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16. Abstract:

The goal of this project was to develop implementation guidance that the Texas Department of Transportation (TxDOT) can use to make better decisions regarding the use of truck mounted changeable message signs (TMCMS) during scheduled and unscheduled operations. The objectives of the project were as follows:

1. Perform a nationwide survey with practitioners to determine the state-of-the-practice with regard to TMCMS and to identify what issues or hazards scheduled and unscheduled operations crews are encountering with regard to the motoring public.
2. Develop messages and application alternatives through the use of text or symbol combinations to address specific scenarios.
3. Conduct human factors comprehension studies.
4. Conduct field studies to determine the most promising message and application alternatives.
5. Develop guidelines to address the issues of design and application for the use of TMCMS.

This project identified the types of messages/information that could be displayed on TMCMS for different situations, and also developed specific guidance for TxDOT on the use of TMCMS during scheduled and unscheduled operations.

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ASSESSMENT OF NEED AND FEASIBILITY OF TRUCK-MOUNTED CHANGEABLE MESSAGE SIGNS (CMS) FOR SCHEDULED AND UNSCHEDULED OPERATIONS: TECHNICAL REPORT

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DISCLAIMER

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- Frank Philips, TxDOT, Lubbock District - Project Advisor.
- Bart Sherrill, TxDOT, Childress District - Project Advisor.
- Janet Manley, TxDOT, Beaumont District - Project Advisor.
- Brent Foard, TxDOT, Childress District - Project Advisor.
- Jianming Ma, TxDOT, Traffic Operations Division - Project Advisor.
- Wade Odell, TxDOT, Research and Technology Implementation Office – Research Engineer.

The authors also appreciate the following important contributions to the research team:

- Mr. Victor Pinon, Jr., (Director of Maintenance, TxDOT Corpus Christi District) and his staff for assisting in the field study evaluations.
- Mr. Jim Jennings (TxDOT Roadway Maintenance Supervisor - Corpus Christi Maintenance Office) and his staff for providing complete support during the field study evaluations.

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INTRODUCTION

PROBLEM STATEMENT

All work areas on roadways create unexpected conditions for motorists. However, operations where work is only present at any one location for a very short time (e.g., pothole patching, guardrail repair, sweeping, snow/ice removal, incident management) are particularly challenging to highway agencies tasked with ensuring safe and efficient travel approaching and passing these operations. Setting up and removing the temporary traffic control zone in short-duration work or mobile work often take longer time than performing the work (*1*). Traditionally, temporary traffic control for mobile and short duration operations has been limited to arrow panels (i.e., directional arrows and four-corner caution) and static warning messages mounted to the back of the first work vehicle for the operation.

The use of warning signs in advance of the work operation is usually not practical due to the nature of the work, typically either continuously moving, stop-and-go movement, or short duration. It is possible that motorist safety approaching all or certain types of scheduled and unscheduled operations could be improved if better information was provided to drivers about the operation they will be encountering. Additional information provided to drivers could also improve motorist compliance and reaction in these unexpected circumstances. Unfortunately, many of the established devices to be used for such purposes, most specifically portable changeable message signs (PCMS), are not practical for application to mobile or very short duration activities as the deployment of such equipment in the area of the work would take as long or longer than the operation itself.

Truck-mounted changeable message signs (TMCMS) are a technology that may be used to improve driver understanding of the specific hazards and desired responses to various types of scheduled and unscheduled operations without adding the burden of extra equipment deployment. TMCMS could be utilized in much the same manner as trailer-mounted PCMS, which have been in use to supplement temporary traffic control at work operations for many years. For mobile or very short duration operations, TMCMS could be used either on a shadow vehicle that would follow the work vehicles or, when a shadow vehicle is not present, on the work vehicle itself as an added warning and information source to drivers of the conditions.

The temporary traffic control (TTC) required for most long-term work operations is relatively extensive, especially on high-speed and high-volume roadways, in order to provide motorists with information necessary for them to make informed and safe driving decisions near or in the work area (*1*). In contrast, mobile and short duration work operation TTC is fairly minimal because of the difficulties in moving advance warning signs or the limited time frame of the operation. The use of TMCMS that are easily move along a roadway with the crew and which do not require additional setup time are a very attractive option in presenting information. However, questions as to what information can and should be displayed, how much information can be presented to a driver in this format, and other issues associated with their use have not been fully identified or evaluated in past research.

PROJECT OBJECTIVES

The goal of this project was to develop implementation guidance that the Texas Department of Transportation (TxDOT) can use to make better decisions regarding the use of TMCMS during scheduled and unscheduled operations. The objectives of the project were as follows:

1. Perform a nationwide survey with practitioners to determine the state-of-the-practice with regard to TMCMS and to identify what issues or hazards scheduled and unscheduled operations crews are encountering with regard to the motoring public.
2. Develop messages and application alternatives through the use of text or symbol combinations to address specific scenarios.
3. Conduct human factors comprehension studies.
4. Conduct field studies to determine the most promising message and application alternatives.
5. Develop guidelines to address the issues of design and application for the use of TMCMS.

CONTENTS OF THE REPORT

The next two chapters of this report provide background on current research and nationwide survey results of the practices regarding the use of portable changeable message signs. The methodology and results of analyses performed to develop messages and application alternatives and human factors and field study investigations are then incorporated into the next three chapters of this report. The final chapter provides a summary of the conclusions and recommendations. A nationwide survey questionnaire, field data collection sites, and recommended implementation guidelines are provided as appendices.

BACKGROUND

Researchers conducted a comprehensive review of TMCMS with consideration of (1) TMCMS implementation in different departments of transportation (DOTs) and countries; (2) gaps/problems reported by transportation agencies on the use of TMCMS; (3) scheduled and unscheduled operations dealt with by DOTs; and (4) manufacturers that provide TMCMS. A list of references collected and reviewed is shown in this report.

Changeable Message Sings (CMSs) have several significant advantages over static signs as they pertain to work zone applications. First and foremost, they tend to have a higher target value (especially those that utilize light-emitting diodes [LEDs] or other light-emitting technologies) and so generally attract more motorist attention to the information being displayed. Secondly, they can be programmed to display any message that an operator wishes to show, and so the message can be specifically tailored to each particular situation where it is applied. In a study by Dudek et al. (*2*) on PCMS, researchers found that a single PCMS displayed 1500 ft upstream of a short duration work zone on a suburban interstate facility resulted in better driver response (measured in terms of earlier lane-changing out of the closed lane) than a standard Temporary Traffic Control (TTC) set up for a stationary lane closure.

Due to the space limitations inherent in TMCMS use, the incorporation of symbols through a full-matrix display is one alternative to allow for providing more concise information to a motorist. Limited research has been conducted on the use of symbols for CMS (*3*). Many symbols are displayed on CMSs in Europe including a number of regulatory and warning messages. In addition, symbols are used (by international agreement) to inform drivers of situations that adversely affect their travel (e.g., crash, congestion or queue, fog, slippery road, oncoming vehicle). These symbols on CMSs are identified to have the similar positives as symbols on static signs. These advantages, as outlined by previous research, include (*3, 4, 5, 6*):

- The signs are more legible for a given size and at shorter exposure durations.
- The signs are more easily recognizable when the information is degraded due to poor environmental legibility.

- Drivers can extract information more quickly from symbols and pictographs than word messages.
- Drivers who have difficulty understanding text messages are able to comprehend pictographs.

However, these advantages do not automatically mean that TMCMS will always provide superior driver understanding and response for all types of operations and conditions. Previous research is extremely limited about TMCMS. Research performed by Finley et al. (*7*) on TMCMS examined various short-term and mobile operations and the best information dissemination for these types of operations, where a standard right arrow treatment was compared to an experimental treatment that utilized a truck-mounted CMS to provide the message PASS ON SHOULDER alternating with an arrow as illustrated in Figure 1. Researchers did not identify a significant change in behavior by the motorists when the CMS information was added to this situation (either positive or negative). Driver understanding of, or response to, other types of messages that could be displayed for various types of scheduled and unscheduled operations were not evaluated in that project. This illustrates the need for additional research to better determine the types of applications that TMCMS are best suited for, and highlights the importance of field evaluation in the development process.

Figure 1. Experimental Treatment (Source: (*7*)).

With regard to symbols on CMS, research has indicated that some symbols can cause comprehension problems for drivers who are not familiar with the design. One of the first studies on symbols was conducted in the Netherlands by Riemersma et al. (*8*). Symbols adopted from existing European static sign symbols as well as newly designed symbols were evaluated with regard to comprehension.

Alternative symbols for the following types of messages were studied: crash, roadwork, congestion or queue, fog, slippery road, two-way traffic, crosswinds, drawbridge, hydroplaning, skidding danger due to ice or snow, and reduced visibility due to rain or snow. The results indicated that the symbols for roadwork, congestion or queue, slippery road, two-way traffic, and drawbridge were adequate for use. The symbols tested for crash, skidding danger due to ice or snow, and reduced visibility due to rain or snow were less acceptable. The symbols for fog and hydroplaning were highly inadequate. For this reason, research is needed to identify what symbols would be appropriate for use on TMCMS and if or when different symbols would be appropriate.

Ullman et al. (*9*) performed research on the incorporation of symbolic arrow data as a means of identifying lane closures on PCMS near an interchange area and concluded that graphics-based PCMS may yield a better comprehension rate than an equivalent text-based PCMS message. Although, this evaluation was done with PCMS in mind, similar applications may be appropriate for TMCMS when attempting to identify closed lanes.

One of the major concerns and questions surrounding the use of TMCMS is the amount of information that can safely be provided to motorists in this format. Existing CMS message design guidance (*10*, *11*) addresses only traditional 3-line, 18-inch character signs and does not provide specific guidance on appropriate messages for TMCMS operations. TMCMS generally cannot present as much information as even a trailer-mounted PCMS because they must be fit on a vehicle. In most cases, it is possible to adjust the amount of information that can be displayed on a TMCMS, but this has significant ramifications on the ability of motorists to read and respond to the message. Smaller characters do not have as great of a legibility distance as larger characters when displayed on LED CMS, and this must be taken into consideration when determining appropriate messages to display on a TMCMS (*12*).

In summary, TMCMS do appear to offer significant opportunities to improve both motorist and worker safety at scheduled and unscheduled operations where traditional TTC support has been limited. However, there is a need for research to determine which types of operations and roadway conditions that this type of technology may be best suited for, and what messages or symbols should be displayed on this technology for the given work operation and roadway condition that would maximize motorist and worker safety.

ASSESSMENT OF TMCMS USE FOR SCHEDULED AND UNSCHEDULED OPERATIONS

The objectives of this task were as follows:

- To identify the state-of-the-practice for driver information during scheduled and unscheduled work activities of mobile and short duration operations and the need of TMCMS for both TxDOT and different state DOTs.
- To identify issues scheduled and unscheduled operations personnel are encountering in regard to motorists.

NATIONWIDE SURVEY WITH THE PRACTITIONERS

It is identified that the practitioners in the field have the experience on various issues of work activities that are marked as scheduled and unscheduled and are performed as either mobile or short duration operations. Therefore, a nationwide survey was performed through telephone and online formats with maintenance personnel and emergency coordinators, regarding situations where a TMCMS could provide benefits. The information collected through these surveys fed the remainder of the project with regard to the types of scenarios and conditions that were addressed through TMCMS.

DEVELOPMENT OF SURVEY INSTRUMENT

In order to conduct the interviews with practitioners, a structured questionnaire was developed and an example of the survey form used for this nationwide survey is provided in Appendix A. An online version of the questionnaire was also developed as a convenience to interviewees to complete the survey. Online surveys were conducted by sending an email to the practitioners of various DOTs, who were interested in participating in the survey online.

Each interview took about 20 minutes to finish on the phone. The research team conducted 130 interviews from 42 states, among which 16 interviews were from Texas. Figure 2 shows the number of interviews conducted with the practitioners through the nationwide survey.

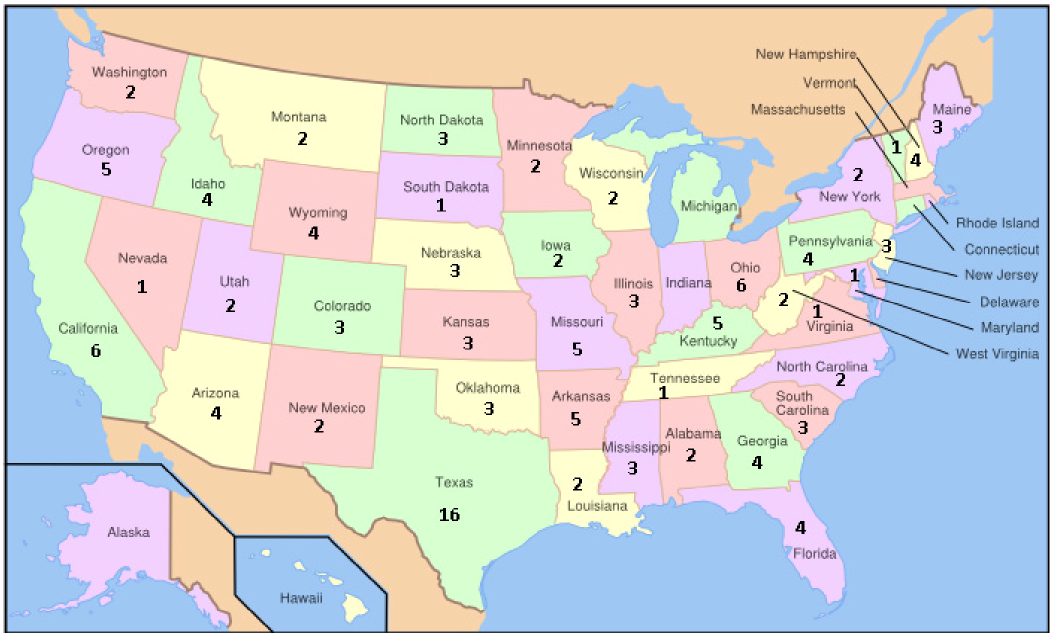


Figure 2. Nationwide Survey Map (with Number of Surveys from Each State).

SURVEY RESULTS

From this nationwide survey, it is identified that 42 percent of the interviewees have some experience of using TMCMS for different operations. Additionally, around 75 percent of interviewees opined that they want to use TMCMS most likely for unscheduled operations, because of its mobility and quick response. Interviewees believed that TMCMS are more adaptable in situations like emergency/accident response and construction and maintenance activities, including lane closures, striping, and other mobile operations.

The major problems and hazards reported by interviewees under scheduled and unscheduled operations on a two-lane, two-way highway include non-availability of shoulders to locate the message board, traffic congestion, and inattentiveness of the drivers. Problems reported for freeways consist of reduced visibility of the message board, thereby reducing motorist response time due to higher speeds and increased truck traffic.

TEXAS SURVEY RESULTS

Out of 130 surveys, 16 surveys are from TxDOT. Interviewees from various Texas districts include Amarillo, Childress, Dallas, Abilene, Fort Worth, Austin, Pharr, Paris, Brownwood, Lubbock, Laredo, Houston, Odessa, Wichita Falls, Atlanta, and San Antonio. Figure 3 shows the districts of Texas that responded to the questionnaire. The districts of Brownwood, San Antonio, Paris, Lubbock, and Odessa reported that they are currently using TMCMS for several operations.

In Texas, TMCMS are being used for operations such as emergency/accident response, lane closure/detour, debris removal, and nighttime maintenance operations. The major advantages reported by TMCMS users include easiness to respond, increased visibility during nighttime operations, and more protection to the worker. All of the 16 TxDOT district interviewees expressed their interests of using TMCMS for unscheduled operations and 12 interviewees also stated that they believed TMCMS could be used for scheduled operations. Some issues suggested to be addressed in future research include reducing the cost of the truck and maintenance and increasing the size of the message board.

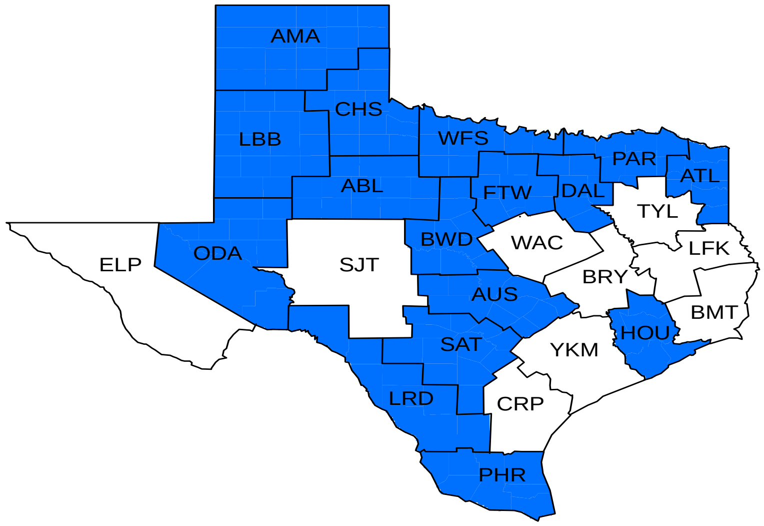


Figure 3. Districts Contacted in Texas (Blue Color).

SURVEY ANALYSIS

Out of the total 130 surveys, 42 percent of interviewees are using TMCMS and the rest (58 percent) are using trailer-mounted CMS or are satisfied with the stationary message signs.

Many interviewees suggested that both TMCMS and trailer-mounted CMS are used based on the necessity of the situation. Non-affordability of the trucks or preferences of trailer mounts are the reasons given for non-usage of TMCMS. It is reported by some TMCMS users that they either lease the truck for a certain amount of time or hand over such work contracts to a local agency, whenever needed.

FREQUENTLY USED TMCMS MESSAGES

TMCMS are used for various operations based on the need of the situation and availability of the resources. Specific operations reported by the interviewees include accidents, lane closures, traffic diversions, striping, bad weather conditions, natural disasters, and nighttime operations. However the percentage of TMCMS usage in such situations varies. The three major situations where the TMCMS are mostly used are emergencies, construction/maintenance work, and unexpected lane closures. The messages displayed on the TMCMS are situation based. Table 1 shows the most frequently used messages, as reported by the interviewees. ACCIDENT AHEAD/PREPARE TO STOP, DO NOT CROSS WET PAINT AHEAD, and TRAFFIC CONGESTION AHEAD are the most preferred messages as these messages take less space, convey more information, and are easily understood by travelers.

Table 1. Most Frequently Used Messages.

ACCIDENT AHEAD/PREPARE TO STOP	ROAD CLOSED AHEAD
DO NOT CROSS WET PAINT AHEAD	SWEEPING OPERATION AHEAD
TRAFFIC CONGESTION AHEAD	SNOW REMOVAL AHEAD

Researchers identified that the perceived benefits of using TMCMS are enhanced visibility of work activity and improved safety and mobility for both workers and the traveling public. Visibility during nighttime operations was considered very advantageous by practitioners as drivers can read the message from a long distance and it gives ample time to react to the situation. The second major advantage is safety, as TMCMS provide workers additional protection during mobile and short duration activities. The third major advantage is mobility, as TMCMS can display a message while either stationary until the work is complete, or while displaying the message while moving.

Seventy-one percent of interviewees reported that TMCMS can be a useful tool for various additional operations like guiding traffic in the right direction by using it as an advance warning indicator, for safety at bridge/road inspections, and also for amber alerts. However a few interviewees were of the opinion that TMCMS cannot be used for any other operations, as they think it is very expensive to purchase and maintain a specific truck just for installing the CMS, which displays very small messages compared to trailer-mounted CMS.

Fifty-three percent of interviewees think that many hazards/issues associated with either stationary or mobile operations can be addressed by the implementation of TMCMS, such as the non-availability of a location to set-up the message board, equipment issues (battery charge), and the message board being moved due to high wind speeds. In addition, TMCMS also captures the drivers' attention easily because of its height and appearance of the carrying truck. However, 60 interviewees suggested that TMCMS cannot resolve driver issues, as they think static signs are more useful and easier to use compared to TMCMS. They also suggested that they would need more guidelines in order to use TMCMS more frequently.

SCHEDULED AND UNSCHEDULED OPERATIONS

The major problems found for scheduled mobile operations on a two-lane, two-way highway are non-availability of shoulder lanes and traffic congestion. Other issues include safety of the flaggers and lack of attention to the message signs by the travelers. On the other hand, the major issues found for scheduled mobile operations on freeways are visibility of the message board, inattentive travelers and safety of the workers due to increased truck traffic, and higher traveling speed at night. Seventy-two percent of interviewees felt that TMCMS could address many safety issues and also captures the driver's attention easily through its brightly illuminated messages. However 36 interviewees do think that TMCMS cannot address these concerns.

The major problems found for unscheduled operations on two-lane highways are location of the message board, traffic congestion and accidents; whereas on freeways, the major issues are traffic congestion, high truck traffic, and inattentiveness of drivers. For unscheduled operations, 77 percent of the interviewees think that these issues could be addressed by using TMCMS compared to 29 interviewees who think TMCMS cannot resolve such issues.

Interviewees also suggested that further research is needed on the following topics:

- Visibility of TMCMS.
- Maintenance and durability of TMCMS.
- Costs effectiveness.
- User friendly interface.

The researchers developed a list of messages based on information identified through the earlier interviews. The researchers also considered the message phrases and graphics that are currently being used on TMCMS, and also the interviewee's recommendation on other potential work operations, which they believe TMCMS could be of use for situations like construction, sweeping, traffic control, and lane closures. The messages identified along with other alternative messages developed including symbol messages were evaluated through human factors and field study investigations. Table 2 and Table 3 show different messages, which have been prioritized for different operations based on interview results and recommendations.

Table 2. Display Message Alternatives for Stationary Operations.

RIGHT LANE CLOSED AHEAD	LEFT LANE CLOSED AHEAD
RGT LN CLSD	USE CAUTION
LEFT LANE CLOSED FOR MAINTENANCE	FORM ONE LINE RIGHT
LFT LN CLSD FOR MAINT	LANE CLOSURE SYMBOL
ARROW GRAPHICS SYMBOL	WATCH FOR WET PAINT

Table 3. Display Message Alternatives for Mobile Operations.

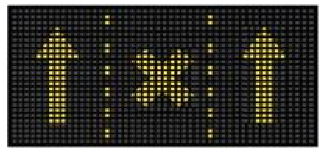
WORKERS ON FOOT	WATCH FOR WORKERS	WATCH FOR TRUCKS	SWEEPING AHEAD
REDUCED VISION	FOLLOW DETOUR	DEBRIS ON ROAD	SLOW DOWN

DEVELOPMENT OF TMCMS DISPLAY ALTERNATIVES

The objective of this task was to develop message and application alternatives to address identified situations where TMCMS could be beneficial. These alternatives focused on addressing motorist information needs through the use of text or symbol combinations. The practitioner interviews indicated that current state-of-the-practice is to use text. Although there has been previous research on the use of symbols on dynamics message signs by Ullman et al. (*13*), there has not been a lot of research performed in regards to the symbol messages on TMCMS. Therefore, researchers wanted to include symbol designs to identify how these may increase the benefit of TMCMS.

With this idea in mind, a group of symbol messages including an accident message were developed and included for experimentation in the study. Various scenarios were considered for both scheduled and unscheduled operations. Table 4 shows the alternative messages developed for various situations.

Table 4. Display Message Alternatives Developed for Various Operations.

Conditions	Alternatives	Alternatives	Alternatives
Striping			
Right Lane Closed			
Lane Blocked			
Maintenance Work			
Workers Out of Vehicle			
Accident			

HUMAN FACTORS ANALYSIS OF INFORMATION ALTERNATIVES

A human factors laboratory study was performed at different locations in Texas. The study was developed to determine motorists understanding of various TMCMS displays and investigated five topic areas:

1. Symbol versus text message to convey an accident condition.
2. Symbol versus text message to convey a roadwork condition.
3. Symbol versus text messages to convey lane blocked conditions.
4. Lane closure action statements.
5. Phrases that identify wet paint lane lines.

STUDY DESIGN

The study content consisted of five different types of human factors methodologies:

- Comprehension analysis.
- Response time analysis.
- Fixed time recall analysis.
- Wet paint lane line identification analysis.
- Preference analysis.

Due to the need to limit the amount of time required to participate in the study, researchers were not able to display each alternative display in every survey. Survey duration was limited to no more than 20 minutes per participant. Ultimately, 18 different versions of the survey were created. Each version contained 56 alternate displays. To remove the primacy bias, the sequence in which the messages were displayed was interchanged for various versions of the survey. A total of 252 surveys were performed during this laboratory study.

Comprehension Analysis

The comprehension portion of the study evaluated alternative messages or designs in four topic areas:

- Accident symbols.
- Roadwork symbols.

- Lane blocked symbols and text.
- Lane closure action statements.

Each alternative consisted of a single message phrase or symbol and was considered to be one unit of information. A total of 22 phrases were included in this portion of the study and each participant evaluated eight of these alternatives. The accident, roadwork, and lane closure action statement alternatives were evaluated on a four-lane facility, whereas the lane blocked information were evaluated on a six-lane facility. These facility types were selected so that research could assess driver understanding of alternatives conveying left, center, or right lanes during this study. During the comprehension task, the participant was told by a survey administrator the type of roadway they were to envision traveling on, and then an image was presented on the computer screen (example: Figure 4). While the image remained on the screen, participants were asked four questions about their driving decisions based on the message displayed.

1. As a driver, what is this message telling you?
2. What lane(s) would you drive in? Why do you think that?
3. How long would you drive in that lane? Why do you think that?
4. What lane(s) would you NOT drive in? Why?

The responses of the participants were written on an answer form.

Figure 4. Comprehension Task Image Examples by Roadway Type.

Response Time Analysis

The second methodology used in this study was a response time analysis. Research included the following topic areas in this portion of the study:

- Accident symbol and text.
- Roadwork symbols and text.
- Lane blocked symbols and text.

In this task, still images were presented to participants on the computer screen and would stay on the screen until the participant had selected either which lane was blocked or what activity (e.g., accident) was occurring (respective to the type of information being evaluated) based on the TMCMS display.

For the section where a participant needed to identify a specific type of work activity, a close up view of the TMCMS was used to display the message (Figure 5). While viewing this image the participants selected between four scenarios as to what information was being provided on the TMCMS:

- Congestion.
- Pedestrian.
- Accident.
- Work zone.

Researchers included the two distracter scenarios (congestion and pedestrian) to give participants a wider array of available responses. These particular events were selected based on hypothesized incorrect interpretations of the information displayed.

For the evaluation of the lane blocked alternatives, researchers used a full roadway view (Figure 5) and had participants identify which lane was blocked using the numbers displayed on the image. Prior to the lane blocked portion of the study, participants were instructed what roadway type would be seen for the next several images and that they would need to press a number on their response pad as soon as they determined which lane was not open.

In both of these evaluations, once the participant had selected a response, the next scenario image would immediately appear and they would repeat the selection process.

Activity Example Lane Blocked Example

Figure 5. Response Time Example Images.

Fixed Time Recall Analysis

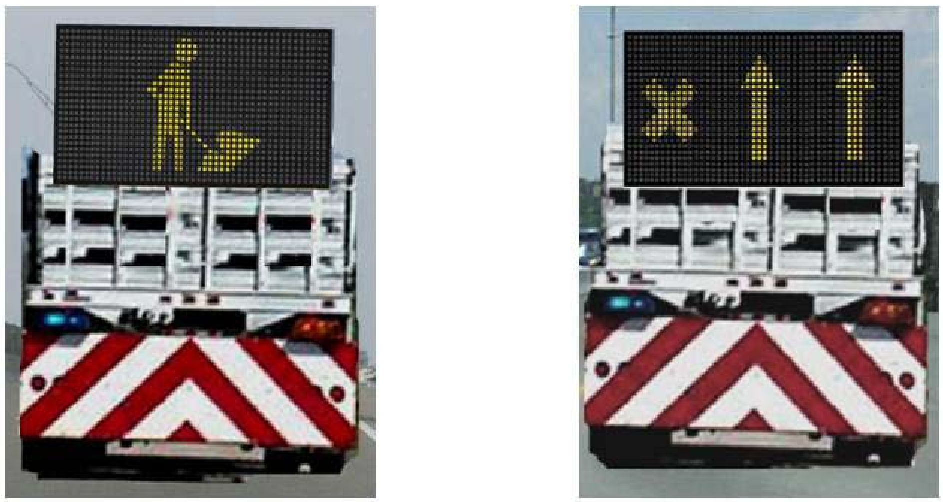
During the fixed time portion of the study, each treatment was preceded by a screen explaining the upcoming task the participant would need to perform. Once the participant understood the instructions, the computer was advanced to a still, close up image of each treatment (Figure 6). This image was displayed for a very short period of time and then was removed from the screen. Once the image was off the screen, participants were asked one of the following sets of two questions (respective to the type of information being displayed):

- For the lane blocked alternatives:

  1. Which lane(s) can you NOT drive in? (Lane 1, Lane 2, Lane 3, Lanes 1 & 2, Lanes 1 & 3, and Lanes 2 & 3.)
  2. Please indicate your confidence in your selection? (Scale of 1–5)

- For the activity alternatives:

    1. Select the number that represents the activity that you think was occurring. (1-congestion, 2-pedestrian, 3-accident, 4-work zone)
    2. Please indicate your confidence in your selection? (Scale of 1–5)



Event Example | **Lane Blocked Example**

Figure 6. Fixed Time Recall Image Examples.

In this research a range of exposure times for the treatments from 50–500 milliseconds were selected. The exposure times used for this study are shown in Table 5. The selection of these exposure times were based on a pilot evaluation that showed that higher exposure times (i.e., larger than 500 milliseconds) were not effective for this analysis as they were universally recognized independent of treatment. The exposure time assigned to each treatment was varied between the different survey instruments.

Table 5. Recall Task Exposure Times.

Exposure Time (milliseconds)	50	150	200	350	450	500
Increase Increment (milliseconds)	--	100	50	150	100	50

Wet Paint Lane Line Identification Analysis

The purpose of this section of the study was to determine motorists' ability to identify segments of the lane line that had been freshly painted given information provided on a TMCMS. The participants were shown an image of a truck with a TMCMS on a multi-lane divided highway or on a two-lane, two-way roadway. Figure 7 shows examples of the images used for this evaluation. As seen in the example images, a number was assigned to each painted line in the image as a way for participants to select specific lines. While the image remained on the screen, participants were asked to identify which line or lines had wet paint based on the information displayed. For both roadway types shown, participants' answer choices included:

- Lane Line 1.
- Lane Line 2.
- Lane Line 3.
- Lanes Lines 1 & 2.
- Lanes Lines 1 & 3.
- Lanes Lines 2 & 3.

For this study, researchers evaluated the following four messages for both roadway types:

- Yellow Line Wet.
- White Line Wet.
- Wet Edgeline.
- Wet Centerline.

Two-lane, Two-way Example

Multi-lane Example

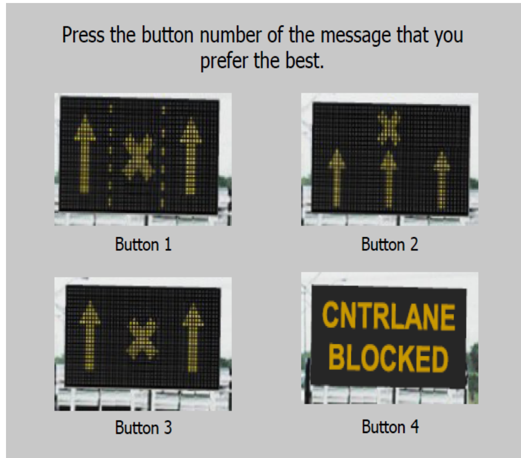
Figure 7. Wet Paint Lane Line Image Examples.

Preference Analysis

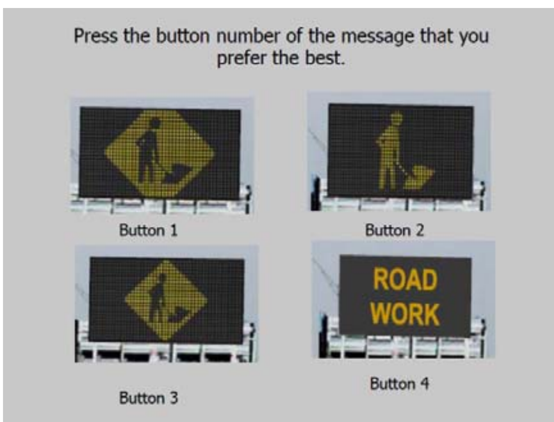
In the final section of the human factors study, participants were provided the opportunity to express which image, they preferred in regards to providing information about the following topics:

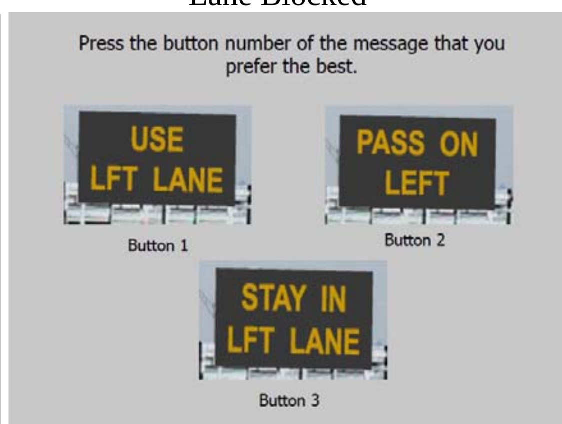
- Road work.
- Accidents.
- Lane blocked.
- Action statements.

Multiple images were shown simultaneously in each category and participants chose their preference by pressing the coordinating button on the response pad. Figure 8 provides a screen shot of the preference questions.



Accident Lane Blocked





Road Work Action Statement

Figure 8. Preference Selections.

SURVEY INSTRUMENT

To randomize the order in which participants saw the study treatments, three survey orders were created. Each survey had the same basic design including: eight comprehension images, 18 fixed time images, 18 response time images, eight wet paint lane lines identification images, and four preference selections. The survey was composed of 11 sections, with each section informing the participant what type of highway facility they were to be on (two lanes in the same direction, three lanes in the same direction, or two-lane, two-way). Additionally, sub-versions of each survey order were created to vary the exposure times assigned to the fixed time recall treatments. This resulted in a total of 18 different survey instruments.

SURVEY ADMINISTRATION

To administer the survey, a computer based stimulus presentation software package was used. This software allowed creating a series of events presented in a survey format to the participants. The software was loaded onto laptop computers that were selected to ensure that participants viewed the same monitor dimensions regardless of which computer they used. Each laptop used a response pad (Figure 9) to allow participants to enter their own responses to survey questions. The response pad had seven buttons side by side which allowed for a more simplified method of responding than a standard keyboard. It was noticed that using the response pad would minimize error in answering as well as make participants who were unfamiliar with computers more comfortable with the equipment. Exclusive of the comprehension portion of the survey, all survey questions were designed to be answered with a multiple choice response selected on the response pad.

Figure 9. Participant Response Pad.

During the comprehension analysis, researchers wanted to obtain participants' responses without introducing bias in the form of multiple-choice selections. Therefore, instead of using the response pad, participants were asked several open-ended questions for each treatment evaluated and the responses were recorded on an answer form.

STUDY LOCATIONS

Data were collected in two cities in Texas: Houston and Bryan. It was determined that 126 participants would be recruited at each location for a total of 252 participants.

PARTICIPANT RECRUITMENT

Participants were recruited at the Department of Public Safety Drivers License offices. Individuals were approached in the waiting room and asked if they would be willing to participate in a 15–20 minute computer survey regarding the use of truck mounted changeable message signs. A demographic sample of the Texas driving population based on age, gender, and education level was used as a guide for subject recruitment. Statistics regarding age and gender were obtained from the United States Department of Transportation – Federal Highway Administration Statistics for 2005. The education level statistics were based on Texas information from the United States Census Bureau, Community Survey 2006. Table 6 shows the demographic sample cross-referencing details in the state of Texas in parentheses. Additionally, in italics the actual sample of participants obtained during this study is indicated. As can be seen in Table 6, the sample obtained during data collection correlated very closely to the demographics developed for this study.

Table 6. Percentage of Survey Demographics (n=252).

	Education Level				
	High School Diploma or Less (49%)		**Some College (51%)**		
Age Category	**Male**	**Female**	**Male**	**Female**	**Total**
18–39 (44%)	(11) *11*	(11) *11*	(11) *10*	(11) *12*	(44) *44*
40–54 (31%)	(8) *7*	(7) *7*	(8) *9*	(8) *8*	(31) *31*
55+ (25%)	(6) *6*	(6) *5*	(7) *7*	(6) *7*	(25) *25*
Total	(25) *24*	(24) *23*	(26) *26*	(25) *27*	(100) *100*

LABORATORY SESSION PROTOCOL

The study set-up allowed for a total of three survey participants at any time. Before beginning the study, participants were informed the survey would last approximately 20 minutes and provided both a demographic and consent form to complete. Once the paperwork was finished, a general description of the study was provided along with instructions for answering survey questions using the response pad. Prior to the participant starting a new task for the first time, instructions were presented detailing the task and providing an example or practice run. The majority of the survey was self-administered; however, the comprehension sections were open ended questions that were asked and recorded by a researcher on an answer form. At the conclusion of the survey, participants were given an opportunity to ask questions and were compensated for their participation.

RESULTS

Symbol versus Text Message to Convey an Accident Condition

Comprehension Evaluation

Researchers investigated one accident image as seen in Figure 10. This symbol was selected based on previous research regarding accident symbols as one that had a good probability of success in being accurately interpreted by drivers. The ACCIDENT text message alternative was not included in the comprehension portion of this study as it has been proven through previous research, that drivers have an accurate understanding of this term.

Figure 10. Accident Symbol Display.

The results of the comprehension evaluation for the accident symbol are presented in Table 7 and Table 8. As seen in Table 7, the majority of participants viewing this image (84 percent) indicated that the symbol referred to an accident. However, it is interesting to note that the symbol was interpreted as “car being towed” by 9 percent of the participants and as a warning not to get too close to the work truck by 4 percent of the participants. It is believed that these results show an acceptable level of understanding for the symbol; however, more investigation was done on the participant responses to identify how participants might react to this image. For this analysis, researchers investigated the question of how long (if at all) a person felt they would need to drive in a different lane. Table 8 shows the results of this analysis.

Table 7. Accident Symbol Interpretation.

Interpretation	Percentage of Responses (n=252)
Accident	84
Car Towed	9
Do Not Follow Closely	4
Other	3

Table 8. Accident Symbol Lane Understanding.

Length of Time	Percentage of Responses (n=252)
Past accident or activity	93%
Unsure	3%
Other	4%

In this analysis, 93 percent of the participants believed they would need to drive in a different lane until they had passed the accident or current activity occurring in the lane with the truck shown. This result indicates that an additional 9 percent of participants who did not necessarily identify the correct event did still understand that they needed to go around this vehicle due to an upcoming incident or concern. This further assures that this graphic would have the desired effect on traffic of having motorists leave the affected lane prior to an incident.

Timed Identification

During this study, research also evaluated the response time of participants to both the accident symbol shown in Figure 10 and to the text ACCIDENT. Additionally, researchers also conducted a fixed time recall study that displayed the image for a short time and then asked the participant to identify the activity. Figure 11 and Figure 12 show the results of these evaluations.

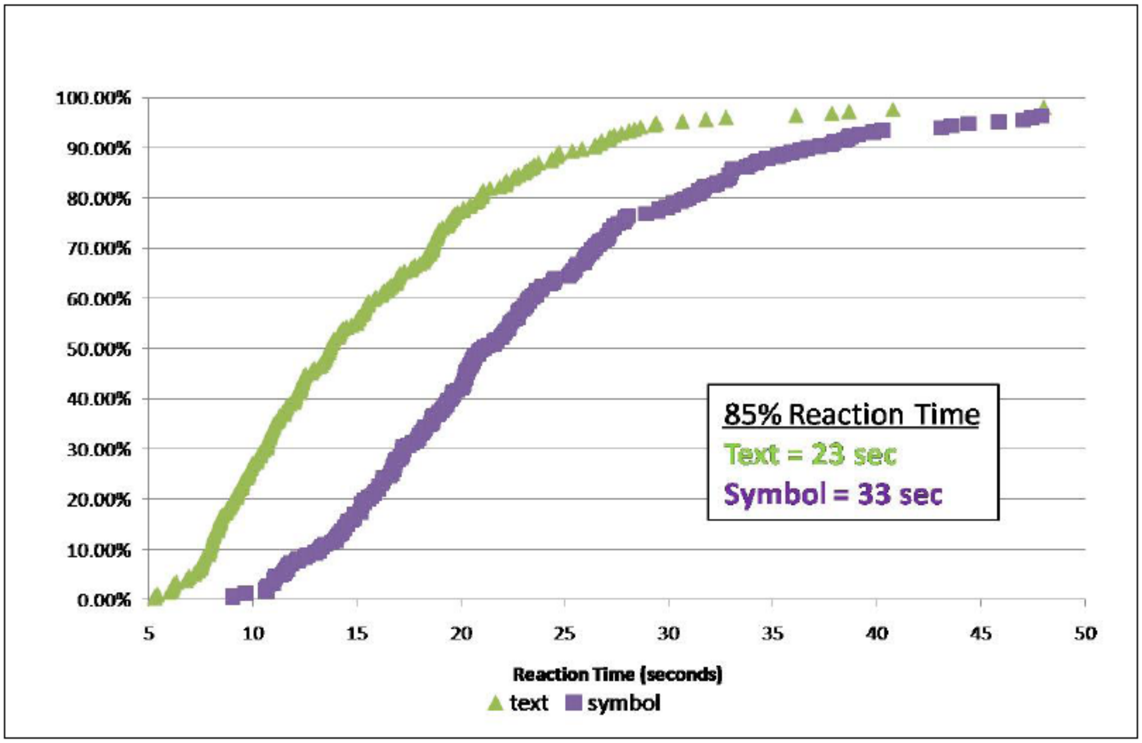


Figure 11. Reaction Time Task – Accident Comparison.

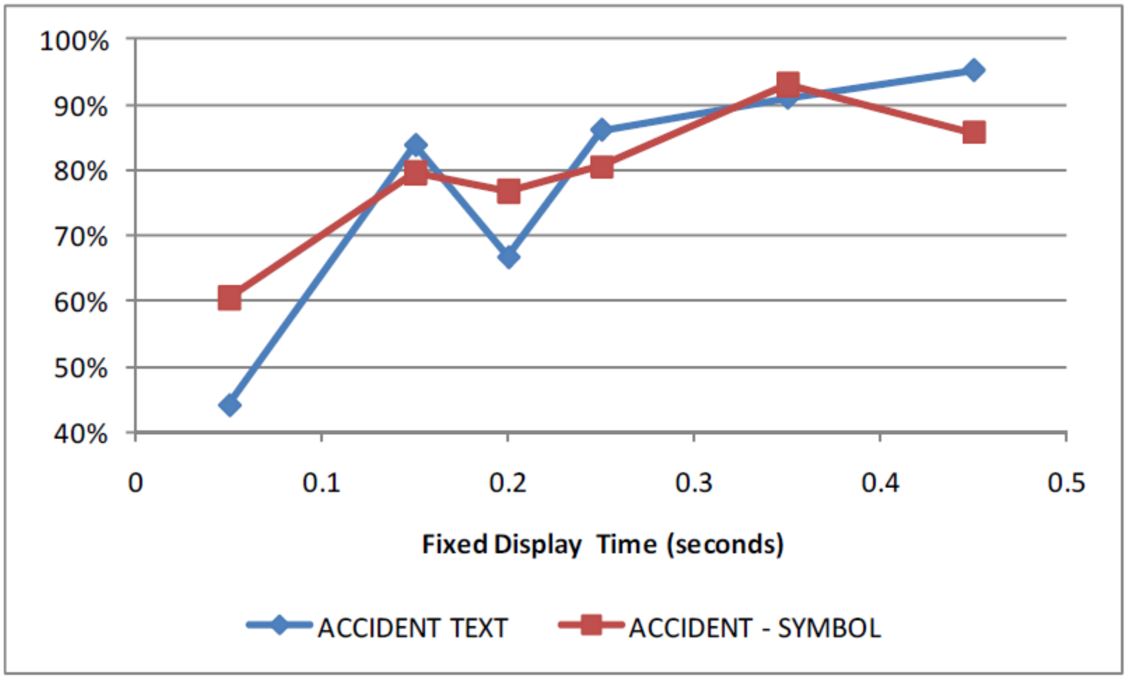


Figure 12. Recall Task – Accident Comparison.

Taking these two different timed experiments together, research identified a few key points with regard to the motorist identification of the accident symbol compared to text. First, given all the time they required (or desired), participants more quickly responded to the traditional text form of this information. However, when times were reduced for the fixed time recall task to very short increments (0.05–0.15 seconds) participants were better able to recall the symbol portraying this event than the text.

Preference

As a final step in the evaluation of this accident symbol, participants were asked to select their preference for the identification of an incident in the lane: symbol versus text. As shown in Table 9 over half of the participants (63 percent) selected the accident text message over the accident symbol message with only 37 percent. However, the text messages used in the survey seemed to be brighter and clearer on the computer screen. With this in mind this difference in screen appearance could have influenced the participant’s preference selection.

Table 9. Preference for Accident Information.

Message Displayed	Percent (n=252)
Text	63
Symbol	37

Accident Recommendation

Based on the cumulative results of the accident symbol versus text evaluation, researchers believe that there are benefits to displaying an accident symbol when available viewing or visibility times are very short. Furthermore, the researchers believe that the symbol evaluated as part of this research would be appropriate for use on TMCMS.

Symbol versus Text Message to Convey a Road Work Condition

Comprehension Evaluation

Research evaluated three road work symbols shown on TMCMS on a multi-lane roadway as shown in Figure 13. In the comprehension task, researchers eliminated the text alternative based on previous research experience that identified the term “road work” as being sufficiently understood by drivers. Additionally, each participant only evaluated one of the three symbol alternatives for comprehension. These two steps were taken to minimize the number of treatments that each participant viewed and to minimize bias.

Roadwork Symbol 1 **Roadwork Symbol 2** **Roadwork Symbol 3**

Figure 13. Road Work Symbols.

The comprehension results for each of these alternatives are shown in Table 10. As can be seen in this table, all three of the alternatives were understood to mean “road work” at a very high level (99–100 percent). Based on these results, any of the three alternatives evaluated could be used to represent road work on a TMCMS.

Table 10. Road Work Symbol Comprehension.

Interpretation	Percentage of Responses (n=84)		
	Symbol 1	Symbol 2	Symbol 3
Road Work	100	99	99
Unsure		1	
Pedestrian			1

Timed Identification

As all of the symbols were well understood, it was further tried to identify if there were any differences between the symbols with regard to response or fixed time recall ability. The results of these two evaluations are displayed in Figure 14 and Figure 15.

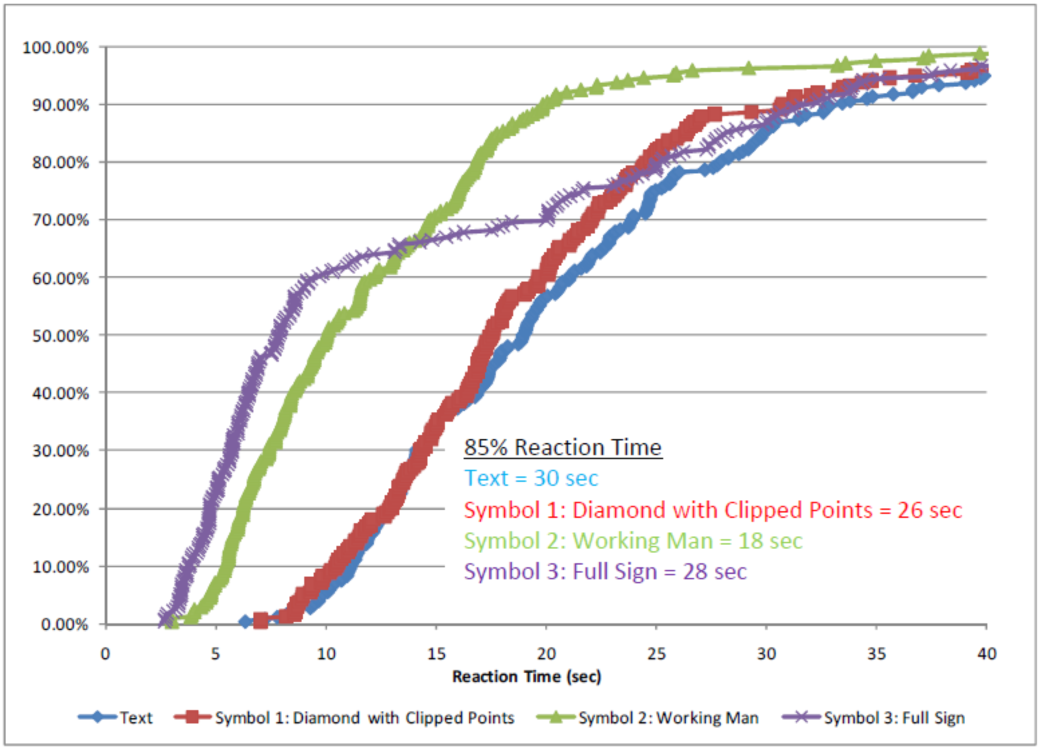


Figure 14. Reaction Time Task – Road Work Comparison.

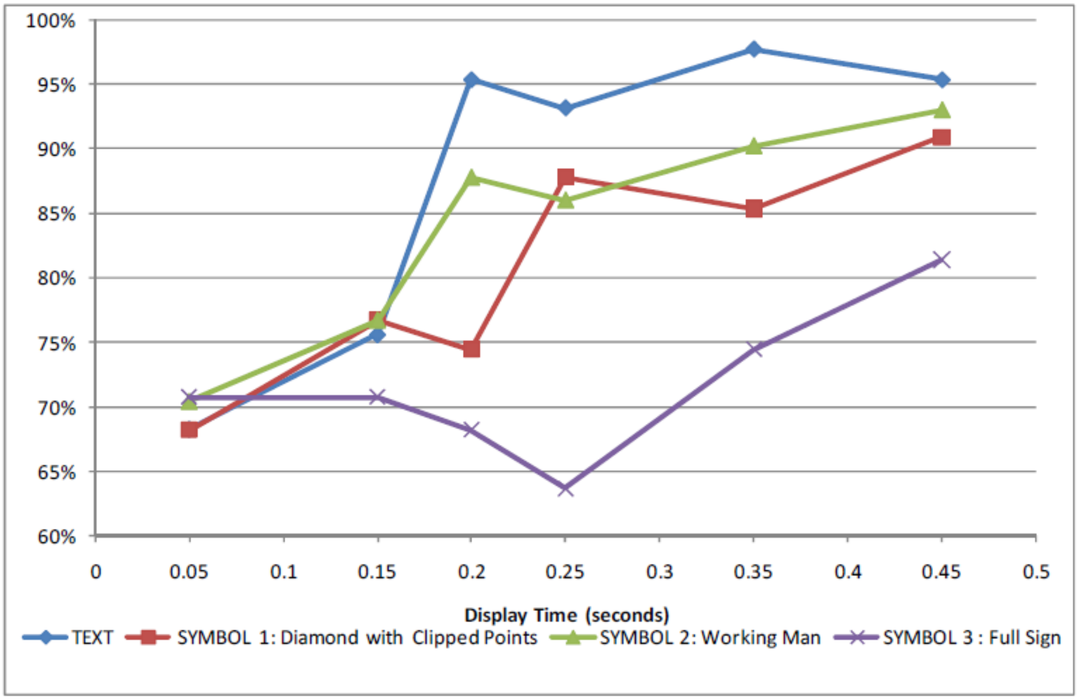


Figure 15. Recall Task – Road Work Comparison.

From looking at these two figures, it can quickly be seen that the results of the two timed studies were not consistent. First, when motorists were allowed unlimited time to react to the road work information, the best performing of the alternatives was symbol 2, the Man Working symbol. Research attributes this result to the fact that this symbol had the least amount of visual information that the participant needed to process before responding (i.e., did not include a sign outline that needed to be interpreted) and that the positive contrast of the Man Working figure in this image shortened participant identification time.

However, when a limited time experiment was performed, the text version of this information had the highest correct recall for the longer time periods. This result may be attributable to familiarity with this text as a display on dynamic message signs (DMS) as compared to the symbols evaluated. Additionally, at the smaller time increments of the study (below 0.2 sec) there was no discernable difference between the four alternatives.

Preference

Researchers conducted a preference comparison of the four alternatives identified to represent road work. The results of this comparison are shown in Table 11. Over half of the participants (61 percent) selected the text message as the best description for this activity. The symbol displaying the larger standard road work sign (symbol 1) was chosen second with 28 percent. The other two symbols reviewed were selected by 6 or less percent of the participants. Again, the lack of symbol message selections could have been influenced by the way they appeared on the computer screen compared to the clearer and brighter text message display. In addition, driver familiarity with the overall shape of symbol 1 (even with the sign points clipped) may have led many participants to select it over the less familiar symbol 2.

Table 11. Preference for Road Work Information.

Message Displayed	Percent (n=252)
Symbol 1 	28
Symbol 2 	6
Symbol 3 	5
Text 	61

Road Work Recommendations

Based on the cumulative results of these studies regarding the identification of road work, researchers believe that any variation on the traditional Man Working symbol would be well understood by participants. However, due to an increase in reaction time researchers feel that the symbol without the sign outline would be the best to implement.

Symbol versus Text Message to Convey Lane Blocked Information

Comprehension

Participants were asked to interpret both text and symbols indicating that a lane was blocked. Regarding the symbols indicating lane blocked, there were three alternatives shown (Figure 16). The first of these symbols was based on the current static lane blocked sign design that can currently be used by TxDOT for temporary traffic control and on previous research. From this original graphic, two different alternatives were created to determine if an improvement in comprehension could be gained through the addition of either an arrow in the blocked lane (Symbol 2) or dashed lines representing lane lines (Symbol 3).

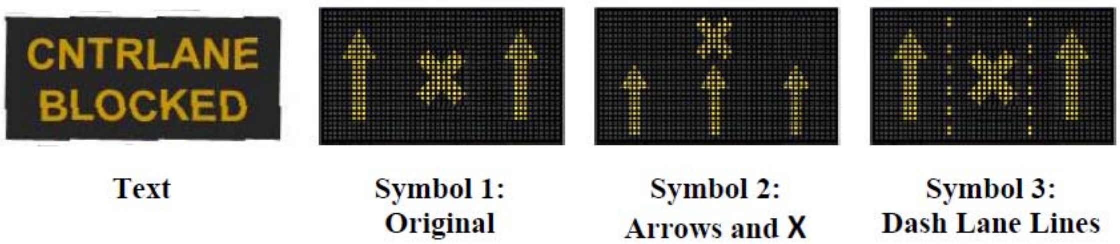


Figure 16. Lane Blocked Image.

Table 12 shows the comprehension results for each of the four alternatives evaluated. As expected, the overwhelming majority of participants correctly interpreted both the text and symbol images to mean lane blocked (all treatments greater than 90 percent). Consequently, the modifications shown in symbols 2 and 3 did not provide a significant improvement in terms of comprehension over the more basic symbol 1.

Table 12. Lane Blocked Information – Comprehension.

Interpretation	Percentage of Responses			
	Symbol 1 (n=252)	Symbol 2 (n=252)	Symbol 3 (n=252)	Text (n=168)
Lane Blocked	97	92	99	100
Other	3	3	1	
Unsure		5		

Next researchers looked at all of these alternatives in relation to how drivers would react to the image. The results of how long a driver felt they should stay out of the blocked lane are shown in Table 13.

Table 13. Lane Blocked Information – Action.

Interpretation	Percentage of Responses			
	Symbol 1 (n=252)	Symbol 2 (n=252)	Symbol 3 (n=252)	Text (n=168)
Past Work/Activity in Lane	82	87	84	85
Until Destination	16	11	14	13
Other	1	1	1	1
Unsure	1	1	1	1

Over 80 percent of responses for text and symbols indicated they would pass all work activity or watch until it was clear/safe before returning to original driving lane. There was no significant difference between the alternatives as to the action drivers would take. The only other response to garner a notable portion of the responses (between 11 and 16 percent for each alternative) was that the driver would stay in the lane they moved to until their destination. It was believed that this alternate response was an example of how drivers do not desire to change lanes more than necessary during their trip.

Based on the results of both of these studies research believes that any of the alternatives evaluated in this study would be effective with regard to motorist understanding of the information.

Timed Identification

As all of the alternatives were well understood, it was further tried to identify if there were any differences with regard to response or fixed time recall ability. The results of these two evaluations are shown in Figure 17 and Figure 18.

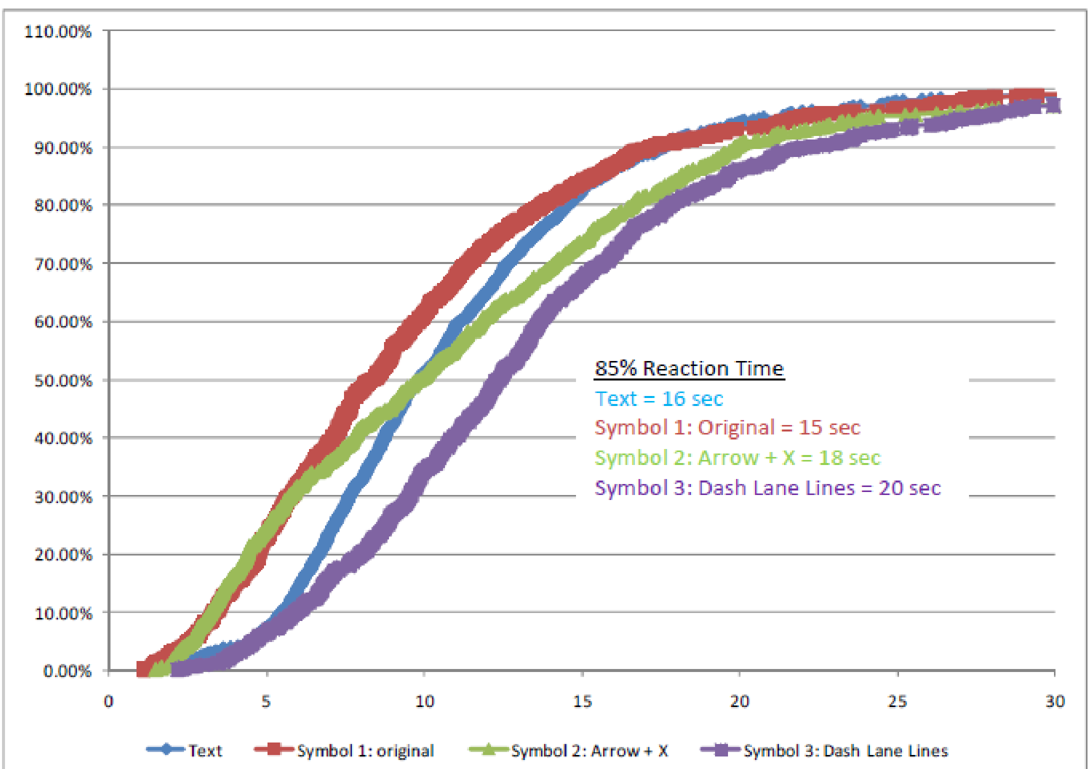


Figure 17. Reaction Time Task – Lane Blocked Information.

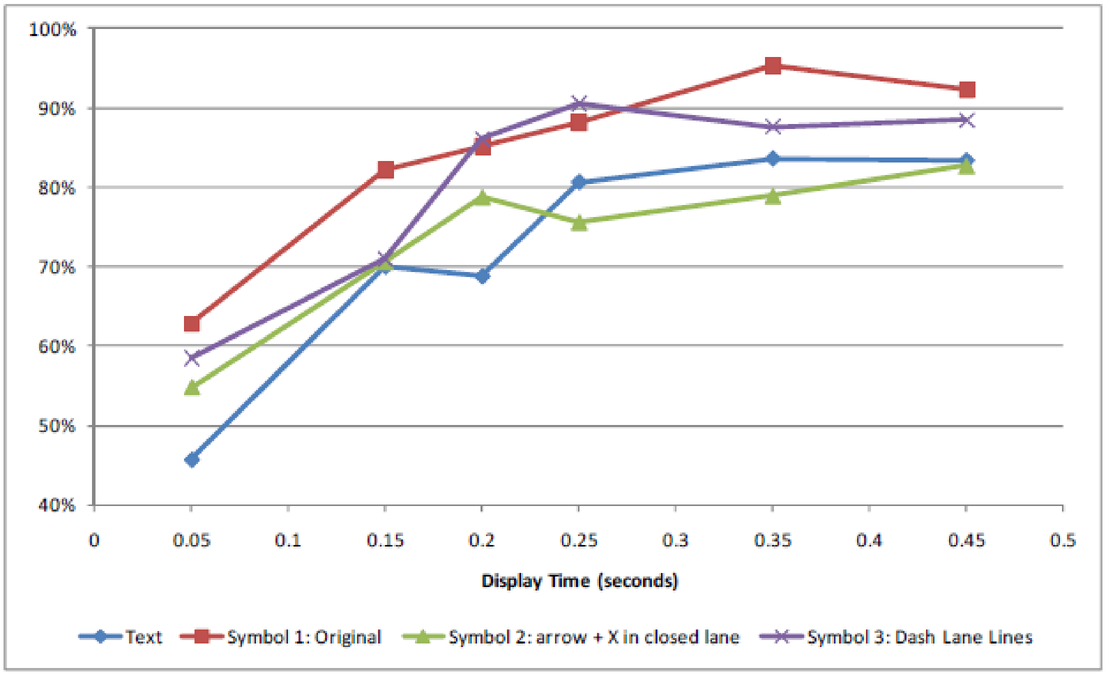


Figure 18. Fixed Time Recall Task – Lane Blocked Information.

In this scenario, the reaction time information for the lane blocked alternatives garnered no significant difference that would indicate one (or more) of these alternatives was decidedly better or worse than the others. However, in examining the fixed time recall information, researchers noted that the first symbol (the original lane blocked sign recreation) was recalled for the most part higher than the other alternatives. This was followed closest by Symbol 3, which included the dash lane lines.

Preference

Table 14 shows that 56 percent of the participants felt that the lane blocked symbol with dash lines best described the situation. The lane blocked text was selected by 31 percent of the participants. The least selected message was the lane blocked symbol with an arrow over the closed lane. This concurs with comments received in the comprehension section that indicated some confusion by the participants, expressing that all three lanes were open to travel.

Table 14. Preference for Lane Blocked Alternatives.

Message Displayed		Percent (n=252)
Text		31
Symbol 1		8
Symbol 2		5
Symbol 3		56

Lane Closure Action Statements

Comprehension

A comprehension analysis of three action statement phrases was conducted in this section of the study. The phrases were (with “XX” being left or right):

- Stay In XX Lane.
- Use XX Lane.
- Pass On XX.

Table 15 shows the participant interpretations for each of these phrases. Each of these terms was well understood as providing information about what lane a driver should or should not use as they approach the vehicle with the TMCMS. However, given the slight wavering in responses for the “Pass On XX” alternative, it was felt that the first two alternatives may be better received by the public.

Table 15. Action Statement Comprehension.

Interpretation	Percentage of Responses (n=168)		
	Stay In XX Lane	Use XX Lane	Pass On XX
Gives Lane Use Information	100	100	97
Use Specified Lane Only to Pass			2
Unsure			1

Researchers also wanted to investigate if one or another of these terms implied a greater need for drivers to stay out of the lane. Therefore, participants were asked to identify how long they felt they needed to stay out of the lane where the vehicle was (if at all). The results of this line of questioning are contained in Table 16.

Table 16. Action Statement Lane Use.

Interpretation	Percentage of Responses (n=168)		
	Stay In XX Lane	Use XX Lane	Pass On XX
Past Work/Activity in Lane	86	91	92
Until Destination	11	5	7
Other	1	1	
Unsure	2	3	1

These results show that there is no significant difference in perceived action between the three statements. In all cases, participants believed they would take their cue of how long to stay out of the lane from visual elements (e.g., end of work) farther downstream and did not make this distinction based on the action statement. A slightly greater percentage of participants interpret the “Stay In XX Lane” as indicating the need to stay in the designated lane until they reached their destination, but the difference was not enough to cause any concern.

Preference

Researchers also gathered participant preference data for the three messages in this grouping. The results, shown in Table 17, indicate that there was a split on preference selection, between STAY IN XX LANE and USE XX LANE with 47 percent selecting each phrase. PASS ON XX was selected the least with only 6 percent. The low level of preference for this particular phrase was not surprising based on comments in the comprehension section where some participants indicated they would just pass the work truck and return to their previous lane of travel.

Table 17. Action Statement Preference.

Message Displayed	Percent (n=256)
STAY IN XX LANE	47
USE XX LANE	47
PASS ON XX	6

Wet Paint Lane Lines Identification Analysis

The final topic addressed during this study was the identification of wet paint during striping operations. As this is one of the most common scheduled operations where vehicles are in a lane without prior warning to reaching the convoy, it was felt that this application was a natural fit for TMCMS information. Furthermore, one of the biggest information needs for these operations is the identification of which line is currently being painted and is therefore wet. Work crews commonly cite driver complaints about getting wet paint on their vehicles, as well as the degradation of the lane line that occurs by having tires track over it prior to the line getting to dry. The use of TMCMS to reduce the frequency of these complaints is highly desired by both painting crews and highway agencies. Researchers addressed two different types of roads during this study: two-lane, two-way and multi-lane facilities. For both of these road types, the following messages were evaluated (Figure 19).

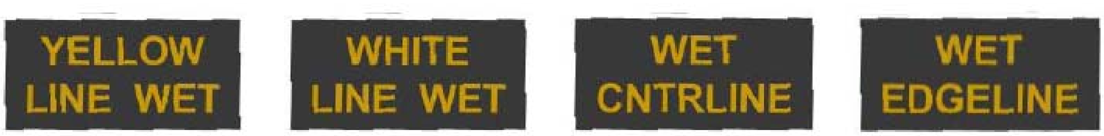


Figure 19. Painting Messages Evaluated.

Depending on the roadway type, the information would vary as to a correct identification of the wet lane line. Additionally, researchers wanted to discern if the drivers believed that the phrases could be implying that multiple lines were being painted. Table 18 shows the results for the two-lane, two-way analysis.

Table 18. Two-Lane, Two-Way Wet Lane Line Identification.

Message	Lane Identified	% Responses (n=256)
WET EDGELINE	Line 1: Left Edgeline	5
	Line 3: Right Edgeline	41
	Line 1 & 3: Both Edgelines	44
	Other (Included centerline in identification)	10
WHITE LINE WET	Line 1: Left Edgeline	4
	Line 3: Right Edgeline	40
	Line 1 & 3: Both Edgelines	53
	Other (Included centerline in identification)	3
WET CENTERLINE	Line 2: Yellow Centerline	90
	Other (Included an edgeline in identification)	10
YELLOW LINE WET	Line 2: Yellow Centerline	92
	Other (Included an edgeline in identification)	8

For the two phrases that identified the white or edgeline of the road, it can be seen that the responses were split between identifying the right edgeline and identifying that it was both the right and left edgelines that are wet. Although researchers do not want to discount this information, it is believed that much of the selection of both edgelines as the participant's response is based on a hyper-vigilance by participants to get the "right" answer during the study (a common challenge in laboratory studies such as these). It is believed that in a real-world application drivers would make the logical assumption that these terms were referring to the white or edgeline closest to the work vehicles. Additionally, both WET CENTERLINE and YELLOW LINE WET were understood at very high comprehension levels (both over 90 percent).

The most interesting information gained from this analysis was that there was no significant difference in the comprehension level of drivers for the color line identification as opposed to "edge-" or "center-" line. This is a positive result in that the space required for the color identification phrases is greater than that of the alternative version and therefore is not as desirable on a TMCMS where space is at a premium.

The second part of this study looked at the identification of wet lane lines on a multi-lane facility. The results of this evaluation are given in Table 19. As with the previous situation, the results for WET EDGELINE and WHITE LINE WET were not as clear-cut as those for WET CENTERLINE and YELLOW LINE WET. For the first two of these messages, the results showed that 58 and 67 percent of the participants identified the right edgeline as the white or edgeline that was being painted. However, for each of these messages, an additional 26 and 25 percent of the participants (respectively) identified that it may be a group of two lines that are wet. Again, it is believed that in the case of edgeline this is more an indication of participants being hyper-vigilant in their responses and not selecting only the line nearest the vehicle. However, for the WHITE LINE WET situation this is less clear as both of these lines are near enough to the work vehicle to be possibilities.

Table 19. Multi-Lane Wet Lane Line Identification.

Message	Lane Identified	% Responses (n=256)
WET EDGELINE	Line 1: Yellow Line at Median	13
	Line 3: Right Edgeline	58
	Line 1 & 3	26
	Other	3
WHITE LINE WET	Line 2: Lane Dividing Line	5
	Line 3: Right Edgeline	67
	Line 2 & 3	25
	Other	3
WET CENTERLINE	Line 2: Lane Dividing Line	92
	Line 1: Yellow Line at Median	2
	Other	6
YELLOW LINE WET	Line 1: Yellow Line at Median	89
	Other	11

For the identification of a WET CENTERLINE it is found that 92 percent of the participants identified the lane dividing line as the "centerline." This implies that if this term is to be used on a multi-lane facility, it must be referring to lines in the "center" of the one-way facility and not to identify the center median line (which is the standard use of such terminology within the transportation field). To identify the line closest to the median, YELLOW LINE WET was a well understood phrase. This phrase garnered an understanding of 89 percent.

FIELD STUDY EVALUATION OF TMCMS INFORMATION ALTERNATIVES

The information collected through human factors studies provided valuable information as to which messages are best understood by drivers; however it did not provide data as to how drivers will respond to the TMCMS in actual field applications. Consequently a field study was developed. The objective of this field study was to evaluate the most promising message alternatives from the human factors studies at real work operations in Texas and also to identify if there are any unintended operational problems that result from the use of TMCMS in the field.

The messages included in this field evaluation were taken from the human factors laboratory study described in the earlier chapter of this report. The outcome of this task is the percent compliance of drivers, when different changeable message signs are displayed during scheduled and unscheduled operations.

STUDY DESIGN

The work plan which follows consists of four steps, as outlined below.

- Step 1 Purchase and Installation of the TMCMS.
- Step 2 Identifying Study Locations and Work Operations.
- Step 3 Field Study Procedures and Data Collection.
- Step 4 Field Observations.

Step 1 Purchase and Installation of the TMCMS

In order to perform this field study a TMCMS was purchased. Researchers contacted several companies to find different types of TMCMS available for the field study. A list of major and minor features of TMCMS along with their prices was documented. The parameters considered in the selection of the message board are multi-functionalities (i.e., the ability of the board to develop and display both text and graphics messages), board dimensions, the number of display message lines on the message board, full matrix design, ease to develop new messages, direct and solar power supply options, user friendliness in programming the equipment, remote operation of the equipment, and the future usability of the TMCMS by TxDOT. After a careful review, researchers purchased an appropriate TMCMS and installed it on a TxDOT vehicle.

TMCMS CHARACTERISTICS

The TMCMS observed in this study was mounted at a height of 4 ft from the ground (to the bottom of the sign). The dimensions of the panel were 46 inches × 78 inches. The TMCMS was a full-matrix board and included standard 230 amber LEDs, which enabled display of both text and graphics. The message board had the ability to display a maximum of three text lines based on a minimum allowable character height of 10.5 inches and a maximum of 15 characters (approx.) per line. Font size and stroke width was changed based on the messages tested in this study.

TMCMS SET-UP

The TMCMS was installed on a TxDOT truck with the help of TxDOT maintenance personnel. Based on the TxDOT maintenance work (i.e., either scheduled or unscheduled operations, stationary or mobile operations) researchers decided on the messages to be evaluated. Researchers also considered the field supervisor's suggestions regarding the set-up of the TMCMS and the location of data collection vehicles in order to acquire accurate field data. Field maintenance personnel also indicated the problems faced by them during stationary and mobile operations. Field personnel showed a great concern about few mobile operations, in particular when drivers come too close to the TMCMS vehicle without anticipating the speed of the vehicle and the number of vehicles involved in the work convoy.

Based on these recommendations and availability of such operations, a new message combination (i.e., WORK CONVOY/USE CAUTION), which was not evaluated in the earlier tasks, was included in this field study. Arrangements were made to collect data from each field location by displaying different selected messages on the truck. Images of the message board installed on the TMCMS are shown in Figures 20 and 21. Also the figures show different angles of the TMCMS along with safety cushion attached to the rear end of the truck.

Figure 20. Rear and Side View of TMCMS Used for Field Evaluations.

Figure 21. CMS Display Board Installed on TMCMS.

Step 2 Identifying Study Locations and Work Operations

Researchers worked with TxDOT personnel to identify suitable study locations and work operations where field evaluations could be performed for both scheduled and unscheduled operations. Depending on TxDOT's maintenance activity schedule, both scheduled and unscheduled operations were included in the study. Researchers observed stationary and mobile operations on both two-lane, two-way and multi-lane roads including road work, ramp closure, lane closures, and herbicide spray. The mounting vehicle was provided by the Corpus Christi

District Maintenance Office, and field evaluations were performed at different locations under TxDOT's jurisdiction.

Sites were selected based on current needs for TMCMS operations. The researchers included a variety of messages like lane blocked/closure statements, road maintenance, accident, and caution messages in this field study. Striping operation messages were not included in the field study as striping work in the Corpus Christi District is carried out by contractors and not TxDOT personnel. The study location details are provided in Appendix B.

Step 3 Field Study Procedures and Data Collection

Field Data Collection

Researchers selected the recommended messages based on the results of earlier tasks in this project. Researchers observed field maintenance operations on both two-lane, two-way and multi-lane roads. Researchers employed a combination of text and symbol messages to be displayed in the field on TMCMS. Researchers selected one symbol message option and one text message option to use together rotating in sequence as a two phase message to create a full message for most of the situations, however at few study locations, it was not possible to have that combination. Instead, a text message combination was found to be more appropriate as per the location. Researchers tried to evaluate all appropriate messages and collect ample data to estimate the drivers understanding of the messages; however researchers were not able to collect vehicle observations for each of these messages due to several challenges encountered in the field during data collection. The challenges faced by the researchers in this process included:

1. Bad weather conditions.
2. Non-availability of appropriate testing sites.
3. Equipment maintenance issues.

STATIONARY AND MOBILE OPERATIONS DESCRIPTION

During the stationary field maintenance operations, the work convoy observed consisted of two or three vehicles: one or two lead maintenance vehicles and a shadow vehicle, varying as per the necessity of the field maintenance work. These vehicles are depicted in Figure 22 during stationary operations.

Figure 22. Work Convoy Vehicles during Stationary Operations.

The one or two lead maintenance vehicles ahead of the shadow vehicle are used to either carry the field maintenance equipment and material to the field location or to perform maintenance work. The shadow vehicle had a TMCMS facing motorists approaching from the rear of the convoy. On the other hand, during mobile operations the work convoy observed consisted of two vehicles: one lead maintenance vehicle and a shadow vehicle. These vehicles are depicted in Figure 23 during mobile operations. During these mobile operations, the work vehicles moved along the travel lane between 12 and 15 mph.

Figure 23. Work Convoy Vehicles during Mobile Operations.

TREATMENTS

Five treatment alternatives were evaluated on the TMCMS during the field studies. All of the message phrases used are shown in Table 20. For the messages displayed in the field, researchers selected a combination of these symbol and text messages to use together (i.e., rotating in sequence as a two phase message) to create a full message. Table 20 shows the messages considered for field study evaluations; however, not all these messages were included in this study due to non-availability of exact field maintenance work and bad weather conditions. Some of the messages were not included in human factors study but were included in this field study due to the constraints of the available work operations to observe.

Table 20. Messages Evaluated.

CONDITIONS	Phase-I	Phase-II	Location #
RAMP CLOSURE	RAMP CLOSED		1
CENTER LANE CLOSED		CNTRLANE CLOSED	2
ROAD WORK		RIGHT LANE CLOSED WITH LEFT MOVING CHEVRONS	3
WORKERS OUT OF VEHICLE	WORKERS ON FOOT	SLOW DOWN/USE CAUTION	4
HERBICIDE SPRAY	WORK CONVOY	USE CAUTION	5

DATA COLLECTION PROTOCOL

Field data were collected in two ways. A passive observation methodology was employed for this field study evaluation. Drivers approaching the TMCMS read the message and passed the work area, while researchers documented the motorist’s behavior, such as sudden braking, lane changes, and erratic maneuvers using video recorders on two different data collection vehicles. Data collection vehicles were positioned at the shadow vehicle and along the convoy to observe the passing driver’s behaviors and speeds approaching the convoy and moving around the convoy during the observation times. Drivers' behaviors, such as direction of passing, stopping, type of passing maneuver and all erratic maneuvers occurring during the observation times were recorded.

Researchers made markings for every 50 ft from a distance of 400 ft to the foot of TMCMS using poles and flags to help researchers measure the distance of the drivers from the message board while making any lane changes or erratic maneuvers. This procedure was followed for all the stationary operations messages tested in the field study operations except for mobile operations, as the maintenance vehicle and TMCMS were on the move and made it highly impossible to follow this procedure. Data collected through the videos were downloaded to the laptops and analyzed in the laboratory to estimate the level of driver comprehension in the field on that particular message.

PILOT FIELD STUDY

Once the message board was installed on the TxDOT truck, researchers performed a pilot field study in one of the field locations with the TMCMS and collected data in the two ways mentioned earlier. The purpose of the pilot study was to determine if there were any changes to be made to the field study process before the actual data collection started.

The pilot study was performed on I-37 in Calallen near Corpus Christi. I-37 is a six-lane interstate facility. TxDOT personnel closed the left lane for maintenance purposes. While the left lane was closed, the TMCMS was placed in the extreme left lane with the panel displaying LEFT LANE CLOSED and the right arrow symbol alternatively informing the drivers about the work being performed and indicating them to move to the other available lanes.

Researchers followed the field crew to collect pictures and videos of the passing vehicles path and behavior of the drivers from different angles. A video recorder was set up at different angles to get the best angle to study driver behavior. Researchers also confirmed that the TMCMS was working well and the drivers were able to read the messages. The pilot study was successfully completed with only a few adjustments, such as the camcorder angle, and location of the field observation trucks, made for the final data collection.

Study Results

Researchers have collected data from nine different locations investigating different combinations of messages, however due to the short time period of the work operations there were less data collected only at a few locations, which were not considered for the final analysis. The following sections give details about the five field locations considered for the analysis including advantages and disadvantages of TMCMS, field observations, and conclusions for the messages evaluated.

Field Data Collection Location-One

The first location for the field data collection was in Corpus Christi, at two different locations; an on-ramp to SH 358 EB and an on-ramp to I-37 NB. It was a scheduled stationary operation. Researchers tested one symbol message option and one text message option to use together rotating in sequence as a two phase message to create a full message. A RAMP CLOSED message along with the right arrow symbol was tested as a two panel message on the TMCMS by alternating the two panels. This evaluation was conducted at the two on-ramps leading to SH 358 EB and I-37 NB on the same day but at different times.

TxDOT personnel performed the stationary operations by closing the on-ramps to vehicles from the frontage roads for 15 minutes at both locations. The speed limit on the frontage roads at both locations was 45 mph. At both locations, the frontage roads were two-lane, one-way roadways leading to single lane entrance ramps for vehicles merging onto the highways. The maintenance work scheduled by TxDOT personnel was to patch potholes at each of the entrance ramps. At each location, TxDOT personnel stationed the TMCMS vehicle at the entrance of the on-ramp and behind the working truck with road patching material, while the field crew was working on the pothole patch.

The messages tested at this location were RAMP CLOSED along with the right arrow symbol, which indicated to the drivers that the ramp is closed and they should continue on the frontage road. Researchers made observations from a location where they could evaluate if the drivers were able to follow the message displayed on the truck mount or not. Researchers collected images, videos, and speed data from the location for the complete period of work, which was about 15 minutes. Figure 24 shows the messages tested on TMCMS.

Figure 24. RAMP CLOSED and Right Arrow Symbol Displayed on TMCMS.

Field Observations from First Location

The following are results of the research based on the field observations and video recording reviews from both locations. A total of 90 and 108 vehicles moved in the direction of ramp closure at SH 358 EB and I-37 NB, respectively, during the observation period of 15 minutes.

The researchers have found through field video recordings that the drivers' compliance of the RAMP CLOSED message was more than 98 percent at both field locations, as the drivers were very cautious and changed lanes well in advance (i.e., at least 300 ft ahead of the TMCMS vehicle) indicating that they were able to understand the message displayed on the TMCMS. Researchers did not notice any erratic maneuvers among these drivers at either of the locations except for four vehicles at the SH 358 EB location that followed the TMCMS vehicle not knowing that it was going to stop on the entrance ramp during the initial set-up. The other 2 percent of the non-compliant drivers at both locations approached too close to the TMCMS vehicle (i.e., within a range of less than 50 ft to the rear of the TMCMS) and changed lanes at the last moment indicating that they did not either understand the message or they had not paid enough attention to the displayed message.

From the speed data collected at the SH 358 EB location, it was identified that 90 percent of the vehicles were below a speed of 35 mph as they approached the TMCMS, whereas at the I-37 NB location about 95 percent of the vehicles were below a speed of 35 mph. Also there was no instance of drivers entering the work convoy while these messages were displayed.

Field Data Collection Location – Two

The second location selected for the field evaluation was on SH 357 WB at the intersection of Saratoga Boulevard and Ranger Avenue in the Corpus Christi area. It was a scheduled stationary operation. It is a six-lane divided facility without shoulders in either direction. TxDOT maintenance personnel had scheduled pothole patch-up work in the center lane on one side of this divided roadway. The work was a little complicated as it was on the center lane at an intersection with traffic signals. TxDOT maintenance personnel closed the center lane but allowed traffic in the right and left lanes.

The field work was scheduled during the non-peak hour period to avoid school traffic, as a school was very close to the work zone. The length of the work zone was less than a half mile and the speed limit on this roadway is 45 mph. The messages tested at this location were a Center Lane Closed symbol and a CNTRLANE CLOSED text shown in Figure 25. Each display message was automated to flash after every 0.3 seconds for 15 minutes separately and observations were noted by the researchers.

Figure 25. Center Lane Closed Symbol and Abbreviated Messages Displayed on TMCMS.

Field Observations from Second Location

The following are conclusions of the researchers based on field observations and video recording reviews from this location. A total of 125 and 140 vehicles moved in the direction of road work, when the Center Lane Closed symbol and abbreviated messages were displayed, respectively. The observation period was 15 minutes per message.

Researchers found through field video recordings that the driver's compliance to the Center Lane Closed symbol message and CNTRLANE CLOSED abbreviated message was 97 percent and

89 percent, respectively. In terms of compliance with the symbol display message, drivers slowed down and changed lanes at least 300 ft ahead of the TMCMS vehicle indicating that they were able to understand the message without difficulty. However out of the remaining 3 percent non-compliant drivers for the symbol message, 2 percent of the drivers swerved between the left and center lane before deciding to move to the left lane and the other 1 percent of the drivers applied their brakes suddenly. Out of the 11 percent non-compliant drivers for the abbreviated message, 6 percent of the drivers changed lanes very late (i.e., after reaching within 50 ft from the rear end of the TMCMS vehicle), 3 percent applied their brakes suddenly and 2 percent maneuvered between lanes.

The major problem noticed at this location was with the 6 percent of the non-compliant drivers who were too close to the TMCMS vehicle before changing lanes. This created trouble for drivers in the next lane as well as themselves as they attempted to merge into the next lane. When the symbol message was displayed, 93 percent of the vehicles were below a speed of 30 mph, and 88 percent were below a speed of 30 mph when the abbreviated message was displayed. Field crews thought that the non-compliance of drivers is primarily due to lack of attention.

Field Study Data Location – Three

The third field study location is on SH 357 EB near the intersection of Saratoga and Kostoryz in Corpus Christi, which is a six-lane, two-way facility with a speed limit of 45 mph. The maintenance work scheduled was resurfacing the road in the right lane for a length of less than one-half mile. Each display message was automated to flash after every 0.3 seconds for 15 minutes separately and observations were noted by the researchers. A total of 85 and 79 vehicles moved in the direction of road work, when the right lane closed phrase with left moving sequential chevrons and the Man Working symbol messages were displayed, respectively. The messages tested at this location were RIGHT LANE CLOSED with Left Chevrons and Man Working symbol shown in Figure 26.

Figure 26. RIGHT LANE CLOSED with Left Chevrons and a Man Working Symbol.

Field Observations from Third Location

It was found through the field video recordings that the driver's compliance to the RIGHT LANE CLOSED with left moving sequential chevrons message and Man Working symbol message were 98 percent and 96 percent, respectively. Drivers changed lanes at least 400 ft ahead of the TMCMS vehicle displaying the RIGHT LANE CLOSED text message indicating that they were able to understand the message board easily. Only 2 percent of non-compliant drivers were noted for this display message as drivers moved to the next lane without any hesitation. When the Man Working symbol message was displayed, 4 percent non-compliancy was noted. Two percent of the drivers got too close (i.e., within 50 ft) to the rear end of the TMCMS vehicle before changing lanes and creating trouble for other drivers in the next lane as they attempted to merge into the next lane. The other 2 percent of the non-compliant drivers applied their brakes suddenly.

When the RIGHT LANE CLOSED message was displayed, 87 percent of the vehicles were below a speed of 30 mph, and 82 percent of the vehicles were below a speed of 30 mph when the Man Working symbol was displayed. Field crews thought that the high non-compliance was primarily due to the inattentive drivers.

Field Study Data Location – Four

The fourth field study location was scheduled on FM 2444 near Corpus Christi, which is a two-lane, two-way facility, where the speed limit is 70 mph. The maintenance work scheduled was a stationary operation to patch potholes. The TMCMS was located on the shoulder displaying the messages tested, while the field crew was patching potholes on one side of this two-lane, two-way facility. WORKERS ON FOOT/SLOW DOWN and WORKERS ON FOOT/USE CAUTION messages were tested at this location. The TMCMS was automated to flash WORKERS ON FOOT and SLOW DOWN messages alternatively every 0.3 seconds and in the same way for WORKERS ON FOOT and USE CAUTION messages. The work scheduled was short term and was finished within 15 minutes.

TxDOT personnel also involved a flagger at this location to provide additional safety to the field crew from high speed vehicles. The flagger managed traffic by stopping and releasing traffic from each end of the work zone, as work was being performed by closing one lane on this two-way facility. Drivers were directed by the flagger to either stop or go based on the amount of traffic from the open lane direction. There were minor traffic back-ups as vehicles coming from the opposite direction had to yield to vehicles coming from the direction where the lane was closed for maintenance. The study was performed during the non-peak time period to minimize interruption to moving traffic and also to make sure there was less traffic while the crew was working. Figure 27 shows the field set up of the TMCMS displaying the WORKERS ON FOOT and SLOW DOWN messages. The flagger can be seen in Figure 27.

Figure 27. WORKERS ON FOOT and SLOW DOWN Messages Displayed on TMCMS.

Field Observations from Fourth Location

The WORKERS ON FOOT/SLOW DOWN message was found to be more effective compared to the WORKERS ON FOOT/USE CAUTION message, as the percentage of drivers compliance with the first message was 99 percent, compared to 96 percent in the latter case. The compliance factor (i.e., the number of vehicles adhering to the message by reducing speed at least 100 ft or more before the work zone) was very satisfactory. No sudden braking or erratic driver behavior was observed at this location, as drivers drove very cautiously. It was also noticed from the videos that 86 percent drivers were below a speed of 30 mph for WORKERS ON FOOT/USE CAUTION display compared to 94 percent drivers for WORKERS ON FOOT/SLOW DOWN display.

Also researchers felt that drivers adhered to the SLOW DOWN portion of the message as a mandatory message rather than a warning message. Researchers noticed that drivers could read the message clearly from a far distance and they safely changed lanes. Researchers also noticed that the TMCMS was very effective as vehicles slowed down and moved into the opposite direction lane before getting too close to the field workers, adhering to the display message and flagger's directions. At this location researchers also noticed that few large trucks went too far into the opposite direction to avoid the work zone field crew members.

Field Study Location – Five

A mobile operation was scheduled on I-37 SB, which is a six-lane divided facility. The work scheduled was very short term and both vehicles were moving and stopping at different locations to perform a herbicide operation. During this mobile operation the work convoy observed consisted of two vehicles, one lead maintenance vehicle and a shadow vehicle with the TMCMS. Based on the field personnel recommendation and field study operation, a WORK CONVOY/USE CAUTION message combination was tested at this location and is shown in Figure 28. The lead maintenance vehicle was spraying herbicide on the roadside vegetation moving between the shoulder and right lane and the TMCMS vehicle was also moving between the shoulder and right lane displaying the message and acting as a safety cushion for the lead maintenance vehicle.

Figure 28. Work Convoy Vehicles during Mobile Operations.

In this mobile operation, the work vehicles moved along the shoulder and right most lane at between 12 and 15 mph. Consequently, at the location on I-37 where the evaluations were performed, there was an average speed differential of approximately 45 mph between the convoy and traffic approaching the work activity. Researchers followed the work convoy in a data collection vehicle from a distance to record the behavior of the traffic. Researchers reviewed the videos and found that there were 83 vehicles passing the operation during the observation period of 15 minutes.

When working on this six-lane divided facility, one of the major safety problems identified for the mobile operations was the speed differential between the approaching traffic and the convoy. Researchers wanted to record speeds of approaching vehicles both upstream of the work convoy and as vehicles were passing the convoy; however, due to the short amount of time (i.e., one or two minutes) of the herbicide operation at different locations, researchers could not gather enough data. Researchers found through the field observations and recorded videos during this mobile operation that the slow speeds of the convoy were not adequate enough to increase the concern regarding speed differential. Most drivers reaching the convoy had an opportunity to easily pass the convoy without having to reduce speed. Overall, despite the speed differential between the motorists and work convoy, this did not constitute a hazardous condition.

With regards to passing driver behavior at this mobile operation, it was very difficult to identify changes in behavior as this maneuver was highly variable depending on sight distance and traffic conditions. However, researchers did take note of these maneuvers, and particularly of anything erratic within the passing behavior, to identify if any of the messages used were providing confusing information to drivers.

The WORK CONVOY/USE CAUTION phrase appeared to be very effective as the vehicles moved into the next lane (left lane for this location) well ahead of the TMCMS. Researchers observed smaller speed change percentages for the TMCMS lane compared to the left traffic lane, which indicates that drivers were able to understand the message. Also researchers believe this is mainly attributable to the fact that slower speed traffic typically travels in the right lane and therefore these drivers had to slow down less both for the convoy and to merge with traffic in the open lane.

While observing the lane changing data for this mobile operation, researchers looked both at the types of erratic maneuvers that were being made near the convoy as well as observing the distance that a vehicle was from the convoy when they moved out of the work lane. There were 7 percent erratic maneuvers noticed during this operation, which included 4 percent of the drivers merging erratically and 3 percent of the drivers stuck in the TMCMS blocked lane. A few of the vehicles got too close to the TMCMS and were stuck in the TMCMS vehicle lane and had to wait to change lanes. It was not possible to make the markings to observe the distances of the approaching vehicles to the TMCMS, as the maintenance and TMCMS vehicles were on the move. Researchers followed the work convoy from an appropriate distance and made observations. Complying with the TMCMS message, 93 percent of the drivers changed lanes approximately 200–250 ft in advance of the TMCMS.

FIELD STUDY CONCLUSIONS

There were several CMS symbol/text messages tested in this field study and there are many key findings. The field investigations were performed for both scheduled and unscheduled operations on single lane and multi-lane facilities. All the test messages were very encouraging, as there were very few erratic maneuvers during the field studies, indicating a possible safety improvement through the use of these messages in the future. The researchers noticed that the usefulness of the TMCMS vehicle to both park and display a variety of messages in different formats (text or symbol) and also on the move is of great help to the maintenance crews.

Researchers identified that the driver's compliance to the Center Lane Closed symbol message was higher compared to the CNTRLANE CLOSED abbreviated message, indicating the drivers understanding and preference for symbol messages. It was also determined from field studies that the WORK CONVOY/USE CAUTION text message phrase for mobile operations was effective as drivers reacted to the TMCMS well ahead of the convoy.

There are several key findings about TMCMS and its usage. It is found that TMCMS are a very effective way of communicating with travelers for both scheduled and unscheduled operations. Also, TMCMS are easily programmable and the messages can be changed by the field crew themselves per the field requirement from the available pool of messages. The TMCMS was particularly effective for unscheduled mobile operations like emergency response and maintenance activities, as it is mobile and highly flexible in that messages can be programmed in advance before reaching the field location.

Researchers found that the TMCMS creates a safety improvement for workers, as it clearly communicates the activity information to the approaching traffic from a far distance, which gives drivers ample time to react to the situation. Also researchers noticed that the major advantage of the mobile operation is that there is no need to set up cones and advance warning message signs, as the work is completed on the move without any major disturbance to the traffic. The major problem noticed during the mobile operations on the freeway was the aggressive and erratic drivers, who tend to ignore the TMCMS message information and approach too close to the TMCMS before changing lanes, which is a hazard for both the driver and the vehicles in the next lane.

It was found from the field study that TMCMS is a very safe option for both the drivers and the field crew, as the TMCMS vehicle does not need any additional equipment to protect the field crew workers because of the attenuator attached to rear of the TMCMS vehicle. It has also been noted through the interaction with field crews that they have had few incidents in the past where a few inattentive drivers entered the work convoy; however, no major problems were encountered.

It has been determined that the major issue that field crews have is with the distracted drivers, who are inattentive and tend to ignore the display messages. Field crews complained that drivers often get confused between the contractor’s messages and TxDOT messages (i.e., the work locations and schedules of contractors are different from TxDOT).

CONCLUSIONS AND RECOMMENDATIONS

The final set of guidelines was developed to address the issues of design and application for the use of TMCMS during scheduled and unscheduled operations. These guidelines can be used by TxDOT personnel responsible for providing critical driver information during mobile and short duration operations. The guidelines were developed based on the results of both a human factors laboratory study and the field evaluation of the information alternatives.

Researchers determined many key points regarding motorist interpretation of TMCMS messages. The following bullets summarize these points:

- The accident symbol was well understood and showed a benefit in the motorists' ability to recall the situation in very limited viewing time situations.
- A roadwork symbol that is a variation on the traditional Man Working sign was well understood by motorists. Researchers recommend using the Man Working figure without the symbol outline as this had the best reaction time by study participants.
- Lane blocked symbols similar to the traditional TxDOT sign for this application was found to work well in communicating with drivers.
- In defining wet paint lines during striping operations researchers recommend the following phrase usage:
    - Two-lane, two-way facility: WHITE LINE WET or WET EDGELINE.
    - Two-lane, two-way facility: YELLOW LINE WET or WET CNTRLINE.
    - Multi-lane facility: WHITE LINE WET or WET EDGELINE (for right shoulder line only).
    - Multi-lane facility: WHITE LINE WET (for lane dividing lines).
    - Multi-lane facility: YELLOW LINE WET (for median/directional dividing line).
- When using an action statement at a lane closure, researchers recommend that either STAY IN XX LANE or USE XX LANE would be appropriate.

Based on these findings and supporting evidence from the field studies, researchers have prepared the following recommended guidelines shown in Table 21 for TMCMS use during different scheduled and unscheduled operations. Although researchers are recommending the use of symbols as part of TMCMS messages, text alternatives for all symbols are provided in case the TMCMS available to the practitioner does not have graphics capabilities.

Table 21 TMCMS Guidelines

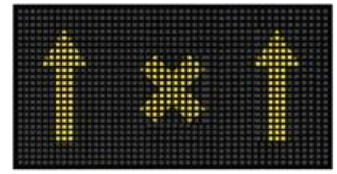
Operation	Condition	Road Type	Concern	Phase-I	Phase-II
Unscheduled	Accident	Multi-Lane	Accident recognition	 *Or* ACCIDENT	 *or* XX LANE CLOSED
		2-Lane, 2-Way	Accident recognition	 *Or* ACCIDENT	ROAD CLOSED *or [action statement – dependent on situation]*
Scheduled	Lane Blocked	Multi-lane	Lane closed recognition	[situation descriptor (*if possible*)]	
Unscheduled /Scheduled	Lane Closure	Multi-lane	Lane closed recognition	[situation descriptor (*if possible*)]	 or XX LANE CLOSED
Unscheduled /Scheduled	Ramp Closure	Any	Ramp closed recognition	RAMP CLOSED	ARROW SYMBOL *or* STAY IN XX LANE

Table 21 TMCMS Guidelines

Operation	Condition	Road Type	Concern	Phase-I	Phase-II
Scheduled (Mobile)	Striping	Multi-lane	Tracking paint	# PAINT TRUCKS	STAY IN XX LANE Or [wet paint line identifier]*
		2-lane, 2-way	Tracking paint	# PAINT TRUCKS	[wet paint line identifier]*
Unscheduled /Scheduled	Workers Out Of Vehicle	Any	Worker safety	WORKERS ON FOOT	SLOW DOWN
Scheduled	Roadwork	Multi-lane	Work activity recognition	 *or* ROADWORK	XX LANE CLOSED

XX = should be replaced by appropriate lane indication (RGT, LFT, or CNTR)
# = should be replaced by appropriate number of vehicles in the work convoy
*appropriate line identifiers are contained in Table 22

Table 22 Wet Paint Line Identifiers

Wet Line Location	**Roadway Type**	
	Multi-lane	**Two-lane, two-way**
Right shoulder line	WHITE LINE WET *or* WET EDGELINE	WHITE LINE WET *or* WET EDGELINE
Lane dividing line	WHITE LINE WET	YELLOW LINE WET *or* WET CNTRLINE
Directional dividing line	YELLOW LINE WET	YELLOW LINE WET *or* WET CNTRLINE

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APPENDIX A: NATIONWIDE SURVEY QUESTIONNAIRE

Phone Interview

Contact Information:

Contact Person:____

District:_____________________________ Position:______________________________

Telephone Number:___________________ Fax Number:_________________________

Email:____

Date and Time of Survey:____

Introduction:

Hello. My name is ___________________ and I am with Texas A&M University-Kingsville / Texas Transportation Institute.

We are currently working on a research project to look at the possible use of truck-mounted changeable message signs (TMCMS) to provide information to motorist. The scope of this project includes the examination of both scheduled operations (such as striping or other stationary or mobile projects) and unscheduled activities (such as debris removal or incident management). As part of this research, we are conducting interviews with appropriate DOT District personnel regarding your current use of TMCMS or your thoughts on possible future use of these signs.

The survey can take up to 20 minutes to complete. Is now a convenient time to talk or would you prefer that I call you back at a later time?

If call back, date and time:____

General Questions:

(1) Does your district currently use a TMCMS during scheduled or unscheduled operations?

____ Yes ____No   If *Yes,* continue. If *No*, start at question 5.

(2) During what situations (operations) do you currently use the TMCMS?

____

(3) During these operations, what information do you put on the TMCMS and do you feel the information is effective? (*Collect information for each situation mentioned in #2*)

____

(4) What benefits (if any) did you recognize by using TMCMS during these operations?

____

(5) Are there any operations (other than those already discussed) that you feel the use of TMCMS would be beneficial? __Yes __No

If yes, list operations and how TMCMS could benefit each operation. If no, please explain why you feel this way.

____

(6) Are there specific hazards, concerns, incorrect driver decisions or behaviors that you have observed or heard about during either stationary or mobile operations that you feel could be addressed with a TMCMS? __Yes __No

a. If yes, list hazards/concerns and how you think they could be addressed:

____

Scheduled Operations:

(7) When you conduct scheduled operations (mobile or stationary) on a two-lane highway, what are the main concerns or problems you may observe?

____

(8) How do these concerns or problems change when you are working on a freeway or interstate (i.e., multi-lane facility)?

____

(9) Do you think TMCMS would help to address these problems? __Yes __No
If yes, how could TMCMS help? If no, why do you believe this would not be useful?

____

Unscheduled Operations:

Unscheduled operations are typically characterized by work that is present at any one location for a very short duration (such as debris removal, incident management, etc.). These operations were specifically brought to our attention as being possible applications for the use of TMCMS. The next few questions are aimed specifically at this type of work.

(10) When you conduct unscheduled operations on a two-lane highway, what are the main concerns or problems you may observe?

____

(11) How do these concerns or problems change when you are working on a freeway or interstate (i.e., multi-lane facility)?

____

(12) Do you think TMCMS would help to address these problems? __Yes __No
If yes, how could TMCMS help? If no, why do you believe this would not be useful?

____

Closing Questions:

(13) Are there any other specific issues regarding the use of TMCMS that you would like us to address during this research?

____

(14) (If district has a TMCMS): Later in this project, we will be collecting field data on TMCMS use. Do you anticipate any specific operations next year where you will be using the TMCMS? __Yes __No

a) If yes, would it be possible for us to observe these operations? __Yes __No

i. Location:____

____

ii. Anticipated time frame:_____________________________________

b) Who would be the appropriate person to contact regarding this operation?

Name:____

Position: ____

Phone:____

Email:____

That completes the survey, thank you for your participation. May we contact you if there are any follow-up questions? __Yes __No

APPENDIX B: FIELD DATA COLLECTION SITES

Site No.	Location	Speed Limit (mph)	Lanes Per Direction	Work Lane	Message Evaluated
1	SH 358 EB	45	3	1	RAMP CLOSED/Right Arrow Symbol
2	SH 357 WB	45	3	1	Center Lane Closed Symbol & CNTRLANE CLOSED
3	SH 357 EB	45	3	1	RIGHT LANE CLOSED with Left Chevrons and Man Working Symbol
4	FM 2444 EB	70	1	1	WORKERS ON FOOT/SLOW DOWN /USE CAUTION
5	I-37 SB	70	3	1	WORK CONVOY/USE CAUTION