORK CONVOY
- SLOW MOVING VEHICLES
- WORKERS AHEAD – DRIVE SLOW, and
- SLOW TO "#" MPH.

As mentioned previously, the participants preferred the YOU/ME display to the YOUR SPEED display. However, the participants also stated that they would rather be provided information regarding the speed of the work vehicle (i.e., ME speed) than information concerning their speed (i.e., YOU speed).

Figure 9. YOU/ME Display.

LANE BLOCKED Sign

As mentioned previously, the evaluation of the LANE BLOCKED sign was added after the initial focus group (Bryan/College Station) was conducted. Thus, the results for this sign are only based on the responses of the 19 participants from Houston and San Antonio.

The participants were shown a picture of a LANE BLOCKED sign (Figure 10) and asked what action they would take if they were traveling in Lane 2 and Lane 3. All of the participants agreed that they would slow down and move out of Lane 2 since that lane was blocked. If traveling in Lane 3, the participants would remain in that lane since it was not blocked. Thus, all of the participants understood the sign and felt it was not confusing.

For three-lane roadways, the participants suggested the following alternatives:

- a CENTER/LEFT/RIGHT LANE BLOCKED sign or CMS,
- placing the X over the number 2 on the LANE BLOCKED sign, and
- placing a circle and slash (⃠) over the number two on the LANE BLOCKED sign.

Overall, the participants preferred the use of the CENTER/LEFT/RIGHT LANE BLOCKED message on a CMS for roadways with three lanes in one direction and the use of the LANE BLOCKED sign for roadways with four or more lanes in one direction.

Figure 10. LANE BLOCKED Sign (FCW20-6).

SUMMARY

Researchers conducted three focus groups to assess motorists' understanding of current and innovative work zone traffic control devices. In addition, the focus groups were used to gather input from motorists with respect to alternative messages or devices that would provide them with more specific information regarding upcoming conditions and/or the appropriate action to take.

WORK CONVOY Sign

The majority of participants interpreted the WORK CONVOY sign to mean there was more than one work vehicle. In addition, participants felt that the work vehicles could be stopped or moving. If moving, all of the participants agreed that the vehicles would be traveling slower than the normal flow of traffic, with the most common response being between 5 mph and 20 mph. The participants preferred the WORK CONVOY sign to any of the alternative suggestions.

Even though the focus group results show that a majority of the participants interpret the WORK CONVOY sign to mean there is more than one work vehicle, in the open discussion format of a focus group an individual's comprehension may be influenced by another participant's comments. Thus, researchers decided to include the WORK CONVOY sign in the motorist survey to further investigate whether this sign conveys to motorists that there are multiple work vehicles in the roadway.

Passing Maneuvers on a Two-Lane, Two-Way Road with Unimproved Shoulders

Approximately half of the participants were uncertain whether they could pass the work vehicle in the given scenarios. In addition, participants were unsure where the work activity was being conducted (e.g., in the roadway or off the roadway). The majority of participants felt that the addition of the four-corner caution display was confusing. Based on the suggestions made by the

participants, researchers decided to include the PASS WITH CARE message in the motorist survey to determine if this message improved motorists' understanding that they could pass the work vehicle.

Passing Maneuvers on a Two-Lane, Two-Way Road with Improved Shoulders

Most of the participants were not confident they could pass the work vehicle on the right (i.e., on the improved shoulder) even though the right flashing arrow panel display was directing them onto the improved shoulder. In addition, participants were unsure where the work activity was being conducted (e.g., in the roadway or on the improved shoulder). The majority of participants felt that the addition of the right flashing arrow display was confusing. Based on the suggestions made by the participants, researchers decided to include the PASS ON SHOULDER, PASS ON RIGHT, and USE SHOULDER messages in the motorist survey to determine if these messages improved motorists' understanding that they are to pass the work vehicle on the right on the improved shoulder.

Speed Displays

All of the participants interpreted the YOUR SPEED and YOU/ME dynamic speed displays correctly. The participants preferred the use of signs (either static or dynamic) over the speed displays to convey information about speed. If speed displays were used, the participants would rather be provided information regarding the speed of the work vehicle (i.e., ME speed). Based on these results, researchers decided to further investigate the speed displays, as well as the use of the word "slow," in the motorist survey to determine whether these devices provide information regarding the speed differential between the work convoy and approaching motorists.

LANE BLOCKED Sign

All of the participants understood the LANE BLOCKED sign and felt it was not confusing. For roadways with three lanes in one direction, the participants preferred the use of the CENTER/LEFT/RIGHT LANE BLOCKED message on a CMS. For roadways with four or more lanes in one direction, the participants preferred the LANE BLOCKED sign. Based on these results, researchers decided not to include the LANE BLOCKED sign in the motorist survey. Instead researchers compiled a synthesis of previous research that evaluated motorists' understanding and the operational effectiveness of the LANE BLOCKED sign and portable changeable message signs. This synthesis is located in Chapter 6.

CHAPTER 4:
MOTORIST SURVEYS

Building on the focus group results, researchers conducted motorist surveys to further assess motorist comprehension of current and innovative work zone devices used to inform motorists about:

- the number of vehicles in a work convoy,
- the speed differential between the work convoy and traffic,
- passing a work convoy on two-lane, two-way roadways with unimproved shoulders, and
- passing a work convoy on two-lane, two-way roadways with improved shoulders.

TREATMENTS

Using the information collected in the focus groups, the review of previous research, and the state survey, researchers determined the treatments to be studied in the motorist survey. The treatments are discussed according to the four issues listed above.

Number of Vehicles in a Work Convoy

Currently, the WORK CONVOY sign (Figure 3) is used on the back of a trail vehicle (i.e., the last work vehicle in a mobile operation, which is the first vehicle motorists encounter) to inform motorists that they are approaching multiple work vehicles. As stated previously, the focus group results show that a majority of the participants interpret this sign to mean there is more than one work vehicle; however, in the open discussion format of a focus group an individual's comprehension may be influenced by another participant's comments. Thus, researchers decided to further investigate whether the WORK CONVOY sign conveys to motorists that there are multiple work vehicles in the roadway. In addition to the WORK CONVOY sign, researchers also studied the signs shown in Figure 11.

Speed Differential between the Work Convoy and Traffic

As mentioned above, the WORK CONVOY sign is used on the back of a trail vehicle to inform motorists that they are approaching multiple work vehicles. However, it is not known whether motorists interpret information regarding the speed of the work vehicles from this sign. Focus group participants felt that the work vehicles could be moving or stopped. If moving, the participants agreed that the work vehicles would be traveling slower than normal traffic speeds, with the most common response being between 5 mph and 20 mph. Thus, researchers further evaluated the signs in Figure 3 and Figure 11 to determine if they provide information regarding the speed differential between the work convoy and approaching motorists. In addition, researchers assessed:

- the addition of the word "slow" to the four signs (Figure 12),
- the YOUR SPEED dynamic speed display (Figure 8),
- the MY SPEED dynamic speed display (Figure 13), and
- the YOUR SPEED/MY SPEED combination dynamic speed display (Figure 14).

It should be noted that researchers decided to test the words MY SPEED instead of ME on the display that shows the work vehicle's speed since the speed display currently used by the TxDOT San Angelo District contains the words YOUR SPEED.

Figure 11. Alternative Messages to the WORK CONVOY Sign.

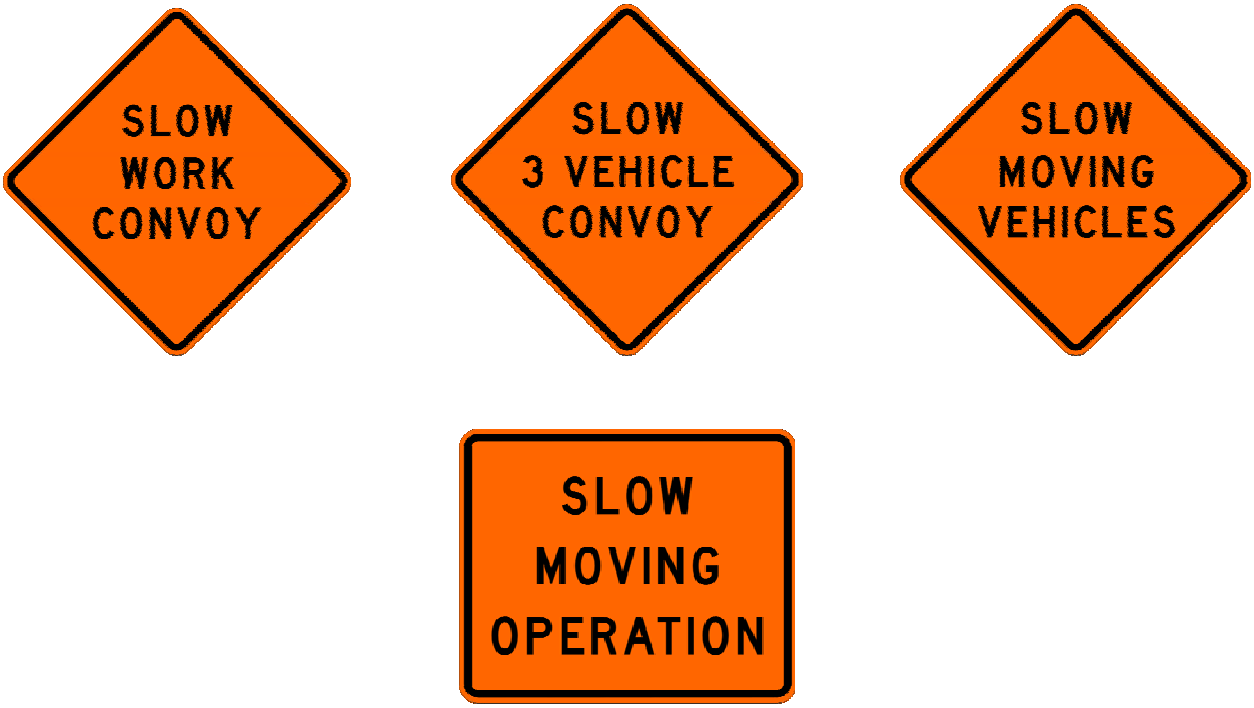

Figure 12. Signs with a "Slow" Descriptor.

Figure 13. MY SPEED Display.

Figure 14. YOUR SPEED/MY SPEED Combination Display.

Passing a Work Convoy on Two-Lane, Two-Way Roadways with Unimproved Shoulders

For mobile operations on a two-lane, two-way roadway with unimproved shoulders, the trail vehicle contains a WORK CONVOY sign, an arrow panel displaying the four-corner caution mode, rotating or strobe lights, and a truck-mounted attenuator (TMA). The *Texas Manual on Uniform Traffic Control Devices* (Texas MUTCD) (5) states that if the work vehicles cannot pull over to allow motorists to pass, a DO NOT PASS sign (R4-1) may be placed on the rear of the trail vehicle. However, in most cases motorists are not provided information with respect to passing the work convoy. During the field observations in the first year of this research project, researchers observed a mobile operation with a YOUR SPEED display and an arrow panel displaying the four-corner caution mode (it did not include a WORK CONVOY sign or a DO NOT PASS sign). Researchers observed motorists passing the trail vehicle to the left into oncoming traffic, to the right on the unimproved shoulder, or remaining behind the vehicle. In addition, half of the focus group participants were uncertain whether they were allowed to pass the trail vehicle when it included a WORK CONVOY sign and four-corner caution display. Thus, researchers evaluated the following setups to determine how well they provide passing information to motorists:

- the current setup (i.e., WORK CONVOY sign and four-corner caution display) (Figure 15),
- the addition of a DO NOT PASS sign to the current setup (Figure 16),
- the addition of a PASS WITH CARE sign (R4-2) to the current setup (Figure 17),
- a WORK CONVOY sign and a CMS with a DO NOT PASS message (Figure 18), and
- a WORK CONVOY sign and a CMS with a PASS WITH CARE message (Figure 19).

Passing a Work Convoy on Two-Lane, Two-Way Roadways with Improved Shoulders

For mobile operations on a two-lane, two-way roadway with improved shoulders, the traffic control devices on the trail vehicle are similar to the devices used on the trail vehicle for the unimproved shoulder condition. The only exception is that the arrow panel displays a right flashing arrow that directs motorists to pass the work convoy to the right on the improved shoulder. The field observations conducted in the first year of this research project showed that while most motorists pass the work convoy on the shoulder, some motorists either hesitate before correctly passing the work convoy (in some cases coming to an abrupt stop behind the trail vehicle), pass the work convoy to the left into oncoming traffic, or follow the work convoy. In addition, most of the focus group participants were not confident they could pass the work vehicles to the right even though the right flashing arrow display was directing them onto the improved shoulder. The participants attributed their indecision to the possibility that the work was being performed on the shoulder and that it is illegal to pass a vehicle on the shoulder. Thus, researchers evaluated the following treatments to determine how well they inform motorists to pass the work vehicles on the right on the improved shoulder:

- the current setup (i.e., WORK CONVOY sign and right flashing arrow display) (Figure 20),
- the addition of a PASS ON SHOULDER sign to the current setup (Figure 21),
- the addition of a PASS ON RIGHT sign to the current setup (Figure 22),

- the addition of a USE SHOULDER sign to the current setup (Figure 23), and
- a WORK CONVOY sign and a CMS to convey passing information (i.e., PASS ON SHOULDER, PASS ON RIGHT, and USE SHOULDER) (Figures 24-26, respectively).

Figure 15. Current Setup Used on Two-Lane, Two-Way Roadways with Unimproved Shoulders.

Figure 16. Addition of a DO NOT PASS (R4-1) Sign.

Figure 17. Addition of a PASS WITH CARE (R4-2) Sign.

Figure 18. Use of a DO NOT PASS CMS Message.

Figure 19. Use of a PASS WITH CARE CMS Message.

Figure 20. Current Setup Used on Two-Lane, Two-Way Roadways with Improved Shoulders.

Figure 21. Addition of a PASS ON SHOULDER Sign.

Figure 22. Addition of a PASS ON RIGHT Sign.

Figure 23. Addition of a USE SHOULDER Sign.

Figure 24. Use of a PASS ON SHOULDER CMS Message.

Figure 25. Use of a PASS ON RIGHT CMS Message.

Figure 26. Use of a USE SHOULDER CMS Message.

SURVEY LOCATIONS

Researchers administered the motorist surveys at Texas Department of Public Safety (DPS) offices in the following four Texas cities: Bryan, Dallas, Rosenberg, and San Angelo. These locations represent four of the five cities where researchers conducted field observations in the first year of this research project. Due to time constraints, researchers were unable to conduct the survey in El Paso (the fifth city where researchers conducted field observations).

PARTICIPANTS

Researchers administered the survey to 241 participants (approximately 60 motorists in each city). The participants were required to have a valid driver's license and were recruited according to a demographic sample of the driving population in Texas with regard to gender, age, and education level. Tables 2 and 3 contain statistics obtained from the Federal Highway Administration (FHWA) regarding Texas driver age (*6*) and the 2000 United States census (*7*) regarding educational background, respectively. In addition, the information obtained from the FHWA shows that there is an even split of male versus female drivers. Since these two data sources are not available in a format that cross-references all three statistics, researchers created a cross-referenced data sample for each location (Table 4).

Table 2. Texas Driver Age Distribution (*6*).

Age Group	Percentage of Texas Drivers
<25	15%
25-39	32%
40-54	29%
55-64	12%
65+	12%

Table 3. Texas Educational Background Distribution (*7*).

Education Attainment	Texas Percentage
No high school diploma	24%
High school diploma	25%
Some college	27%
College degree	24%

Table 4. Survey Participant Demographics by Location.

Age Category	Education Background								
	No High School Diploma (25%)		High School Diploma (25%)		Some College (29%)		College Degree (21%)		Total
	Male	Female	Male	Female	Male	Female	Male	Female	
18-39 (47%)	4	3	3	4	4	4	3	3	28
40-64 (41%)	3	3	3	3	4	3	2	3	24
64+ (12%)	1	1	1	1	1	1	1	1	8
Total	8	7	7	8	9	8	6	7	60

PROTOCOL

Researchers approached individuals and asked them to participate in the survey; however, participation was on a volunteer basis only. As an incentive to take the survey, researchers handed out Texas state maps, wildflower identification guides, litterbags, and bumper stickers to those that participated. The participants did not receive any monetary compensation for completing the survey. The survey took approximately 20 minutes per participant to complete.

The survey instrument included a laptop computer, a survey booklet, and a written answer form. The study administrator gave all instructions and survey questions verbally. In addition, the survey administrator recorded the participants' responses.

Prior to beginning the survey, the survey administrator provided the participant with information about the survey and asked them a series of demographic questions. To familiarize the participant with the computer and survey procedure, the participant began with a practice session on the computer.

The survey was divided into four sections, which corresponded to the four issues previously discussed. At the beginning of each section, the participant received a description of a roadway (e.g., number of lanes, speed limit, etc.) and instructions regarding the survey procedure. The participant then viewed a picture of one of the treatments on the computer screen. When the participant felt he/she clearly understood the situation, he/she pressed the space bar. The computer screen then went blank and the survey administrator asked the participant a series of questions about the treatment he/she just saw.

To encourage participation, the survey needed to take 30 minutes or less to complete. Thus, each participant only evaluated one treatment per section. In other words, each participant was only shown four treatments (one per issue) on the computer screen. However, at the end of each section the participant was shown printed color pictures of all the treatments and asked to either rank or rate them (dependent upon the section) based on certain criteria.

In order to counter any learning effects that may be present, researchers used seven versions of the survey. Within each version, the sections and the order in which the treatments were shown for the ranking/rating questions were randomized. The seven versions of the survey were distributed across the age categories and education levels.

ANALYSIS

As previously mentioned, the survey needed to take 30 minutes or less to complete to encourage participation. To accomplish this, each participant only evaluated one treatment per issue, which yielded small sample sizes for each treatment per location, age category, and education level. Thus, researchers only performed an overall analysis of the data.

Researchers combined the participants' responses from the four survey locations and computed the percentage of correct responses for each treatment. Treatments were considered to be understood by motorists when 85 percent of the total participants correctly interpreted the treatment. The 85 percent criterion is based on the threshold used by Dudek et al. (*8*), which is often used for traffic engineering design purposes. When a treatment was determined to have a comprehension level less than 85 percent, a confidence interval test (alpha equals 0.05) was used to determine if the comprehension percentage was statistically different from the 85 percent criterion (*9*).

To determine if there was a statistical difference between the comprehension level of the treatments, the Bernoulli model was used (*9*). This test compares two proportions (p_1 and p_2) of independent random samples. The null hypothesis was that the two proportions were equal, while the alternative hypothesis was that the two proportions were not equal. The null hypothesis was rejected if the test statistic, Z, was greater than 1.96. This value was selected using a level of significance of alpha equal to 0.05 (i.e., a 95 percent level of confidence). Rejection of the null hypothesis indicated that there was a statistically significant difference in comprehension levels between the treatments.

RESULTS

Number of Vehicles in a Work Convoy

In order to determine if the four treatments conveyed to motorists that there was more than one work vehicle in the road, researchers showed each participant a picture of one of the treatments mounted on the back of a work vehicle. Researchers then asked the participant whether he/she was approaching one or more work vehicles. Correct comprehension is the percentage of the participants that answered "more than one work vehicle" and incorrect comprehension is the percentage of participants that answered "one work vehicle."

Table 5 shows the comprehension percentages of the static signs tested. Only 53 percent of the participants understood that the WORK CONVOY sign meant that there was more than one work vehicle in the road ahead. In contrast, the 3 VEHICLE CONVOY sign was understood by 79 percent of the participants (which is not statistically different from 85 percent based on a confidence interval test with alpha equal to 0.05). This is not surprising since the number of

vehicles is provided. However, for the same reason one might wonder why this comprehension percentage was not a lot higher. For the 3 VEHICLE CONVOY sign, as well as the other three signs, the majority of the participants who answered "one work vehicle" did so because they only saw one vehicle in the picture (even though they also saw the sign). This shows that the participants received their primary information from other visual cues in the roadway environment and may be indicative of credibility issues with signs in work zones.

Researchers hypothesized that the MOVING VEHICLES sign would convey that there was more than one vehicle since the word "vehicle" was plural. However, this was not the case (only 52 percent correct comprehension). Based on the comments made by the participants, researchers concluded that the participants did not notice the "s."

Table 5. Static Signs Comprehension Percentages.

Treatment	Comprehension Percentages	
	Correct (More Than One Work Vehicle)	Incorrect (One Work Vehicle)
WORK CONVOY (n=36)	53%	47%
3 VEHICLE CONVOY (n=68)	79% [a,b]	21%
MOVING VEHICLES (n=69)	52%	48%
MOVING OPERATION (n=68) [c]	37%	62%

Shading indicates comprehension percentages that were statistically less than 85 percent.
[a] Based on a confidence interval test (alpha = 0.05), this percent is not statistically different from 85 percent.
[b] Statistically different from all the other treatments at a 95 percent level of confidence.
[c] One percent did not answer.

Of the participants that answered "more than one work vehicle," researchers asked them how many vehicles they were about to encounter. Researchers grouped the data into two categories: two to three work vehicles and more than three work vehicles. Table 6 shows the percent of participants that chose each of these categories. For all four signs, the majority of the participants expected to encounter two to three work vehicles.

Table 6. Number of Vehicles in Work Convoy – Static Signs. [a]

Treatment	Number of Work Vehicles	
	2 to 3	More Than 3
WORK CONVOY (n=19) [b]	69%	26%
3 VEHICLE CONVOY (n=54)	98%	2%
MOVING VEHICLES (n=36)	64%	36%
MOVING OPERATION (n=25)	72%	28%

[a] Based on the number of participants that stated there was more than one work vehicle (i.e., correct comprehension).
[b] Five percent did not answer.

The participants also ranked the four static signs from best (1) to worst (4) according to their ability to inform motorists that there was more than one work vehicle in the road ahead of them (Table 7). Based on these rankings, researchers computed a total score for each treatment by assigning one point each time a treatment was ranked first and four points each time a treatment was ranked fourth. Thus, the treatment perceived to be best would have the lowest score. The following is the participant ranking (total score) of the treatments from best treatment to worst treatment:

1. 3 VEHICLE CONVOY sign (407),
2. MOVING VEHICLES sign (556),
3. WORK CONVOY sign (692), and
4. MOVING OPERATION sign (751).

Table 7. Participant Ranking of Static Signs.

Number of Participants That Chose Each Rank					
Treatment	**Rank 1**	**Rank 2**	**Rank 3**	**Rank 4**	**Total**
WORK CONVOY	34	55	60	92	241
3 VEHICLE CONVOY	150	42	23	26	241
MOVING VEHICLES	44	103	70	24	241
MOVING OPERATION	13	41	92	95	241
Rank Score					
Treatment	**Rank 1 Score**	**Rank 2 Score**	**Rank 3 Score**	**Rank 4 Score**	**Total Score**
WORK CONVOY	34	110	180	368	692
3 VEHICLE CONVOY	150	84	69	104	407
MOVING VEHICLES	44	206	210	96	556
MOVING OPERATION	13	82	276	380	751

Speed Differential between the Work Convoy and Traffic

Speed Displays

In order to determine if the three speed display treatments provided motorists with information about the large speed differential between the work convoy and the traffic stream, researchers showed each participant a picture of one of the speed displays mounted on the back of a work vehicle. Researchers then asked the participant how fast he/she was driving and how fast the work vehicle was going. Correct comprehension of the speed displays was determined as follows:

- YOUR SPEED display – correctly stated the number shown on the speed display when asked how fast they were driving,
- MY SPEED display – correctly stated the number shown on the speed display when asked how fast the work vehicle was going, and

- YOUR SPEED/MY SPEED display – correctly stated the number shown on the YOUR SPEED display when asked how fast they were driving and correctly stated the number shown on the MY SPEED display when asked how fast the work vehicle was going.

Table 8 shows the comprehension percentages of the speed displays. The YOUR SPEED display was the only speed display understood by more than 85 percent of the participants. The MY SPEED and YOUR SPEED/MY SPEED displays resulted in low comprehension levels (53 percent and 62 percent, respectively). For the MY SPEED display, 36 percent of the participants interpreted the display as the speed they were traveling instead of the speed of the work vehicle. Based on the participants' comments, researchers hypothesize that the YOUR SPEED/MY SPEED display contained too much information for the participants to process (e.g., could remember one speed but not the other).

Table 8. Speed Display Comprehension Percentages.

Speed Display	Comprehension Percentages	
	Correct	Incorrect
YOUR SPEED (n=68)	93% [a]	7%
MY SPEED (n=64)	53%	47%
YOUR SPEED/MY SPEED (n=109)	62%	38%

Shading indicates comprehension percentages that were less than 85 percent.
[a] Statistically different from all the other treatments at a 95 percent level of confidence.

The subjects also ranked the three speed displays from best (1) to worst (3) according to their ability to inform motorists that the work vehicles are moving a lot slower than they are (Table 9). The following is the participant ranking (total score) of the treatments from best treatment to worst treatment:

1. YOUR SPEED/MY SPEED combination display (293),
2. MY SPEED display (483), and
3. YOUR SPEED display (663).

Table 9. Participant Ranking of Speed Displays.

Number of Participants That Chose Each Rank				
Speed Display	**Rank 1**	**Rank 2**	**Rank 3**	**Total**
YOUR SPEED	3	51	186	240 [a]
MY SPEED	39	159	42	240 [a]
YOUR SPEED/MY SPEED	200	30	11	241
Rank Score				
Speed Display	**Rank 1 Score**	**Rank 2 Score**	**Rank 3 Score**	**Total Score**
YOUR SPEED	3	102	558	663
MY SPEED	39	318	126	483
YOUR SPEED/MY SPEED	200	60	33	293

[a] One participant did not rank this display.

Static Signs

Researchers also evaluated how well the four static signs from the previous section provide information about the speed of the work convoy (Tables 10 and 11). Not surprisingly, including the word "moving" on a static sign improves motorists' understanding that the convoy is mobile. In addition, the word "moving" seems to imply lower work vehicle speeds.

Table 10. Are the Work Vehicles Moving? – Static Signs.

Treatment	Are the Work Vehicles Moving?	
	Yes	No
WORK CONVOY (n=36)	78% [a]	22%
3 VEHICLE CONVOY (n=68)	79% [a]	21%
MOVING VEHICLES (n=69) [b]	91%	7% [c]
MOVING OPERATION (n=68)	97% [c]	3% [c]

[a] Based on a confidence interval test (alpha = 0.05), this percent is not statistically different than 85 percent.
[b] Two percent did not answer.
[c] Statistically different from WORK CONVOY and 3 VEHICLE CONVOY signs at a 95 percent level of confidence.

Table 11. Speed Associated with Static Signs. [a]

Treatment	Speed Ranges (mph)		
	5 to 25	30 to 50	55+
WORK CONVOY (n=28)	43%	50%	7%
3 VEHICLE CONVOY (n=54)	59%	30%	11%
MOVING VEHICLES (n=63)	67% [b]	33%	0% [d]
MOVING OPERATION (n=66)	65% [b]	23% [c]	12%

[a] Based on the number of participants that stated the work vehicles were moving.
[b] Statistically different from WORK CONVOY sign at a 95 percent level of confidence.
[c] Statistically different from WORK CONVOY sign at a 95 percent level of confidence.
[d] Statistically different from all the other treatments at a 95 percent level of confidence.

Each participant was shown one of the static signs with the word "slow" added as the first line of the message and asked if the word "slow" implies that the work vehicle is going "slow" or that it is telling you to "slow down." Table 12 contains the participants' interpretations of the word "slow." For the SLOW WORK CONVOY and SLOW 3 VEHICLE CONVOY sign, the majority of the participants interpreted the message to mean that they should "slow down." In contrast, the majority of the participants thought that the SLOW MOVING VEHICLES and SLOW MOVING OPERATION signs meant that the work vehicles were going "slow."

The participants were also asked what speed they associated with the word "slow." Researchers grouped the data into three categories: 5 to 25 mph, 30 to 50 mph, and greater than or equal to 55 mph. Comparing Table 11 and Table 13 shows that adding the word "slow" produced mixed results. For two of the signs (SLOW WORK CONVOY and SLOW MOVING VEHICLES)

adding the word "slow" increased the percent of participants that thought the work vehicles would be traveling 5 to 25 mph. In contrast, for the other two signs (SLOW 3 VEHICLE CONVOY and SLOW MOVING OPERATION) the percent of participants that thought the work vehicles would be traveling 5 to 25 mph slightly decreased.

Table 12. Participant Interpretation of the Word "Slow."

Treatment	Work Vehicle Going Slow	Telling Motorist to Slow Down
SLOW WORK CONVOY (n=36)	39%	61%
SLOW 3 VEHICLE CONVOY (n=68)	43%	57%
SLOW MOVING VEHICLES (n=69)	84% [a]	16% [a]
SLOW MOVING OPERATION (n=68)	68% [a]	32% [a]

[a] Statistically different from all the other treatments at a 95 percent level of confidence.

Table 13. Speed Associated with the Word "Slow."

Treatment	Speed Ranges (mph)		
	5 to 25	30 to 50	55+
SLOW WORK CONVOY (n=36)	58%	42%	0%
SLOW 3 VEHICLE CONVOY (n=68)	56%	41%	3%
SLOW MOVING VEHICLES (n=69)	75% [a]	22% [b]	3%
SLOW MOVING OPERATION (n=68) [c]	61%	34%	4%

[a] Statistically different from SLOW 3 VEHICLE CONVOY sign at a 95 percent level of confidence.
[b] Statistically different from SLOW WORK CONVOY and SLOW 3 VEHICLE CONVOY signs at a 95 percent level of confidence.
[c] One percent did not answer.

The participants also ranked the static signs from best (1) to worst (8) according to their ability to inform motorists that the work vehicles are moving a lot slower than they are (Table 14). The following is the participant ranking (total score) of the treatments from best treatment to worst treatment:

1. SLOW MOVING VEHICLES sign (600),
2. SLOW 3 VEHICLE CONVOY sign (618),
3. SLOW WORK CONVOY sign (762),
4. SLOW MOVING OPERATION sign (850),
5. 3 VEHICLE CONVOY sign (1185),
6. MOVING VEHICLES sign (1394),
7. WORK CONVOY sign (1450), and
8. MOVING OPERATION sign (1491).

Table 14. Participant Ranking of Static Signs.

Number of Participants That Chose Each Rank									
Treatment	**Rank 1**	**Rank 2**	**Rank 3**	**Rank 4**	**Rank 5**	**Rank 6**	**Rank 7**	**Rank 8**	**Total**
WORK CONVOY	10	7	15	12	26	42	33	90	235
3 VEHICLE CONVOY	6	27	19	11	66	34	38	28	229
MOVING VEHICLES	3	3	11	13	39	66	59	37	231
MOVING OPERATION	2	6	7	6	31	48	67	65	232
SLOW WORK CONVOY	28	46	55	63	21	9	6	3	231
SLOW 3 VEHICLE CONVOY	98	41	30	24	16	10	8	7	234
SLOW MOVING VEHICLES	73	64	40	34	12	8	5	0	236
SLOW MOVING OPERATION	21	38	56	66	18	14	13	7	233
Rank Score									
Treatment	**Rank 1 Score**	**Rank 2 Score**	**Rank 3 Score**	**Rank 4 Score**	**Rank 5 Score**	**Rank 6 Score**	**Rank 7 Score**	**Rank 8 Score**	**Total Score**
WORK CONVOY	10	14	45	48	130	252	231	720	1450
3 VEHICLE CONVOY	6	54	57	44	330	204	266	224	1185
MOVING VEHICLES	3	6	33	52	195	396	413	296	1394
MOVING OPERATION	2	12	21	24	155	288	469	520	1491
SLOW WORK CONVOY	28	92	165	252	105	54	42	24	762
SLOW 3 VEHICLE CONVOY	98	82	90	96	80	60	56	56	618
SLOW MOVING VEHICLES	73	128	120	136	60	48	35	0	600
SLOW MOVING OPERATION	21	76	168	264	90	84	91	56	850

Passing a Work Convoy on Two-Lane, Two-Way Roadways with Unimproved Shoulders

In order to determine how well the five treatments provided passing information to motorists, researchers showed each participant a picture of one of the treatments mounted on the back of a work vehicle on a two-lane, two-way roadway with unimproved shoulders. Researchers then asked each participant whether he/she could pass the work vehicle. Correct comprehension for the current devices and two PASS WITH CARE messages is the percentage of the participants that stated they could pass the work vehicle. Correct comprehension for the DO NOT PASS messages is the percentage of the participants that stated they could not pass the work vehicle.

Table 15 shows the comprehension percentages of the treatments tested. All of the treatments evaluated, except the current devices, were understood by more than 85 percent of the participants. In addition, it appears that the CMS messages were understood slightly better than the static sign messages.

Table 15. Passing Information Comprehension Percentages – Two-Lane, Two-Way Roadways with Unimproved Shoulders.

Treatments	Comprehension Percentages	
	Correct	Incorrect
Current devices (n=36)	69%	31%
DO NOT PASS sign (n=32)	88%	12%
DO NOT PASS CMS (n=73)	93% [a]	7%
PASS WITH CARE sign (n=68)	93% [a]	7%
PASS WITH CARE CMS (n=32)	97% [a]	3%

Shading indicates comprehension percentages that were less than 85 percent.
[a] Statistically different from the current devices at a 95 percent level of confidence.

The participants also rated each treatment on a scale from one (excellent) to five (terrible) on their ability to inform motorists whether they can pass the work vehicle (Table 16). The average rating for the DO NOT PASS and PASS WITH CARE signs was 1.6, and the average rating for both messages on a CMS was approximately 2.0. In contrast, the average rating for the current devices was 3.7.

Passing a Work Convoy on Two-Lane, Two-Way Roadways with Improved Shoulders

In order to determine how well the seven treatments informed motorists to pass the work vehicles on the right on the improved shoulder, researchers showed each participant a picture of one of the treatments mounted on the back of a work vehicle on a two-lane, two-way roadway with improved shoulders. Researchers then asked each participant whether he/she could pass the work vehicle and which side he/she would pass on. Correct comprehension for all of the treatments is the percentage of the participants that stated they would pass the work vehicle to the right on the improved shoulder.

Table 16. Participant Rating of Passing Information for Two-Lane, Two-Way Roadways with Unimproved Shoulders.

Rating Scale	Number of Participants That Chose Each Rating				
	Current Devices	DO NOT PASS		PASS WITH CARE	
		Sign	CMS	Sign	CMS
1-Excellent	14	110	161	71	139
2-Good	21	67	48	92	72
3-OK	54	34	12	59	24
4-Bad	88	22	14	15	4
5-Terrible	64	8	6	4	2
Total # of Participants	241	241	241	241	241
Average Rating	3.7	2.0	1.6	2.1	1.6

Table 17 shows the comprehension percentages of the treatments tested. All of the treatments evaluated, except the current devices, were understood by more than 85 percent of the participants. In general, the PASS ON SHOULDER message was understood by the highest percentage of the participants (97 percent). In addition, the correct comprehension of the PASS ON SHOULDER CMS was significantly higher than the correct comprehension of the other two CMS messages.

Table 17. Passing Information Comprehension Percentages – Two-Lane, Two-Way Roadways with Unimproved Shoulders.

Treatments	Comprehension Percentages	
	Correct	Incorrect
Current devices (n=32	66%	34%
PASS ON SHOULDER sign (n=37)	97% [b,c]	3%
PASS ON SHOULDER CMS (n=36)	97% [b,c]	3%
PASS ON RIGHT sign (n=32)	94% [b]	6%
PASS ON RIGHT CMS (n=36)	83% [a]	17%
USE SHOULDER sign (n=36)	92% [b]	8%
USE SHOULDER CMS (n=32)	81% [a]	19%

Shading indicates comprehension percentages that were less than 85 percent.
[a] Based on a confidence interval test, these were not statistically different than 85 percent at alpha = 0.05.
[b] Statistically different from the current setup at a 95 percent level of confidence.
[c] Statistically different from the PASS ON RIGHT CMS and USE SHOULDER CMS at a 95 percent level of confidence.

The participants also rated each treatment on a scale from one (excellent) to five (terrible) on their ability to inform motorists to pass the work vehicle on the improved shoulder (Table 18). The treatments with the passing information on static signs received average ratings from 1.5 to

1.8, and the treatments with the passing information on a CMS received average ratings from 1.9 to 2.4. In contrast, the current devices received an average rating of 2.7.

Table 18. Participant Rating of Passing Information for Two-Lane, Two-Way Roadways with Unimproved Shoulders.

Rating Scale	Number of Participants That Chose Each Rating						
	Current Devices	PASS ON SHOULDER		PASS ON RIGHT		USE SHOULDER	
		Sign	CMS	Sign	CMS	Sign	CMS
1-Excellent	49	155	98	139	108	123	72
2-Good	58	61	85	66	61	58	57
3-OK	67	18	41	25	50	46	64
4-Bad	53	6	11	10	19	12	39
5-Terrible	14	1	6	1	3	2	9
Total # of Participants	241	241	241	241	241	241	241
Average Rating	2.7	1.5	1.9	1.6	2.0	1.8	2.4

Additional Findings

Researchers also evaluated how well the speed displays provide information about the number of work vehicles. As shown in Table 19, when the speed displays are used without a WORK CONVOY sign the majority of the participants thought there was only one work vehicle on the road ahead of them because that was all they saw.

Table 19. Number of Vehicles in Work Convoy – Speed Displays.

# of Vehicles in Work Convoy	Speed Displays			
	YOUR SPEED (n=68)	MY SPEED (n=64)	YOUR SPEED/ MY SPEED (n=109)	Overall (n=241)
1	66%	72%	78%	72%
More than 1	31%	28%	21%	27%
Did Not Answer	3%	0%	1%	1%

SUMMARY AND RECOMMENDATIONS

Researchers conducted 241 motorist surveys to further assess motorist comprehension of current and innovative work zone devices used to inform motorists about the following four issues. Treatments were considered to be understood by motorists when 85 percent of the total participants correctly interpreted the treatment.

Number of Vehicles in a Work Convoy

Currently, the WORK CONVOY sign is used on the back of a trail vehicle (i.e., the last work vehicle in a mobile operation, which is the first vehicle motorists encounter) to inform motorists that they are approaching multiple work vehicles. However, the motorist survey showed that only 53 percent of the participants interpret the WORK CONVOY sign to mean that there is more than one work vehicle in the road ahead. The MOVING VEHICLES and MOVING OPERATION signs also resulted in low comprehension levels (52 percent and 37 percent, respectively).

Placing the number of work vehicles on the sign (e.g., 3 VEHICLE CONVOY) improved comprehension (79 percent which is not statistically different from the 85 percent criterion based on a confidence interval test with alpha equal to 0.05) since the participants were provided with more specific information regarding the number of work vehicles they were approaching. Thus, researchers recommend that TxDOT use the # VEHICLE CONVOY sign instead of the WORK CONVOY sign on the back of the trail vehicle for mobile operations. A mobile operation typically consists of two to four vehicles, so the number needs to be adjustable and easily changed. This research effort did not include a legibility study of the # VEHICLE CONVOY sign. However, based on other work zone signing (*10*), researchers recommend the sign layout in Figure 27.

Speed Differential between the Work Convoy and Traffic

Speed Displays

Even though the YOUR SPEED display (showing the speed of approaching vehicles) used in the San Angelo District was understood by 93 percent of the participants, this display does not provide information to motorists about the speed of the work vehicle and thus the large speed differential between the work convoy and approaching traffic. Nevertheless, the YOUR SPEED display may yield operational effects (e.g., alert motorists, decrease approach speeds, etc.) that increase the safety of mobile operations; however, this was not evaluated in this research project. Thus, future research should evaluate the operational effects of the YOUR SPEED display.

The MY SPEED (showing the speed of the work vehicle) and YOUR SPEED/MY SPEED (showing both the speed of approaching vehicles and the speed of the work vehicle) displays resulted in low comprehension levels (53 percent and 62 percent, respectively). The MY SPEED display was interpreted by approximately one-third of the participants as the speed they were traveling instead of the speed of the work vehicle. Some of the confusion may be attributed to the text MY SPEED, which was chosen to compliment the text already being used in the San Angelo District (i.e., YOUR SPEED). There was also evidence that the YOUR SPEED/MY SPEED display contained too much information for the participants to correctly interpret. Based on the results of the motorist survey, researchers do not recommend the use of the MY SPEED and YOUR SPEED/MY SPEED displays. However, future research should evaluate the potential of the ME speed display.

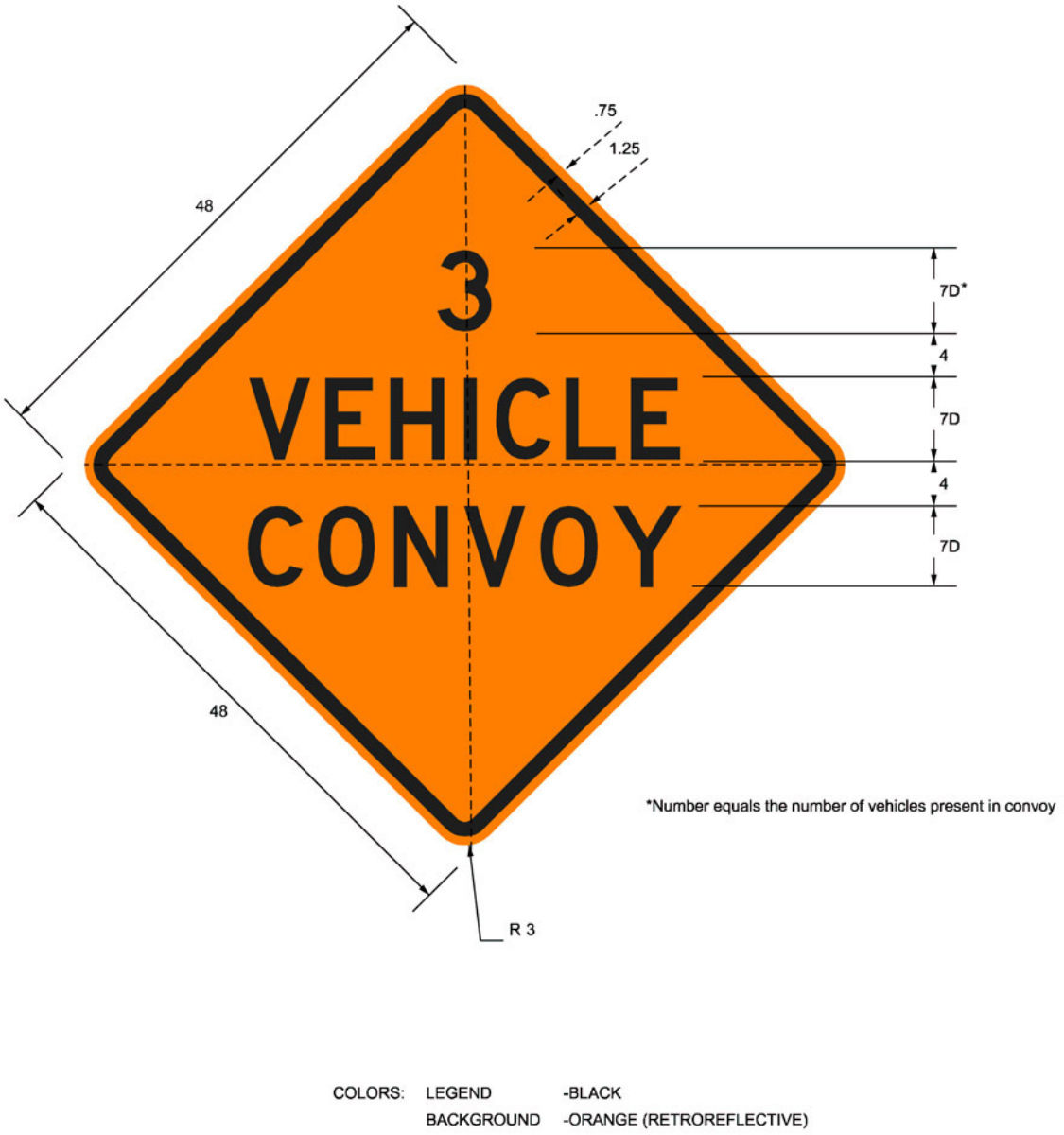

Figure 27. # VEHICLE CONVOY Sign Layout.

Static Signs

Not surprisingly, including the word "moving" on static signs (MOVING VEHICLES and MOVING OPERATION) improved motorists' understanding that the convoy is mobile. The word "moving" also seems to imply lower work vehicle speeds. However, the MOVING VEHICLES and MOVING OPERATION signs were not understood by participants to mean that they were approaching more than one work vehicle. Thus, researchers do not recommend the use of the MOVING VEHICLES and MOVING OPERATION signs. In order to convey to motorists that they are approaching multiple work vehicles and that the work vehicles are

moving at low speeds, future research should evaluate the potential of the word "moving" in combination with the number of vehicles (i.e., 3 MOVING VEHICLES).

For the SLOW WORK CONVOY and SLOW 3 VEHICLE CONVOY sign, the use of the word "slow" was interpreted to mean that the participant should "slow down." In contrast, participants thought that the SLOW MOVING VEHICLES and SLOW MOVING OPERATION signs meant that the work vehicles were going "slow." However, the addition of the word "slow" did not significantly change the participants' perception of the work vehicle speed. Thus, researchers do not recommend the use of the word "slow" to describe the speed of mobile operations.

Passing a Work Convoy on Two-Lane, Two-Way Roadways with Unimproved Shoulders

For mobile operations on a two-lane, two-way roadway with unimproved shoulders, the trail vehicle contains a WORK CONVOY sign, an arrow panel displaying the four-corner caution mode, rotating or strobe lights, and a TMA. Only 69 percent of the participants understood that they were allowed to pass the work vehicles when this set of devices was used. In contrast, when a PASS WITH CARE message or a DO NOT PASS message was used more than 85 percent of the participants understood that they could or could not pass the work vehicles, respectively. However, researchers acknowledge that implementation of the PASS WITH CARE message would be difficult since the message would have to be removed/turned off every time the work vehicle entered a no passing zone. In addition, TxDOT expressed concern over the shift in liability from the motorist to the work crew with the use of the PASS WITH CARE message. Due to these concerns, researchers did not further investigate the potential of the PASS WITH CARE message. Unlike the PASS WITH CARE message, the Texas MUTCD already allows the use of the DO NOT PASS message for mobile operations. As stated in the Texas MUTCD, researchers recommend that the work vehicles pull over periodically to allow traffic to pass. In addition, the DO NOT PASS sign (R4-1) should be placed on the rear of the trail vehicle when motorists are not allowed to pass the work convoy.

Passing a Work Convoy on Two-Lane, Two-Way Roadways with Improved Shoulders

For mobile operations on a two-lane, two-way roadway with improved shoulders, the traffic control devices on the trail vehicle are similar to the devices used on the trail vehicle for the unimproved shoulder condition. The only exception is that the arrow panel displays a right flashing arrow that directs motorists to pass the work convoy to the right on the improved shoulder. Only 66 percent of the participants understood that they were supposed to pass the work vehicles on the right on the improved shoulder when this set of devices was used. All of the alternative messages (PASS ON SHOULDER, PASS ON RIGHT, and USE SHOULDER) improved the comprehension rate; however, the PASS ON SHOULDER message was understood by the highest percentage of participants (97 percent). Thus, researchers recommend that the PASS ON SHOULDER message be evaluated in the field to determine if it improved compliance.

CHAPTER 5:
FIELD STUDY

During mobile operations on a two-lane, two-way roadway with improved shoulders, the traffic control devices on the trail vehicle typically display a right flashing arrow that directs motorists to pass the work convoy to the right on the improved shoulder. Field observations conducted in the first year of this project showed that while most motorists pass the work convoy on the shoulder, some motorists either hesitate before correctly passing the work convoy (in some cases coming to an abrupt stop behind the trail vehicle), pass the work convoy to the left into oncoming traffic, or follow the work convoy. In addition, as discussed in Chapter 3, most of the focus group participants were not confident they could pass the work vehicles to the right even though the right flashing arrow display was directing them onto the improved shoulder. During the motorist survey (discussed in Chapter 4) several alternatives were evaluated to determine how well they informed motorists to pass the work convoy to the right on the improved shoulder. From this survey it was determined that the message PASS ON SHOULDER was understood by the highest percentage of participants (97 percent). Therefore, researchers decided to conduct a field study to determine if this message improves motorist compliance of passing the work convoy on the improved shoulder. Since there are locations on two-lane, two-way roadways where the improved shoulder is dropped (e.g., bridge), the PASS ON SHOULDER message cannot be continually displayed. Thus, researchers decided to display the experimental message on a truck-mounted CMS instead of on a static sign.

STUDY DESIGN

Field data collection was conducted in the San Angelo District. This area was chosen as the study location because there is a dedicated pavement marking crew that serves the entire district. With the existence of such a crew it was easier to coordinate research activities and identify roadways that had the necessary characteristics for this study.

Study Location

The study site was located southwest of San Angelo on US 67 in Irion County. During the observation period, the work crew was painting centerline and edge line stripes between the eastern Irion County line and approximately 14 miles south of Mertzon.

The study location consisted of a rural two-way, two-lane roadway with improved shoulders. For the data collection areas, the speed limit was 70 mph. In general, the roadway cross section consisted of 12-ft lanes and a 10-ft shoulder. It should also be noted that frequent passing lanes were present within the study area and thereby limited the amount of data that researchers were able to collect.

Mobile Operations Description

The work convoy consisted of four vehicles: a lead vehicle, a work vehicle (striping truck), a shadow vehicle that remained immediately behind the work vehicle, and a trail vehicle located upstream of the other vehicles. All vehicles used multiple amber and blue warning lights and had a Type B flashing arrow panel facing opposing traffic. With the exception of the trail

vehicle, each vehicle also used a Type B flashing arrow panel facing motorists approaching the rear of the convoy. In place of the second arrow panel, the trail vehicle used the experimental truck-mounted CMS, which is described in further detail in the following section. Also on the trail vehicle was a WORK CONVOY sign. All flashing arrow panels displayed flashing right arrows when there was an improved shoulder. In areas without shoulders, the arrow panels displayed four-corner caution. Both the trail and shadow vehicles had TMAs with red and white conspicuity markings. The shadow vehicle had a speed display panel; however, it was not operational during this study. The entire pavement marking crew was primarily located in vehicles. When crew members were required to leave the vehicles to check striping or equipment, they wore orange vests with florescent yellow-green markings and hardhats. During this mobile operation, the work vehicles moved in the travel lane between 5 and 10 mph and directed traffic approaching the rear of the convoy to pass the work convoy to the right on the improved shoulder.

Throughout the study, there were issues concerning the amount of electrical draw on the trail vehicle due to addition of the CMS. In order to keep the CMS working properly, the warning lights on the trail vehicle were not always operating. It should also be noted that on one day of data collection there was no lead vehicle in the convoy. This did not appear to affect the passing activities at the trail and shadow vehicles.

Treatments

Several alternatives were evaluated in the motorist survey to determine how well they informed motorists to pass the work convoy to the right on the improved shoulder. From this survey, it was determined that the message PASS ON SHOULDER was understood by the highest percentage of participants. Therefore, researchers decided to conduct a field study using this message to determine if it improved motorist compliance of passing the work convoy on the improved shoulder as compared to the current traffic control setup.

The current traffic control setup on the back of the trail vehicle (i.e., standard treatment) shown in Figure 28 included a WORK CONVOY sign and used the CMS to simulate a flashing right arrow. The experimental treatment also included these devices; however, the CMS was used to display the experimental message, as well as simulate a right arrow. In other words, the CMS display alternated between the PASS ON SHOULDER message and a right arrow (Figure 29). Each of these phases (the message and arrow) was displayed for two seconds.

CMS Characteristics

The CMS used in this study was truck mounted at a height of 9 ft 9 inches (measured from the ground to the bottom of the CMS). The dimensions of the panel were 3 ft high by 6 ft wide. The CMS was a full matrix panel and was therefore able to display either text or traditional symbols, such as an arrow.

As stated above, the message to be used in the field study was selected based on the motorist surveys. However, the layout of the message needed to be altered from a three-line message to a two-line message in order to increase the font size of the message and thereby increase the legibility distance of the message. The original and alternative formats are illustrated below:

Original Format:	Alternative Format:
PASS ON SHOULDER	PASS ON SHOULDER

In the original format, the letter height for the message would have been approximately 6 inches, much smaller than is recommended for use on a high-speed roadway (*11*). Therefore, the alternative format was used and the letter height was increased to 10 inches (maximum letter height that could be used when displaying a two-line text message).

Figure 28. Standard Treatment.

Figure 29. Experimental Treatment.

Data Collection Protocol

Two data collection vehicles were used for this study. One of the vehicles was positioned to observe passing behaviors at the shadow vehicle, and the other at the trail vehicle. At both data collection locations, researchers recorded a time, basic vehicle description, and passing maneuver for each vehicle. For the passing maneuvers, researchers observed if the motorist passed on either the right or left and passing behaviors. The different passing behaviors were categorized as: passing smoothly, hesitating prior to passing, stopping behind the vehicle before making a passing decision, and stopping behind the vehicle and passing only after being directed by a worker. Data collection times were broken down as to which of the two treatments was being displayed: the experimental treatment or the standard treatment.

STUDY RESULTS

Data collection was done for a total of five days. Due to difficulties experienced with the electric function of the truck-mounted CMS panel, much of this time was lost to installation and repairs on the electrical functions of the trail vehicle. During the available data collection time, 497 observations were made of motorists passing the work convoy. Another difficulty encountered during data collection was the existence of passing lanes within the roadway section used for the study site. In these sections, data could not be analyzed to assess compliance with the traffic control devices since the passing lanes provided motorists with an opportunity to pass the work convoy in an open travel lane. Therefore, any data collected in an area with a passing lane was discarded. These two issues complicated the data collection effort and minimized the amount of usable data points available for this analysis. After these factors were considered, the final count of usable data points for the field study was 362 observations. This number includes all motorists that passed the trail vehicle in a two-way, two-lane section of the roadway with improved shoulders.

Of the data points that were usable, 206 were during the experimental treatment and 156 were during the standard treatment. Table 20 shows the passing maneuver observations at the trail vehicle for these data points. With both treatments, 95 percent or greater of the motorists passed on the right, as directed by the traffic control devices. Using the Bernoulli model, researchers found no statistical difference between the standard and experimental treatments with respect to the number of vehicles that passed on the right versus the left of the trail vehicle. In addition, researchers found no statistical difference between the types of passing behaviors (i.e., passed smoothly, hesitated prior to passing, stopped behind the vehicle before making a passing decision, and stopped behind the vehicle and passed only after being directed by a worker). Thus, it may be concluded that the experimental message did not increase motorist compliance as compared to the standard treatment. In addition, the experimental message did not reduce the number of motorists that passed the trail vehicle to the left.

Researchers believe that these results may have been impacted by a lack of time to read the PASS ON SHOULDER message prior to initiating the passing maneuver. According to passing sight distance criteria (*12*), motorists traveling between 60 and 70 mph begin the passing maneuver approximately 350 ft upstream of the overtaken vehicle. However, previous research has shown that the legibility distance of a 10.6-inch letter is only 324 ft (*13*). (The 10-inch letters used in this study would provide even less legibility distance.) Thus, researchers

hypothesize that motorists had already made their decision to pass the trail vehicle on either the left or right (most likely from the simulated arrow panel) and initiated the passing maneuver prior to receiving the additional information in the experimental message (i.e., PASS ON SHOULDER).

Table 20. Passing Maneuvers at the Trail Vehicle.

Passing Maneuver		Treatment			
		Standard		Experimental	
		Number	%	Number	%
Right	Smooth	125	80	170	83
	Hesitated	15	10	15	7
	Stopped – Made Decision	11	7	8	4
	Stopped – Worker Directed	0	0	2	1
Left	Smooth	1	1	4	2
	Hesitated	2	1	2	1
	Stopped – Made Decision	2	1	5	2
	Stopped – Worker Directed	0	0	0	0
Total		156	100	206	100

It is worth noting that for both treatments approximately 2 percent of the motorists passed the trail vehicle to the left even though they were provided ample time to read and comprehend the messages (i.e., stopped behind the trail vehicle before making their passing decision). Thus, it appears that a small portion of motorists will not go against their learned behavior (taught to pass a vehicle to the left) no matter what the traffic control devices instruct them to do.

Further analysis was completed for only those vehicles that passed both the trail and shadow vehicle in a two-way, two-lane section of roadway with improved shoulders. For this analysis, 264 total observations were used, with 129 of those being during the experimental treatment and 135 during the standard treatment. The observations for these data are shown in Table 21. Again, the Bernoulli model indicates that there is no statistical difference between the motorists passing behaviors for the two treatments. One interesting point regarding these data is that the level of compliance (i.e., people passing to the right of the work convoy) increased from the trail vehicle to the shadow vehicle for both treatments. Researchers believe that this may be because it is the second time the motorists are exposed to the traffic control devices.

SUMMARY AND RECOMMENDATIONS

Two treatments were examined during the field study. The standard treatment consisted of a WORK CONVOY sign and a flashing right arrow display (simulated using a full-matrix CMS) on the back of the trail vehicle. The experimental treatment incorporated the PASS ON SHOULDER message by alternating the CMS display between this text message and the flashing right arrow.

Table 21. Passing Maneuvers at the Trail and Shadow Vehicles.

Passing Maneuver		Trail Vehicle				Shadow Vehicle			
		Standard Treatment		Experimental Treatment		Standard Treatment		Experimental Treatment	
		Number	%	Number	%	Number	%	Number	%
Right	Smooth	108	80	105	81	127	94	118	91
	Hesitated	16	12	9	7	4	3	4	3
	Stopped – Made Decision	7	6	5	4	2	1	6	5
	Stopped – Worker Directed	0	0	2	2	0	0	0	0
Left	Smooth	0	0	3	2	1	1	1	1
	Hesitated	2	1	2	2	0	0	0	0
	Stopped – Made Decision	2	1	3	2	1	1	0	0
	Stopped – Worker Directed	0		0	0	0	0	0	0
Total		135	100	129	100	135	100	129	100

Overall, there was no significant difference with respect to motorist compliance (i.e., passing the trail vehicle to the right on the improved shoulder) between the standard treatment and the experimental treatment. For both treatments, 95 percent or greater of the motorists passed on the right, as directed by the traffic control devices. Furthermore, the addition of the PASS ON SHOULDER message did not reduce the number of motorists that passed the trail vehicle to the left. Thus, researchers do not recommend the use of the PASS ON SHOULDER message on a truck-mounted CMS. In addition, due to the character height limitations of truck-mounted CMS, TxDOT should use caution when displaying text messages on these devices. Future research should evaluate the use of a portable changeable message sign (PCMS) located on the shoulder upstream of the work convoy (similar to the use of the LANE BLOCKED sign for mobile operations on divided roadways) to display alternative messages that inform motorists to pass the work convoy to the right.

CHAPTER 6:
LANE BLOCKED SIGN

Currently, the LANE BLOCKED sign shown in Figure 10 is used by TxDOT on multilane divided highways to tell motorists which lane is blocked by a mobile work convoy (*5*, *14*). This sign identifies the number of lanes and illustrates which lanes are blocked with a large X mounted under the lane number. The LANE BLOCKED sign mounts on a truck or trailer that is located on the shoulder approximately 1500 ft upstream of the last vehicle in the mobile work convoy. This setup is required unless the divided highway has only two lanes per direction. In this case, a RIGHT/LEFT LANE CLOSED sign (CW20-5) may be substituted for the LANE BLOCKED sign.

In focus groups held during the first year of this research project, TxDOT personnel expressed their opinion that motorists do not understand the LANE BLOCKED sign. In addition, some TxDOT personnel stated that they would prefer to use PCMSs to convey lane closure information.

Based on the results of the focus groups held during the second year of the research project (documented in Chapter 3), all of the participants understood the LANE BLOCKED sign and felt it was not confusing. For roadways with three lanes in one direction, the participants preferred the use of the CENTER/LEFT/RIGHT LANE BLOCKED message on a CMS. For roadways with four or more lanes in one direction, the participants preferred the LANE BLOCKED sign. In addition to these focus group results, researchers compiled a synthesis of previous research that evaluated motorist understanding and the operational effectiveness of the LANE BLOCKED sign and PCMSs.

PREVIOUS RESEARCH

As early as the 1960s, research was completed to assess the effectiveness of lane control signals that utilize red X and green arrow symbols to indicate lane blockage and availability on urban freeways (*15*, *16*, *17*, *18*). In the 1970s, Dudek et al. (*19*) conducted human factors studies to evaluate alternative methods for informing motorists that lanes on freeways with four or more lanes per direction were closed or open. Examples of the treatments evaluated are shown in Figure 30. All signs were white on green, except as noted. Below is a summary of the results:

- Signs without titles (e.g., LANES BLOCKED) that use word descriptors relative to the specific lanes on two lines (Sign 1) were understood by 93 percent of the participants. Placing word descriptors on one line (Sign 2) significantly reduced motorist understanding (72 percent correct responses).
- Side-mounted signs containing Xs and arrows without titles (Signs 3 and 4) were understood by only 57 percent of the participants regardless of the color of the symbols (i.e., separate colors for Xs and "arrows" versus all the symbols being one color). Adding a title to these signs (Signs 5, 6, and 7) significantly increased motorist understanding (80 to 97 percent correct responses).
- Adding lane numbers to the signs with titles and symbols (Sign 8) slightly increased the comprehension of the sign.

- When lane numbers were used, there was no difference in comprehension between the sign using Xs and arrows (Sign 8) and signs without arrows (Signs 9 and 10).
- Sixty percent of the participants believed that LANE BLOCKED had the same meaning as LANE CLOSED. The remaining 40 percent stated that LANE BLOCKED meant a temporary obstruction and LANE CLOSED indicated a physical closure of prolonged duration.

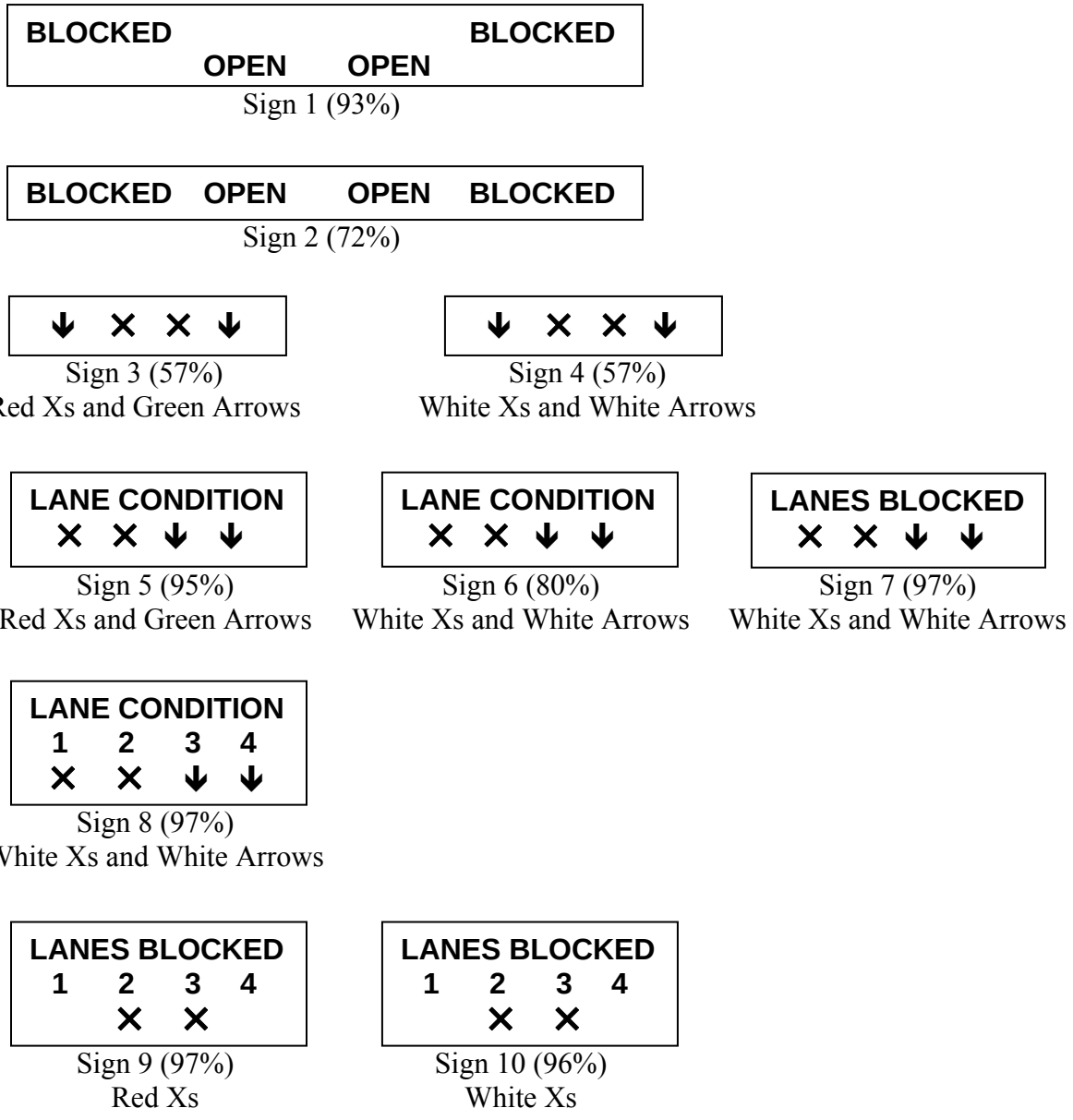

Figure 30. Examples of Treatments Evaluated by Dudek et al. (*19*).

Based on these findings, Dudek et al. (*19*, *20*) developed guidelines for the design and operation of lane blockage/closure messages on real-time displays. The guidelines state that the phrase LANE BLOCKED should be used to indicate a temporary blockage, whereas the phrase LANE CLOSED should only be used to indicate a prolonged closure. In addition, the following design guidelines apply to lane blockages:

- When there are two or three lanes per direction, the word message may be either descriptive (LEFT LANE BLOCKED/CLOSED or RIGHT LANE BLOCKED/CLOSED) or it may be directive (KEEP RIGHT or KEEP LEFT).
- When there are three lanes per direction and the center lane is blocked, a directive message is not recommended. The preferable message is CENTER LANE BLOCKED/CLOSED.
- When there are four or more lanes per direction, word descriptors like "left," "center," and "right" are ambiguous in designating the specific lane that is blocked. Thus, anchored displays are recommended (Figure 30, Signs 1, 7, and 8).

With respect to anchored signs, the guidelines state the following:

- Motorists correctly interpret the Xs and arrows even when they are all one color rather than coded red and green, respectively.
- If the lanes are not numbered (Figure 30 Sign 7), both Xs and arrows must be displayed. However, if the lanes are numbered, only the blocked lanes (Xs) need to be shown (Figure 30, Sign 9 or 10).
- For side-mounted CMSs, numbered lanes are recommended.

Through the application of previous study results (*19*), in the 1980s the LANE BLOCKED sign (Figure 10) was developed for moving maintenance operations (*21*). Prior to the development of the LANE BLOCKED sign, the word descriptors being used on vehicle-mounted warning signs (i.e., "left," "center," and "right") failed to identify the blocked lane(s) on roadways with four or more lanes per direction. The LANE BLOCKED sign had an orange background and black legend to be consistent with other construction/maintenance signing. Researchers recommended that the LANE BLOCKED sign be mounted on a vehicle that was located on the shoulder at least 1000 ft upstream of the last (trail) vehicle in the mobile work convoy (*21*).

In the 1980s, Richards and Dudek (*4*) cataloged traffic control strategies and devices that were identified during field studies and interviews conducted at numerous freeway work zones in Texas. With respect to mobile and short duration operations, the field studies showed that the LANE BLOCKED sign resulted in improved traffic operations by encouraging earlier lane changing out of the blocked lane. In addition, this sign proved to be flexible since it could be quickly adapted to any lane closure condition.

In 1988, Dudek et al. (*22*) developed a traffic control plan for short duration (work activity lasting 20 minutes or less at only one location) or stop-and-go maintenance (work activity lasting 20 minutes or less at more than one location) operations based on the concept of positive guidance (*23*) and motorist information requirements in work zones. The traffic control plans evaluated consisted of an arrow panel located behind the lane closure taper and advance signing

located 1500 ft from the beginning of the lane closure taper. To evaluate the effectiveness of the following candidate advance signing treatments, a series of field studies were conducted on rural and suburban four-lane divided roadways:

- ROAD WORK AHEAD sign (CW20-1),
- RIGHT/LEFT LANE CLOSED AHEAD sign (CW20-5),
- symbolic lane closure sign,
- PCMS (Panel 1 – ROAD WORK AHEAD and Panel 2 – RIGHT/LEFT LANE CLOSED), and
- LANE BLOCKED sign.

The results of the field studies showed that the PCMS and the LANE BLOCKED sign were the most effective in encouraging motorists to exit the closed lane farther upstream from the work zone. The results also showed that the performance of these two treatments resulted in similar responses by motorists as to when they chose to exit the closed lane. Based on these results, researchers recommended the use of either treatment for short duration and stop-and-go maintenance operations on four-lane divided highways with traffic volumes less than or equal to 30,000 average daily traffic (ADT) (*22*).

SUMMARY AND RECOMMENDATIONS

Previous (*2*, *4*, *19*, *22*) and current research efforts have shown that the LANE BLOCKED sign is understood by motorists and operationally yields a similar response from motorists as a PCMS (i.e., encouraging motorists to exit the closed lane farther upstream from the work zone). In addition, design guidelines for real-time displays (*19*, *20*) state that word messages such as LEFT LANE BLOCKED/CLOSED, RIGHT LANE BLOCKED/CLOSED, and CENTER LANE BLOCKED/CLOSED are effective on roadways with two or three lanes per direction. However, on roadways with four or more lanes per direction, word descriptors (i.e., "left," "center," and "right") are ambiguous in designating the specific lane that is blocked.

Based on these findings, researchers recommend that TxDOT:

- require the use of the LANE BLOCKED sign (FCW20-6) for mobile operations on divided highways with four or more lanes in each direction and
- allow a PCMS to be substituted for the LANE BLOCKED sign (FCW20-6) for mobile operations on divided highways with three or less lanes in each direction.

Previous research has also shown that a majority of participants believe that the terms LANE BLOCKED and LANE CLOSED have the same meaning. For those participants that noted a difference between these two terms, LANE BLOCKED meant a temporary obstruction and LANE CLOSED indicated a physical closure of prolonged duration. However, both of these definitions apply to mobile maintenance operations, since a work convoy moving along a roadway could be considered a temporary obstruction at any one location and a physical closure of the roadway. In order to be consistent with other work zone signing used to denote lane closures, researchers recommend that TxDOT require the use of the PCMS messages shown in Figure 31.

Figure 31. Recommended PCMS Messages for Mobile Operations on Divided Highways.

The recommended messages in Figure 31 contain one unit of information. Previous research has shown that motorists require two seconds of reading time per unit of information on a CMS (*20*). Thus, at 70 mph a motorist will require approximately 200 ft to read the message. In addition, motorists must be able to read the entire message before it is out of view. The typical out of view angle (subtended by the direction of vehicle motion and the observation axis between the eye and the sign) is 10 degrees. The worst case scenario would be when the PCMS is located on the outside shoulder and the motorist is traveling in the inside lane of a six-lane divided highway (i.e., three lanes in each direction). Assuming 12 ft lanes and a 10 ft shoulder, the PCMS would be out of view approximately 200 ft upstream of the sign. Thus, the minimum required legibility distance of the messages in Figure 31 is the distance it takes to read the sign plus the out of view distance or approximately 400 ft. Based on recent research (*13*), a 12-inch character height is needed to provide 400 ft of legibility distance during daytime conditions. Thus, researchers also recommend that TxDOT require the PCMS message to use a minimum letter height of 12 inches.

CHAPTER 7:
PRACTICES TO IMPROVE THE SAFETY OF MOBILE AND SHORT DURATION OPERATIONS

The Texas MUTCD provides the basic principles that govern the design and use of traffic control devices. This manual provides the information needed to make appropriate decisions regarding the use of traffic control devices in work zones. Three types of information are provided: standards that must be followed, guidance that should be followed, and options that may be applicable. In addition, the Texas MUTCD contains typical applications for a variety of commonly encountered situations. While not every situation is addressed, the information provided can be adapted to a broad range of conditions.

TxDOT also has three mobile and 15 short duration traffic control plans that can be used by TxDOT personnel to decide what types of traffic control devices are needed for these operations. In some cases, these traffic control plans have subtle differences. In addition, since these traffic control plans were not all created at the same time there are some inconsistencies.

Due to the subtle differences and inconsistencies among the TxDOT traffic control plans, as well as the need to adapt the information in the Texas MUTCD and TxDOT traffic control plans to specific situations, it is difficult for maintenance personnel (who are not engineers) to make decisions about which traffic control devices are needed on a day to day basis for mobile and short duration maintenance operations. In addition, researchers found that the definitions of mobile and short duration operations, as well as the classification of specific operations as either mobile or short duration, were not consistent among TxDOT maintenance personnel. With this in mind, researchers concluded that there was a need to:

- examine the terminology used to define mobile and short duration operations and determine if changes would help distinguish between these types of operations,
- develop maintenance traffic control plans for select mobile and short duration operations,
- develop guidance for the use of "optional" devices based on roadway conditions, and
- categorize mobile and short duration operations and develop a process that directs maintenance personnel to the appropriate practice(s).

In order to gain input from persons knowledgeable about mobile and short duration operations, researchers assembled an advisory panel comprised of TxDOT personnel and contractors. A list of the advisory panel participants is located in the appendix. This panel met initially on October 13, 2003, and again on August 25, 2004.

TERMINOLOGY USED TO DEFINE MOBILE AND SHORT DURATION OPERATIONS

Currently, the Texas MUTCD and TxDOT Traffic Control Plan Selection Worksheet *(24)* utilize the following five categories to define work duration:

- mobile – work that moves intermittently or continuously;
- short duration – work that occupies a location up to 1 hour;
- short-term stationary – daytime work that occupies a location from 1 to 12 hours;
- intermediate-term stationary – work that occupies a location more than one daylight period up to 3 days, or nighttime work lasting more than 1 hour; and
- long-term stationary – work that occupies a location more than 3 days.

Information gathered during the first year of this research project highlighted the fact that the classification of specific operations as either mobile or short duration was not consistent. Acknowledging that some types of operations can be completed as both mobile and short duration operations, researchers still felt that there was a need for a clearer distinction between the definitions of mobile and short duration operations.

Some of the uncertainty about which operations are considered mobile and which operations are considered short duration may be due to the use of the word "work" in the definitions. For example, a long-term stationary operation (e.g., adding new lanes to a roadway) may contain "work" that moves intermittently or continuously (e.g., paving). To help distinguish between the types of operations, researchers recommend that the duration be associated with the "temporary traffic control zone" instead of the "work" being performed. A "temporary traffic control zone" is an area of a roadway where the conditions are changed using temporary traffic control devices (*5*). Thus, to be considered a mobile operation the "temporary traffic control zone" would have to move intermittently or continuously. If the "temporary traffic control zone" is stationary (independent of whether the "work" is moving), the operation is not considered a mobile operation.

Another issue raised during the first year of this research project concerned the amount of time a mobile operation can be stopped before it is considered a short duration operation. Several states, as well as one of the TxDOT Barricade and Construction Standard Sheets (*25*), specify that a mobile operation cannot stop for more than 15 minutes. Likewise, researchers feel that short duration operations are stationary operations and thus should include the "stationary" descriptor in the duration definition.

To help maintenance personnel distinguish between mobile and short duration operations, researchers recommend the following changes to the work duration definitions (deletions are shown as strikeouts and additions are underlined):

- Mobile is ~~work~~ a temporary traffic control zone that moves intermittently (stops up to 15 minutes) or continuously.
- Short duration stationary is ~~work~~ a temporary traffic control zone that occupies a location up to 1 hour.
- Short-term stationary is a daytime ~~work~~ temporary traffic control zone that occupies a location for more than 1 hour, but less than 12 hours.
- Intermediate-term stationary is ~~work~~ a temporary traffic control zone that occupies a location more than one daylight period up to 3 days, or nighttime work lasting more than 1 hour.

- Long-term stationary is ~~work~~ a temporary traffic control zone that occupies a location more than 3 days.

DEVELOPMENT OF MAINTENANCE TRAFFIC CONTROL PLANS

Mobile Operations

Based on existing TxDOT traffic control plans, field observations of mobile operations conducted during the first year of this research project, findings from the second year of this research project, and input from the advisory panel, researchers developed maintenance traffic control plans for the following mobile operations:

- striping,
- RPM installation/removal,
- shoulder texture,
- spot pothole patching,
- spot edge repair,
- sweeping,
- herbicide,
- retroreflectivity measurements,
- core sampling,
- temporary tab placement/removal,
- short-line striping, and
- in-lane (lateral) rumble strips.

Striping, RPM Installation/Removal, and Shoulder Texture

For striping, RPM installation/removal, shoulder texture, and other similar types of operations, researchers developed two mobile maintenance traffic control plans: one for undivided highways (Figure 32) and one for divided highways (Figure 33). Both of these maintenance traffic control plans were based on the current TxDOT traffic control plans for mobile operations (TCP(3-1)-98, TCP(3-2)-98, and TCP(3-3)-98) (*14*, *26*, *27*). The following changes were made to TCP(3-1)-98 to create the mobile maintenance traffic control plan for undivided highways (MNT(3-1)-04):

- Added general note 1: This traffic control plan is intended for the following mobile maintenance operations or other similar types of operations that move continuously or intermittently (stops up to 15 minutes): striping, RPM installation/removal, and shoulder texture. When activities are anticipated to take longer amounts of time or traffic conditions warrant, a short duration or short-term stationary traffic control plan should be used.
- Added general note 3: A lead vehicle shall be used when the work vehicles are working on the centerline.
- Added general note 12: If a trail vehicle is not used, the CW21-10 sign shall be located on the shadow vehicle.

- Added general note 13: On two-way roadways, the work and protection vehicles should pull over periodically to allow motor vehicle traffic to pass. If motorists are not allowed to pass the work convoy, a DO NOT PASS sign (R4-1) should be placed on the back of rearmost protection vehicle.
- Deleted all references to "optional" striping on TMA.
- Made the arrow panel on the work vehicles optional.
- For 3-1a, added a lead vehicle.
- For 3-1b and 3-1c, deleted the "Arrow Panel (optional)" for the lead vehicle thus making the arrow panel required on the lead vehicle. This is consistent with general note 2, which requires the lead vehicle to be equipped with an arrow panel as illustrated.
- For 3-1b in-lane, changed the arrow panel display on the lead vehicle to a flashing arrow instead of four-corner caution, so motorists approaching from the front will see the same display on both the lead and work vehicle.

The following changes were made to TCP(3-2)-98 to create the mobile maintenance traffic control plan for divided highways (MNT(3-2)-04):

- Added general note 1: This traffic control plan is intended for the following mobile maintenance operations or other similar types of operations that move continuously or intermittently (stops up to 15 minutes): striping, RPM installation/removal, and shoulder texture. When activities are anticipated to take longer amounts of time or traffic conditions warrant, a short duration or short-term stationary traffic control plan should be used.
- Made the underlined changes to general note 11: The LANE BLOCKED sign (FCW20-6) shall be used on divided highways <u>with four or more lanes in each direction</u> and may be mounted on a truck or trailer. <u>For divided highways with three or less lanes in each direction, a portable changeable message sign (PCMS) with the message LEFT, RIGHT, or CENTER LANE CLOSED may be substituted for the LANE BLOCKED sign (FCW20-6). The minimum letter height for the PCMS message is 12 inches.</u> For divided highways with two lanes in each direction, the RIGHT or LEFT LANE CLOSED sign (CW20-5, 48" x 48") may be substituted for the LANE BLOCKED sign (FCW20-6).
- Added general note 12: If a trail vehicle is not used, the CW21-10 sign shall be located on the shadow vehicle.
- Added an optional arrow panel on the work vehicles.
- Added the note "work vehicles with strobes" to the work vehicles.
- Deleted all references to "optional" striping on TMA.

Spot Pothole Patching, Spot Edge Repair, Sweeping, Herbicide, Retroreflectivity Measurements, Core Sampling, and Tab Placement/Removal

Researchers developed two mobile maintenance traffic control plans (MNT(3-3)-04 and MNT(3-4)-04) for spot pothole patching, spot edge repair, sweeping, herbicide, retroreflectivity measurements, core sampling, tab placement/removal, and other similar operations (Figures 34 and 35, respectively). These two mobile maintenance traffic control plans are similar to MNT(3-1)-04 and MNT(3-2)-04 with the following differences:

- Trail, lead, and advance warning vehicles are not used.
- When a shadow vehicle is not used, herbicide trucks and sweepers are required to have an arrow panel.

It should be noted that if these activities are not continuously moving, are stopped for longer than 15 minutes, or traffic conditions warrant, a short duration or short-term stationary traffic control plan should be used.

Short-Line Striping and In-Lane (Lateral) Rumble Strips

Based on a traffic control plan from the Tyler District, researchers developed the mobile maintenance traffic control plan in Figure 36 (MNT(3-5)-04) for short-line striping and in-lane (lateral) rumble strips on undivided roadways. Similar to the other activities previously discussed, if these activities are not continuously moving, are stopped for longer than 15 minutes, or traffic conditions warrant, a short duration or short-term stationary traffic control plan should be used.

Short Duration Operations

Based on the TxDOT Traffic Control Plan (1-1)-98 (*28*), field observations of short duration operations conducted during the first year of this research project, and input from the advisory panel, researchers developed the maintenance traffic control plan in Figure 37 (MNT(3-6)-04) for the following short duration operations:

- sign maintenance,
- delineator maintenance, and
- lighting maintenance.

This short duration maintenance traffic control plan is for work being performed on or adjacent to the shoulder and can be used for other similar operations. Work requiring full lane closures should not utilize this maintenance traffic control plan.

GUIDANCE FOR THE USE OF "OPTIONAL" DEVICES

In the Texas MUTCD and TxDOT *Traffic Control Plan Standard Sheets* (*14*, *26*, *27*) several of the traffic control devices for mobile operations are "optional." Based on information received during the first year of the research project and input from the advisory panel, researchers developed guidance for the use of some of these "optional" devices based on the roadway volume (average daily traffic [ADT]) and posted speed.

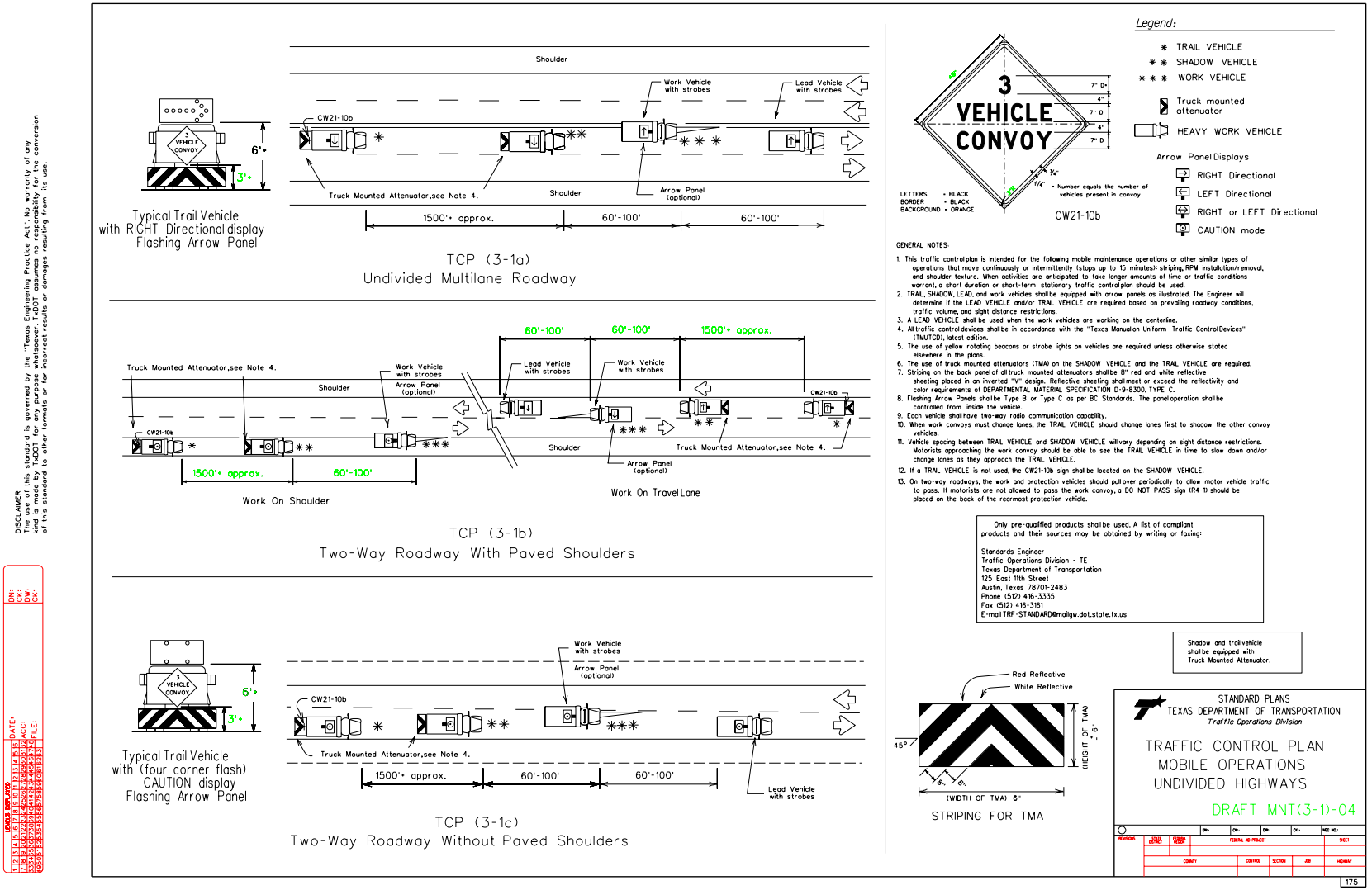

Figure 32. Mobile Maintenance Traffic Control Plan for Striping, RPM Installation/Removal, Shoulder Texture, and Other Similar Operations on Undivided Highways (MNT(3-1)-04).

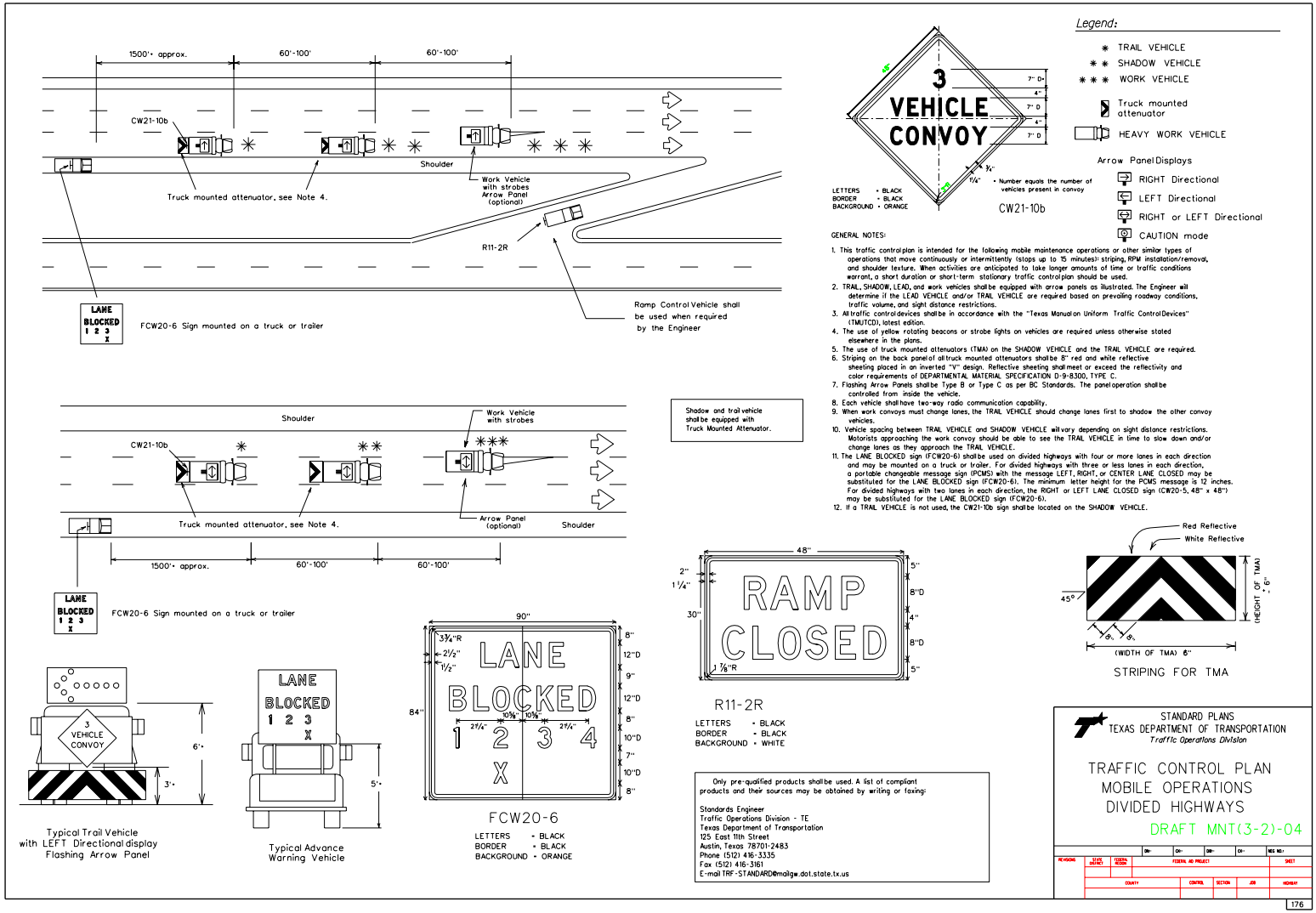

Figure 33. Mobile Maintenance Traffic Control Plan for Striping, RPM Installation/Removal, Shoulder Texture, and Other Similar Operations on Divided Highways (MNT(3-2)-04).

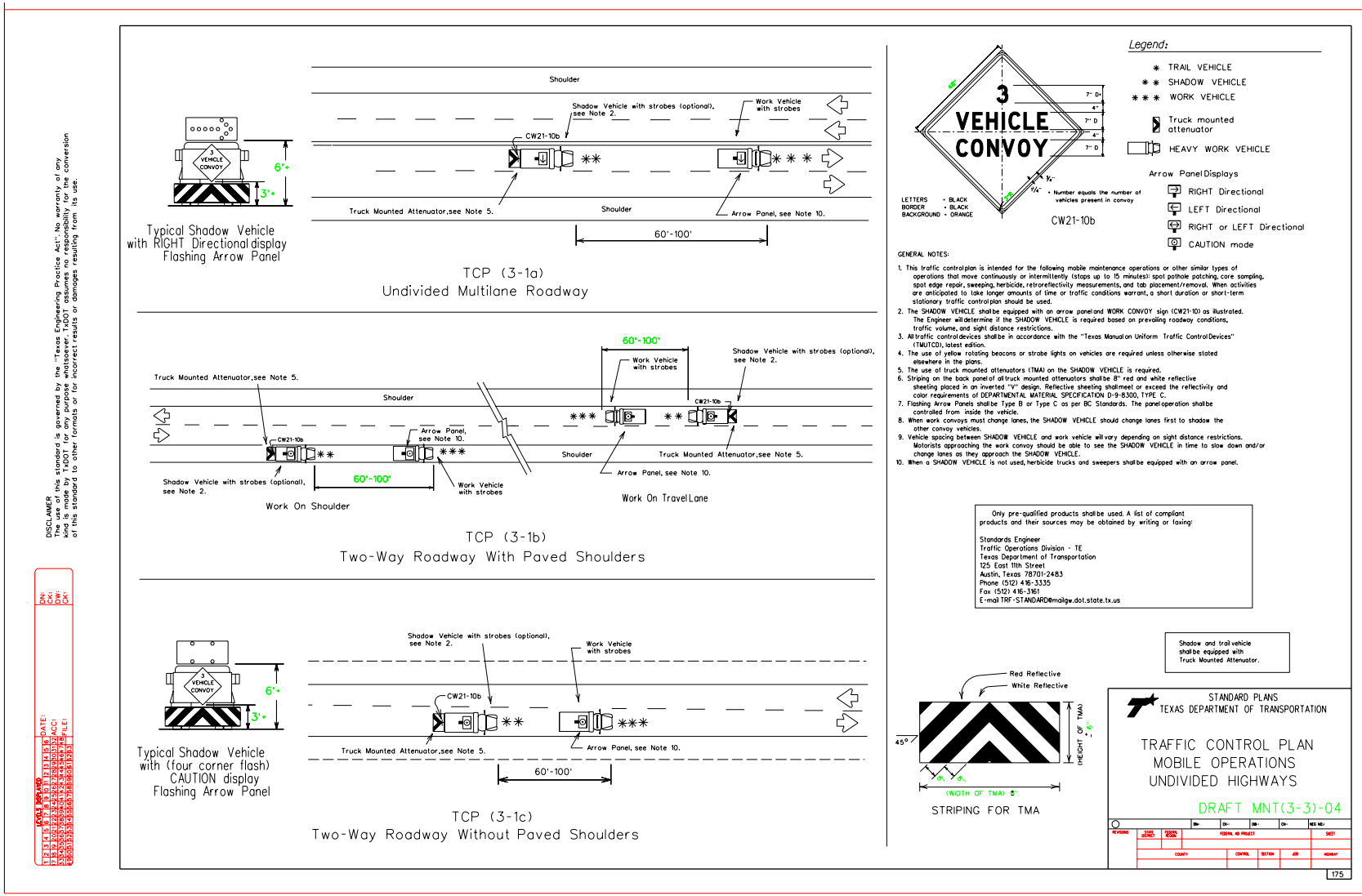

Figure 34. Mobile Maintenance Traffic Control Plan for Spot Pothole Patching, Spot Edge Repair, Sweeping, Herbicide, Retroreflectivity Measurements, Core Sampling, Tab Placement/Removal, and Other Similar Operations on Undivided Highways (MNT(3-3)-04).

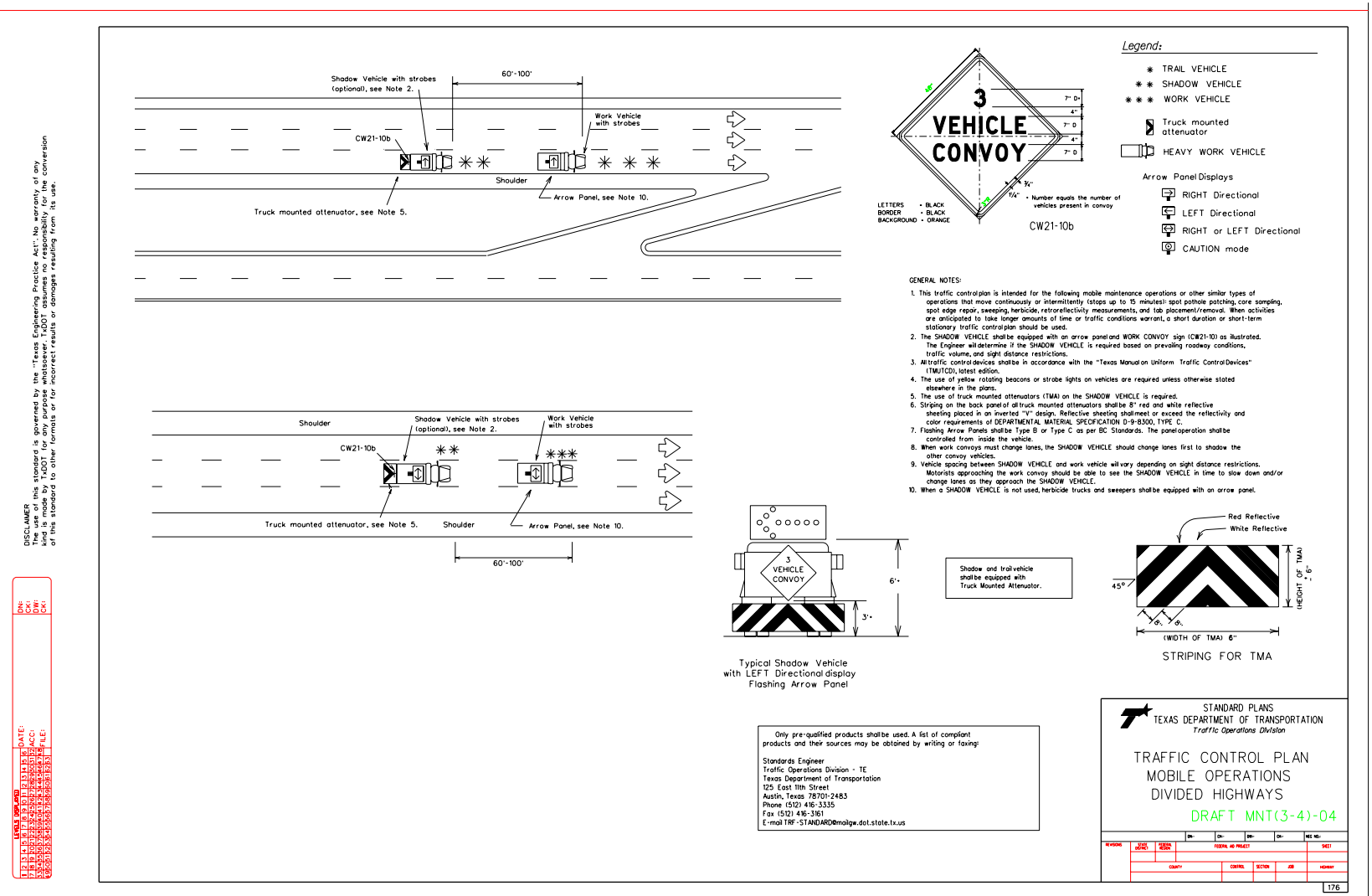

Figure 35. Mobile Maintenance Traffic Control Plan for Spot Pothole Patching, Spot Edge Repair, Sweeping, Herbicide, Retroreflectivity Measurements, Core Sampling, Tab Placement/Removal, and Other Similar Operations on Divided Highways (MNT(3-4)-04).

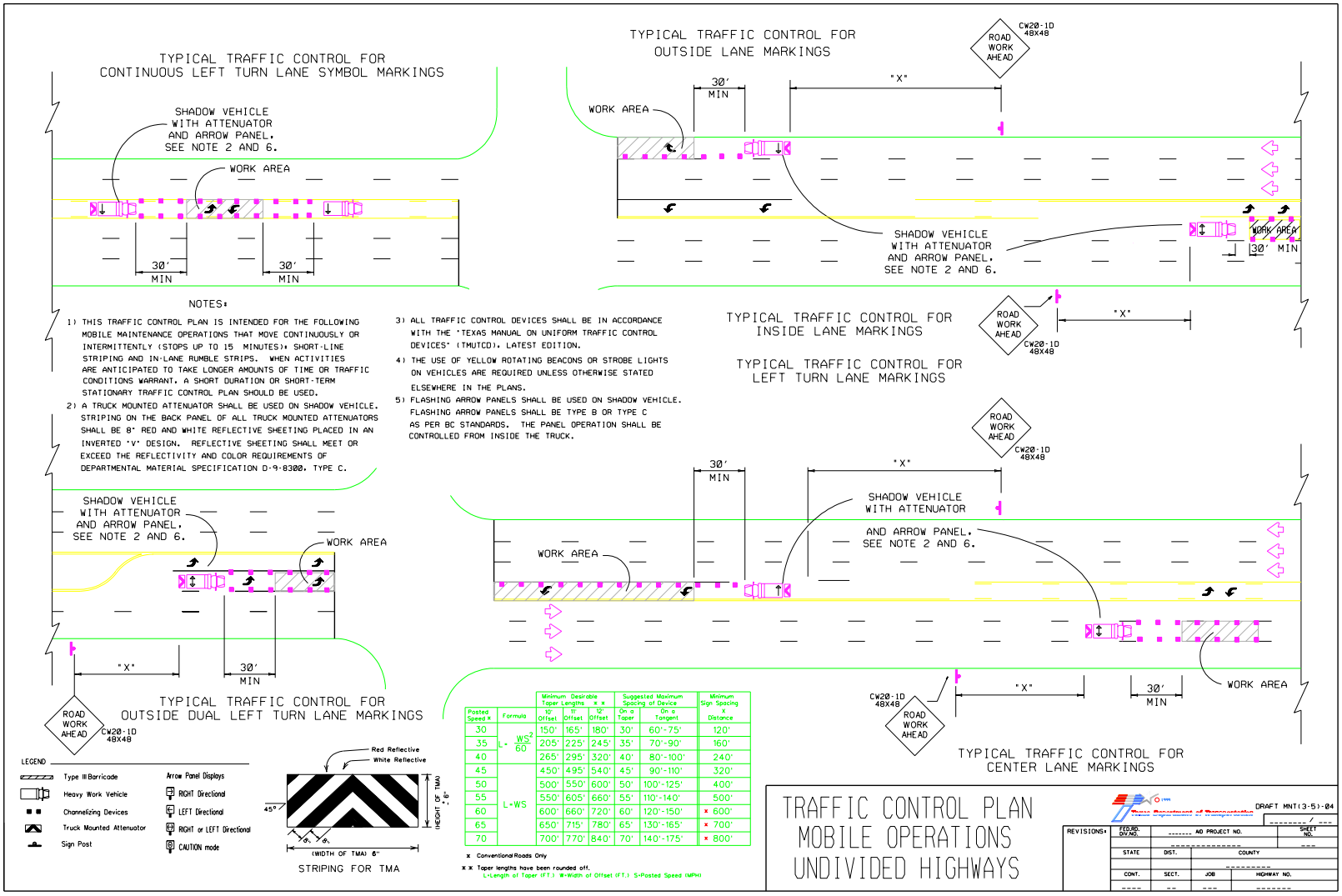

Figure 36. Mobile Maintenance Traffic Control Plan for Short-Line Striping and In-Lane (Lateral) Rumble Strips on Undivided Highways (MNT(3-5)-04).

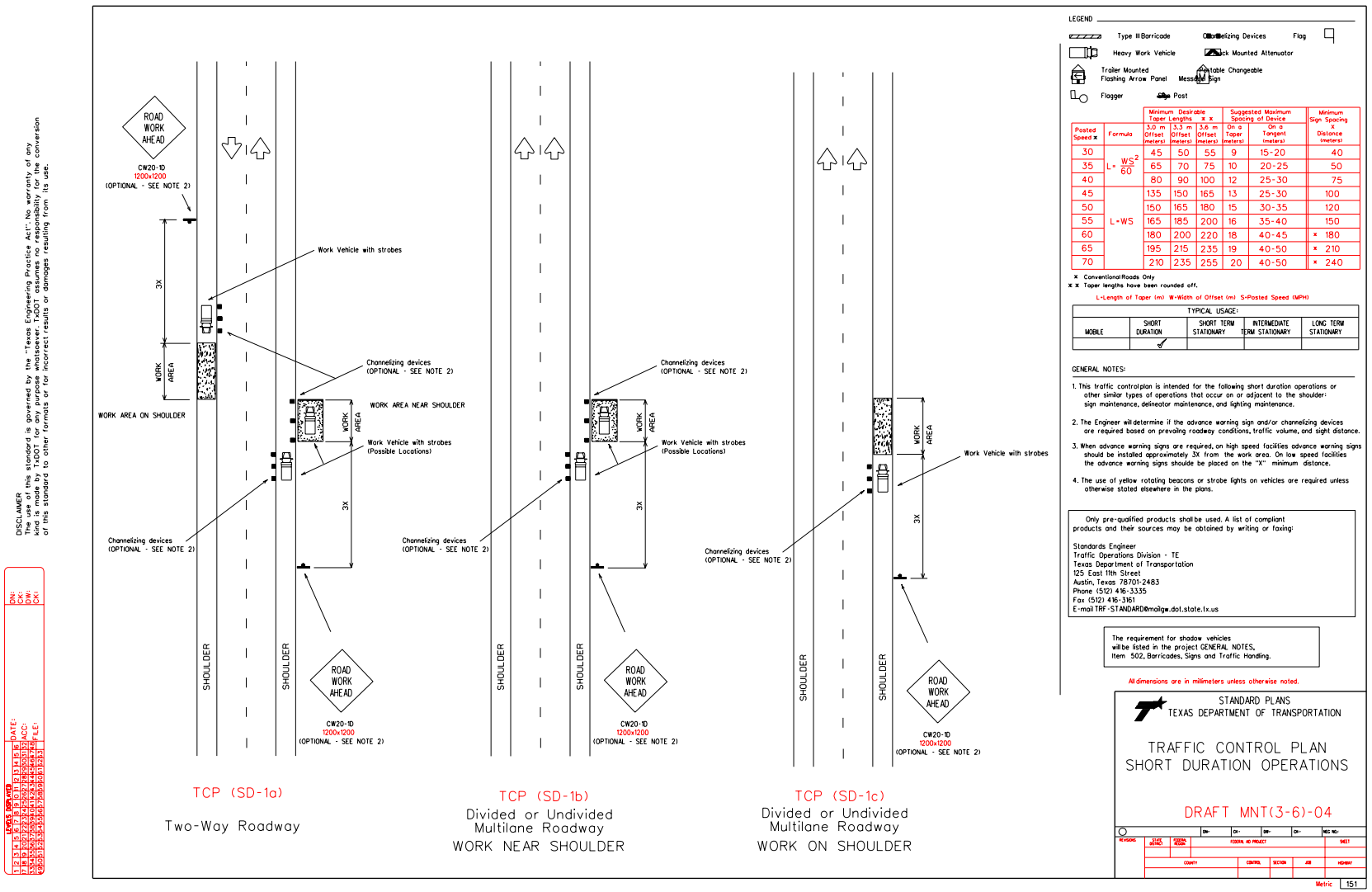

Figure 37. Short Duration Maintenance Traffic Control Plan for Sign Maintenance, Delineator Maintenance, Lighting Maintenance, and Other Similar Operations on or Adjacent to the Shoulder (MNT(3-6)-04).

Currently, there is no standard threshold value that separates low-volume roadways from high-volume roadways. This is also true with respect to low-speed versus high-speed roadways. Instead, researchers reviewed previous literature and other states' work zone manuals to help determine these threshold values. Table 22 contains the findings with respect to volume, while Table 23 contains the information with respect to speed. Based on these findings and input from the advisory panel, researchers utilized the following definitions:

- low volume – < 2000 ADT,
- high volume – ≥ 2000 ADT,
- low speed – ≤ 45 mph, and
- high speed – > 45 mph.

Researchers worked with the advisory panel to create Tables 24 and 25. Table 24 contains guidance for choosing whether a trail vehicle is needed on striping, RPM installation/removal, and shoulder texture operations (MNT(3-1)-04 and MNT(3-2)-04). Similarly, Table 25 provides guidance for choosing whether a shadow vehicle is needed on spot edge repair, spot pothole patching, herbicide, sweeping, retroreflectivity measurements, core sampling, tab placement/removal (MNT(3-3)-04 and MNT(3-4)-04).

Table 22. Low-Volume Definitions.

Entity/Reference	Low-Volume Definition
Washington State DOT (*29*)	< 10,000 ADT
Illinois DOT (*30*)	< 5000 ADT
North Carolina DOT (*31*)	≤ 5000 ADT
TxDOT Research Project 0-4048 (*32*)	< 2000 ADT
NCHRP Report 362 (*33*)	< 2000 ADT
Louisiana DOT (*34*)	< 1500 ADT
Oregon DOT (*35*)	≤ 500 ADT
Wisconsin DOT (*36*)	≤ 500 ADT
2003 MUTCD [a] (*11*)	< 400 AADT

[a] The MUTCD definition of a low-volume road does not include roads on a designated state highway system.

Table 23. Low-Speed Definitions.

Entity/Reference	Low-Speed Definition
Illinois DOT (*30*)	≤ 45 mph
Green Book (*12*)	≤ 45 mph
TxDOT *Roadway Design Manual* (*37*)	≤ 45 mph
Oregon DOT (*35*)	< 45 mph
2003 Texas MUTCD Work Zone Taper Length Calculations [a] (*5*)	≤ 40 mph
Maryland DOT (*38*)	≤ 40 mph
Washington State DOT (*29*)	≤ 35 mph

[a] Above 40 mph the formula to calculate the work zone taper length changes.

Table 24. Guidance for Choosing Whether a Trail Vehicle Is Needed on Striping, RPM Installation/Removal, and Shoulder Texture Operations.

Volume (ADT)	Speed (mph)	Type of Roadway			
		Two-Lane, Two-Way	Multilane Undivided	Multilane Divided	Freeway
< 2000	≤ 45	No	No	No	NA
< 2000	> 45	No	No	No	No
≥ 2000	> 45	Yes	Yes	Yes	Yes
≥ 2000	≤ 45	No	No	No	NA

NA – Not applicable

Table 25. Guidance for Choosing Whether a Shadow Vehicle Is Needed on Spot Edge Repair, Spot Pothole Patching, Herbicide, Sweeping, Retroreflectivity Measurements, Core Sampling, and Tab Placement/Removal.

Volume (ADT)	Speed (mph)	Type of Roadway		
		Two-Lane, Two-Way	Multilane Undivided	Multilane Divided
< 2000	≤ 45	No	No	No
< 2000	> 45	No [b]	No [b]	Yes [a,b]
≥ 2000	> 45	Yes [a]	Yes [a]	Yes [a]
≥ 2000	≤ 45	No [b]	No [b]	No [b]

[a] The shadow vehicle may be omitted if the work vehicle does not encroach into a travel lane.

[b] A shadow vehicle is recommended when a tractor sweeper is used.

It is important to note that the guidance provided in these tables is not based on a crash analysis. Instead, researchers utilized observational data collected during the first year of the research project and input from the advisory panel to develop the tables. Even if a crash analysis would have been within the scope of this project, several factors limit the use of crash data with respect to determining when a trail or shadow vehicle should be used. First, existing crash databases do not decipher between the types of work zones (i.e., mobile, short duration, short-term stationary, intermediate-term stationary, and long-term stationary). Second, existing crash databases do not include a description of the traffic control devices used (e.g., whether or not a shadow vehicle was used). Third, the likelihood of establishing accurate traffic exposure numbers during maintenance activities is low since few, if any, existing crash databases include the actual traffic volumes through the work zone. Also with respect to exposure, estimates of the number and type of maintenance operations conducted on a yearly basis are not readily available.

Researchers recommend that each district review Tables 24 and 25 and further refine the guidelines with respect to the roadways in their area. Additional factors to consider would include sight distance, number of lanes, width of lanes, whether a shoulder is present, etc. One district that has completed a similar process is the Wichita Falls District. This district developed several low-volume (≤ 1000 ADT) traffic control plans for its maintenance personnel to use. In

addition, they developed two maps: one showing all the low-volume roads in the district and one showing the required traffic control for pavement marking operations on each roadway.

QUICK REFERENCES FOR THE SELECTION OF MOBILE AND SHORT DURATION TRAFFIC CONTROL PLANS

Tables 26 and 27 are quick references that direct maintenance personnel to the appropriate traffic control plan(s) for mobile and short duration operations, respectively. These tables include the maintenance traffic control plans developed during this project, as well as existing traffic control plans.

Table 26. Quick Reference Table for Selecting Mobile Maintenance Traffic Control Plans.

Type of Mobile Operation	Type of Roadway			
	Two-Lane, Two-Way	Multilane Undivided	Multilane Divided	Freeway
Core Sampling	MNT(3-3)-04	MNT(3-3)-04	MNT(3-4)-04	MNT(3-4)-04
Herbicide	MNT(3-3)-04	MNT(3-3)-04	MNT(3-4)-04	MNT(3-4)-04
In-Lane Rumble Strips	NA	MNT(3-5)-04	NA	NA
Retroreflectivity Measurements	MNT(3-3)-04	MNT(3-3)-04	MNT(3-4)-04	MNT(3-4)-04
RPM Installation/Removal	MNT(3-1)-04	MNT(3-1)-04	MNT(3-2)-04	MNT(3-2)-04
Short-Line Striping	NA	MNT(3-5)-04	NA	NA
Shoulder Texture	MNT(3-1)-04	MNT(3-1)-04	MNT(3-2)-04	MNT(3-2)-04
Spot Edge Repair	MNT(3-3)-04	MNT(3-3)-04	MNT(3-4)-04	MNT(3-4)-04
Spot Pothole Patching	MNT(3-3)-04	MNT(3-3)-04	MNT(3-4)-04	MNT(3-4)-04
Striping	MNT(3-1)-04	MNT(3-1)-04	MNT(3-2)-04	MNT(3-2)-04
Sweeping	MNT(3-3)-04	MNT(3-3)-04	MNT(3-4)-04	MNT(3-4)-04
Tab Placement/Removal	MNT(3-3)-04	MNT(3-3)-04	MNT(3-4)-04	MNT(3-4)-04

NA – Not applicable

SUMMARY

Based on existing TxDOT traffic control plans, field observations of mobile and short duration operations conducted during the first year of this research project, findings from the second year of this research project, and input from the advisory panel, researchers:

- recommended changes to the existing work duration definitions to help maintenance personnel distinguish between mobile and short duration operations,
- developed maintenance traffic control plans for select mobile and short duration operations,
- developed guidance for the use of trail and shadow vehicles for selected operations based on the roadway volume (ADT) and posted speed, and

- developed quick reference tables that direct maintenance personnel to the appropriate mobile and short duration practice(s).

Table 27. Quick Reference Table for Selecting Short Duration Maintenance Traffic Control Plans.

Type of Mobile Operation	Type of Roadway			
	Two-Lane, Two-Way	**Multilane Undivided**	**Multilane Divided**	**Freeway**
Core Sampling	TCP(1-2)-98 TCP(1-3)-98 TCP(2-2)-03	TCP(1-4)-98	TCP(6-1)-98A thru TCP(6-6)-98A	TCP(6-1)-98A thru TCP(6-6)-98A
Delineator Maintenance	MNT(3-6)-04 TCP(1-2)-98 TCP(1-3)-98 TCP(2-2)-03	MNT(3-6)-04 TCP(1-4)-98	MNT(3-6)-04 TCP(6-1)-98A thru TCP(6-6)-98A	MNT(3-6)-04 TCP(6-1)-98A thru TCP(6-6)-98A
Lighting Maintenance	MNT(3-6)-04 TCP(1-2)-98 TCP(1-3)-98 TCP(2-2)-03	MNT(3-6)-04 TCP(1-4)-98	MNT(3-6)-04 TCP(6-1)-98A thru TCP(6-6)-98A	MNT(3-6)-04 TCP(6-1)-98A thru TCP(6-6)-98A
In-Lane Rumble Strips	TCP(1-2)-98 TCP(1-3)-98 TCP(2-2)-03	TCP(1-4)-98	TCP(6-1)-98A thru TCP(6-6)-98A	NA
Short-Line Striping	TCP(1-2)-98 TCP(1-3)-98 TCP(2-2)-03	TCP(1-4)-98	TCP(6-1)-98A thru TCP(6-6)-98A	TCP(6-1)-98A thru TCP(6-6)-98A
Sign Maintenance	MNT(3-6)-04 TCP(1-2)-98 TCP(1-3)-98 TCP(2-2)-03	MNT(3-6)-04 TCP(1-4)-98	MNT(3-6)-04 TCP(6-1)-98A thru TCP(6-6)-98A	MNT(3-6)-04 TCP(6-1)-98A thru TCP(6-6)-98A
Signal Maintenance	WZ(BTS-1)-03 WZ(BTS-2)-03	WZ(BTS-1)-03 WZ(BTS-2)-03	WZ(BTS-1)-03 WZ(BTS-2)-03	NA

NA – Not applicable

CHAPTER 8:
SUMMARY AND RECOMMENDATIONS

Researchers conducted a synthesis of previous research, three focus groups, 241 motorist surveys, and a field study to assess motorist comprehension and the operational effectiveness of current and innovative traffic control devices used to inform motorists about:

- the number of vehicles in a work convoy,
- the speed differential between the work convoy and traffic,
- passing a work convoy on two-lane, two-way roadways with unimproved shoulders,
- passing a work convoy on two-lane, two-way roadways with improved shoulders, and
- the LANE BLOCKED sign.

Based on the results of these activities, researchers recommend the following traffic control devices to improve the safety of mobile work zone operations. These recommendations should be incorporated into the Texas MUTCD and TxDOT traffic control plans for mobile operations.

- The # VEHICLE CONVOY sign should be used instead of the WORK CONVOY sign. The number needs to be adjustable and easy to change. The recommended design of the sign is shown in Figure 27.
- On two-way roadways, the DO NOT PASS sign (R4-1) should be placed on the rear of the trail vehicle when motorists are not allowed to pass the work convoy.
- The LANE BLOCKED sign (FCW20-6) should be required on divided highways with four or more lanes in each direction.
- A PCMS can be substituted for the LANE BLOCKED sign (FCW20-6) on divided highways with three or less lanes in each direction. TxDOT should require the use of the PCMS messages shown in Figure 31 and a minimum letter height of 12 inches.

In addition, researchers recommend the use of the following items, developed as part of this research project, to improve the safety of mobile and short duration operations:

- maintenance traffic control plans for the selected operations (Figures 32 through 37),
- guidance for the use of trail and shadow vehicles for selected operations based on the roadway volume (ADT) and posted speed (Tables 24 and 25), and
- quick reference tables that direct maintenance personnel to the appropriate mobile and short duration practice(s) (Tables 26 and 27).

Researchers also recommend the following changes to the work duration definitions used in the Texas MUTCD and TxDOT *Traffic Control Plan Standard Sheets* to help distinguish between the types of operations (deletions are shown as strikeouts and additions are underlined):

- Mobile is ~~work~~ a temporary traffic control zone that moves intermittently (stops up to 15 minutes) or continuously.
- Short duration stationary is ~~work~~ a temporary traffic control zone that occupies a location up to 1 hour.

- Short-term stationary is a daytime ~~work~~ temporary traffic control zone that occupies a location for more than 1 hour, but less than 12 hours.
- Intermediate-term stationary is ~~work~~ a temporary traffic control zone that occupies a location more than one daylight period up to 3 days, or nighttime work lasting more than 1 hour.
- Long-term stationary is ~~work~~ a temporary traffic control zone that occupies a location more than 3 days.

Based on the findings of this research, researchers do not recommend the use of:

- the MOVING VEHICLES and MOVING OPERATION signs to inform motorists that there are multiple work vehicles in the roadway,
- the MY SPEED display to inform motorists about the speed of the work vehicles in a mobile operation,
- the YOUR SPEED/MY SPEED to inform motorists about their speed and the speed of the work vehicles in a mobile operation,
- the use of the word "slow" to describe the speed of mobile operations, and
- the PASS ON SHOULDER message on a truck-mounted CMS to reiterate the desired motorist action (i.e., to pass the work vehicles to the right on the improved shoulder) on a two-lane, two-way roadway with improved shoulders.

Future research should evaluate the potential of:

- the YOUR SPEED display to yield operational effects (e.g., alert motorists, decrease approach speeds, etc.) that increase the safety of mobile operations,
- the ME speed display to inform motorists about the speed of the work vehicles in a mobile operation,
- the 3 MOVING VEHICLES sign to inform motorists that they are approaching multiple work vehicles and that these work vehicles are moving at low speeds, and
- the use of PCMS located on the shoulder upstream of the mobile operation (similar to the LANE BLOCKED sign for mobile operations on divided highways) to display alternative messages that inform motorists to pass the work vehicles to the right on two-lane, two-way roadways with improved shoulders.

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APPENDIX: ADVISORY PANEL PARTICIPANTS

Table A1. Advisory Panel Participants.

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Russel Lenz	TxDOT Waco District
Terry Sams	TxDOT Dallas District
Doug Skowronek	TxDOT Traffic Operations Division
Brian Stanford	TxDOT Traffic Operations Division
Jerral Wyer	TxDOT Occupational Safety Division
Chad England	N-Line Construction
Wayne Culpepper	N-Line Construction
Danny Long	Striping Technologies

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