RECOMMENDED MESSAGES FOR TRUCK-MOUNTED CHANGEABLE MESSAGE SIGNS DURING MOBILE OPERATIONS

Final Report
FHWA-WY-09/07F

Sponsored by:

WYOMING DEPARTMENT OF TRANSPORTATION

In cooperation with the:

U.S. DEPARTMENT OF TRANSPORTATION
FEDERAL HIGHWAY ADMINISTRATION

Research Performed by:

Texas Transportation Institute

August 2009

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Technical Report Documentation Page

Report No.	Government Accession No.	Recipient's Catalog No.
FHWA-WY-09/07F		

Title and Subtitle	Report Date
RECOMMENDED MESSAGES FOR TRUCK-MOUNTED CHANGEABLE MESSAGE SIGNS DURING MOBILE OPERATIONS	August 2009
	Performing Organization Code
Author(s)	Performing Organization Report No.
Brooke R. Ullman, Nada D. Trout, and Gerald L. Ullman	Report
Performing Organization Name and Address	Work Unit No. (TRAIS)
Texas Transportation Institute The Texas A&M University System College Station, Texas 77843-3135	Contract or Grant No. Project No. RS02208
Sponsoring Agency Name and Address	Type of Report and Period Covered
Wyoming Department of Transportation 5300 Bishop Blvd. Cheyenne, WY 82009-3340 WYDOT Researcher Center (307) 777-4182	Final Report May 2008 – July 2009
	Sponsoring Agency Code

Supplementary Notes

Abstract

The use of truck-mounted changeable message signs (TMCMSs) for mobile operations is desirable for providing drivers with information to better prepare them for unexpected conditions. Traditionally, temporary traffic control for mobile operations has been limited to arrow panels and sometimes static warning messages mounted to the work vehicle. The use of warning signs in advance of the work operation is typically not practical due to the constant movement or stop-and-go nature of the work. TMCMSs can fill an information gap for these mobile operations and providing drivers with better information regarding both the operation and the expected actions based on the operation.

Based on the findings of both a human factors laboratory study and field evaluations conducted during this research and basic message design principles, researchers have created a sampling of recommended messages for use on TMCMS during mobile operations. These messages are defined by the type of work, road type, and identified concerns being addressed by the message.

Key Words	Distribution Statement
Truck-mounted changeable message sign Mobile work operations Work zone Changeable message sign	Unrestricted

Security Classif.(of this report)	Security Classif.(of this page)	No. of Pages	Price
Unclassified	Unclassified	90	

SI* (Modern Metric) Conversion Factors

Approximate Conversions from SI Units

Symbol	When You Know	Multiply By	To Find	Symbol
Length				
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
Area				
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
Volume				
ml	milliliters	0.034	fluid ounces	fl oz
l	liters	0.264	gallons	gal
m^3	cubic meters	35.71	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
Mass				
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg	megagrams	1.103	short tons (2000 lbs)	T
Temperature (exact)				
°C	Centigrade temperature	1.8 C + 32	Fahrenheit temperature	°F
Illumination				
lx	lux	0.0929	foot-candles	fc
cd/m^2	$candela/m^2$	0.2919	foot-Lamberts	fl
Force and Pressure or Stress				
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	pound-force per square inch	psi

Approximate Conversions to SI Units

Symbol	When You Know	Multiply By	To Find	Symbol
Length				
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
Area				
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yards	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
Volume				
fl oz	fluid ounces	29.57	milliliters	ml
gal	gallons	3.785	liters	l
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
Mass				
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lbs)	0.907	megagrams	Mg
Temperature (exact)				
°F	Fahrenheit temperature	5(F-32)/9 or (F-32)/1.8	Celsius temperature	°C
Illumination				
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	$candela/m^2$	cd/m^2
Force and Pressure or Stress				
lbf	pound-force	4.45	newtons	N
psi	pound-force per square inch	6.89	kilopascals	kPa

ACKNOWLEDGMENTS

This project was conducted in cooperation with the Wyoming Department of Transportation and the Federal Highway Administration. The authors would like to thank several people within WYDOT for their insights and assistance during this research: Mike Gostovich, Don Edington, Randy Griesbach, Dan Bromley, Nathan Fierro, Mark Williams, Paul Jones, Mike Hoover, Dennis King, and Hilary LaBudda. Additionally, researchers gratefully acknowledge all of the drivers licensing office and striping crew field personnel who accommodated us during our data collection efforts in Wyoming. The authors also recognize the assistance of Sandra Schoeneman, Sarah Young, Jon Re, and Andrew Persyn of the Texas Transportation Institute for their assistance during various phases of this project.

Executive Summary

The use of truck-mounted changeable message signs (TMCMSs) for mobile operations is desirable for providing drivers with information to better prepare them for unexpected conditions. Traditionally, temporary traffic control for mobile operations has been limited to arrow panels (i.e. directional arrows and caution displays) and sometimes static warning messages mounted to the back of the work vehicles. The use of warning signs in advance of the work operation itself is typically not practical due to the constant movement or stop-and-go nature of the work operation. TMCMSs are a means of filling an information gap for these mobile operations and providing drivers with better information regarding both the operation and the expected actions based on the operation.

The objective of this research was to develop specific guidance for the Wyoming DOT (WYDOT) on applicable situations and appropriate messages for use on TMCMSs during mobile work zone operations. To accomplish this objective, TTI researchers 1) conducted a survey of field personnel within the Wyoming DOT to identify the main hazards associated with mobile operations and potential ways in which the TMCMS could be used to help mitigate those hazards; 2) conducted a series of human factors laptop-based driver comprehension and opinion studies of several potential TMCMS messages to address those hazards; 3) conducted field studies at several Wyoming DOT mobile operations with TMCMS to assess driver reaction to several of the more promising messages; and 4) developed recommended TMCMS message sets for mobile operations based on the laboratory and field studies.

As a starting point for creating an effective message set, researchers reviewed basic message design principles as they would apply to TMCMSs. Based on this evaluation, the following key points should be kept in mind when designing and displaying messages on TMCMS.

- The character heights typically used on TMCMS only provide enough sight distance to allow 2 units-of-information (or phrases) to be displayed in a message.
- For most applications, the two critical units that should be displayed on a TMCMS are 1) a problem/roadwork descriptor, and 2) an action statement.
- A message cannot contain more than 2 phases.
- Message elements should not flash or scroll.
- Abbreviations should be used when necessary to keep the message to two phases, and should be used in accordance with accepted practices.

Finally, the selection of message elements should be based on the identification of specific concerns for the type of operation and road. These concerns include (but are not limited to):

- Communication of the convoy situation.
- Communication of passing or action information.
- Avoidance of paint tracking during striping.
- Speed differential.

Based on the findings of this research and message design principles, researchers have created the following sampling of recommended messages for use on TMCMS during mobile operations. These messages are defined by the type of work, road type, and identified concerns being addressed by the message.

Table A. Recommended Messages for Use on TMCMS During Mobile Operations.

Operation	Road Type	Primary Concern	Phase 1	Phase 2
Striping	2-Lane, 2-Way	Convoy recognition	# PAINT TRUCKS	DO NOT CUT IN
		Convoy Recognition & Tracking Paint	# PAINT TRUCKS	YELLOW [*or WHITE*] LINE WET
		Tracking Paint	YELLOW [*or WHITE*] LINE WET	DO NOT CUT IN
	Multi-lane	Convoy recognition	# PAINT TRUCKS	DO NOT CUT IN
		Convoy & Passing Maneuver	# PAINT TRUCKS	STAY IN LFT [*or RGT*] LANE
		Tracking Paint	# PAINT TRUCKS	CNTRLINE [*or EDGELINE*] WET
Sweeping	2-lane, 2-way Or Multi-lane	Debris/Dust obstructing vision	SWEEPING AHEAD	REDUCED VISION
	Multi-lane	Lane encroachment	SWEEPING AHEAD	STAY IN LFT [*or RGT*] LANE
Workers Out of Vehicle	2-lane, 2-way Or Multi-lane	Protection of Workers	# WORK TRUCKS	WATCH FOR WORKERS
		Reducing Vehicles Entering Convoy as protection.	# WORK TRUCKS	DO NOT CUT IN

Where there is a # symbol, the total number of trucks present in the convoy should be inserted.

Items in italics are alternatives to be used in place of other similar descriptors shown in the message. For example, Yellow could be interchanged with White.

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CHAPTER 1: INTRODUCTION

STATEMENT OF THE PROBLEM

All work areas on roadways create unexpected conditions for motorists. However, mobile operations (e.g. striping, pothole patching, snow/ice removal, etc.) where work is only present at any one location for a very short time are probably the most unexpected, and so are particularly challenging to highway agencies tasked with ensuring safe and efficient motorist travel approaching and passing these operations. Traditionally, temporary traffic control for mobile operations has been limited to arrow panels (i.e. directional arrows and caution displays) and sometimes static warning messages mounted to the back of the work vehicles. The use of warning signs in advance of the work operation is usually not practical due to the constant movement or stop-and-go nature of the work operation.

Motorist behavior approaching mobile operations could be improved if the drivers had better information about the work operation they will be encountering. Additional information provided to drivers could help improve compliance and safety 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 activities as the deployment of such equipment in the area of the work would take as long or longer than the operation itself in that area.

The truck-mounted changeable message sign (TMCMS) is a technology that may be used to improve driver understanding of the specific hazards and desired responses to various types of mobile operations without adding the burden of extra equipment deployment. Trailer-mounted PCMS have been in use to supplement temporary traffic control at stationary work operations for many years; the effectiveness of PCMS in aiding drivers in negotiating travel paths through work areas (as well as other beneficial uses) has been well documented. For mobile operations, TMCMS could be used for many of the same purposes when mounted on a shadow vehicle that would follow the work vehicles, on an upstream warning vehicle, or on the work vehicle itself as an added warning and information source to drivers.

STUDY OBJECTIVES

The objective of this research was to develop specific guidance for the Wyoming DOT (WYDOT) on applicable situations and appropriate messages for use on TMCMS during mobile work zone operations. To accomplish this objective, TTI researchers 1) conducted a survey of field personnel within the Wyoming DOT to identify the main hazards associated with mobile operations and potential ways in which the TMCMS could be used to help mitigate those hazards; 2) conducted a series of human factors laptop-based driver comprehension and opinion studies in Wyoming of several potential TMCMS messages to address those hazards; 3) conducted field studies at several Wyoming DOT mobile operations with TMCMS to assess driver reaction to several of the more promising messages; and 4) developed recommended TMCMS message sets for mobile operations based on the laboratory and field studies.

CHAPTER 2: CHANGEABLE MESSAGE SIGN (CMS) MESSAGE DESIGN PRINCIPLES

To be effective, a changeable message sign (or a PCMS or a TMCMS) must communicate a meaningful message that can be read and comprehended by motorists within a very short time. To accomplish this, the following message design factors must be considered:

- Content — the specific information displayed.
- Load — the number of units of information in the message.
- Length — the number of words or characters and spaces.
- Character size – the height, width, and stroke width of characters in the message.
- Format — the order and arrangement of the units of information.

MESSAGE CONTENT

Traditionally, the key elements of message content are:

- What is wrong ahead (e.g., in the case of mobile operations a roadwork descriptor).
- Where the problem is located.
- What action the motorist should take. (*1*)

Typically, motorists expect information about the problem or reason to appear first, followed by where the problem occurs. Advice, such as "use other routes," should be presented at the end of the brief message (if advice is given and can fit in the message). In the case of TMCMS messages used for mobile operations, the location is somewhat irrelevant as the message is not located at a point upstream of a problem, but is traveling with the identified problem. Consequently, the information priorities in a TMCMS message will typically be a problem statement and an advice statement.

When motorists are advised by a CMS message to take a specific action, it is essential that the information given is consistent with existing signing and operational conditions. Inconsistency

between a CMS message and either existing signing or lane configuration may cause motorists to either misinterpret the message or disregard all information in the message as incorrect (e.g., if advised to use a lane that is unavailable or blocked). Therefore, the message creator must have a full knowledge of the area in which work will be performed and of the preferred motorist actions for the given circumstances.

MESSAGE LOAD

An informational unit refers to each separate data item given in a message which a motorist can recall and which can be a basis for making a decision. The following example of a CMS message in response to road work serves to illustrate the concept of units of information.

UNIT OF INFORMATION

Question	Answer	Unit of Info
1. What is the problem?	ROADWORK	1 unit
2. Where?	PAST ROWLAND	1 unit
3. What lanes are closed	LEFT 2 LANES	1 unit
4. What is advised?	USE RIGHT LANE	1 unit

Research and experience have shown that on urban freeways, CMS messages must not exceed four units of information when the freeway operating speed is greater than 35 mi/h. When speeds are equal to or less than 35 mi/h, no more than five units should be displayed on a single CMS. However, on TMCMS the information that can be provided within a message is much more limited due to the size of the display. In these cases, researchers do not expect that greater than two units of information can be provided and still achieve desirable legibility characteristics.

MESSAGE LENGTH

The maximum length of a CMS message is controlled in part by the reading time of that message (i.e., the time the motorist has available to read the message based on sign legibility distance). Research has shown that motorists require two seconds of reading time for each unit of information on a CMS, and can only process a maximum of four units of information from a

CMS message while traveling at typical freeway speeds (five units is acceptable under low-speed operating conditions).

Whereas the total length of the message is controlled by the amount of information that is included in it, the available reading time is controlled by the size of the letters used to create the message. A message must be designed such that it is short enough to allow motorists to glance at the sign, read it, and comprehend it while attending to the complex driving environment. Furthermore, it takes motorists longer to read flashing messages, messages with one of the lines flashing, and messages on a multi-line CMS where one line alternates text and the other two lines of text remain the same.

For TMCMS, in the message length and the character height are both limited by the size of the board itself. Typical TMCMS boards will allow for approximately 7 to 10 characters on a message line and be able to accommodate two lines of text on a message phase (or panel). This significantly restricts the amount of information that can be included in a message and requires careful consideration of priorities and word selection during message development. Also, when a full-matrix TMCMS is used, the programming of the full-matrix grid allows for the changing of font size to accommodate greater numbers of characters (i.e., by reducing font size). Therefore, a message designer must be careful in the selection of wording that the text line does not adapt to a smaller font size than is legible for the speed of the facility.

Based on previous research conducted with regard to legibility distance for difference size characters on CMS (*2, 3*), Figure 1 shows the 85th percentile daytime legibility distance for three different character heights (9, 10.6, and 18 inches). Additionally, the line shown in this figure illustrates a clear linear relationship exists between these data points. Consequently, it is reasonable to extrapolate from this graph for all possible character heights between 9 and 18 inches with regard to legibility distance.

Figure 1. 85th Percentile Daytime Legibility Distance by Character Height.

Given the information from Figure 1, researchers extrapolated to identify legibility distance for font heights that are found on TMCMSs. These heights were 11, 14, and 16 inches. Researchers then used this data to calculate available viewing time for a message created using these different heights. Figure 2 shows the viewing time information for multiple vehicles speeds from 45 to 75 mi/h.

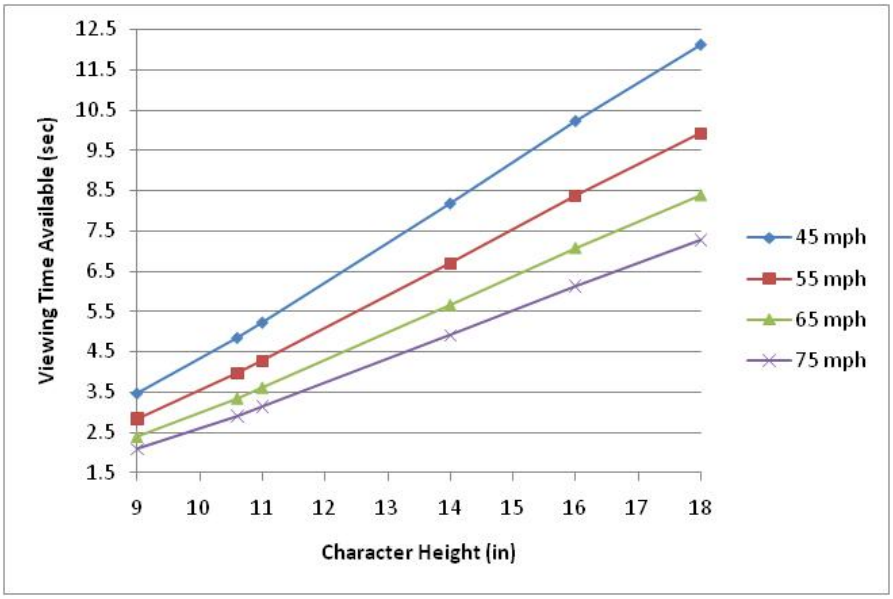

Figure 2. Viewing Time Available to Motorist Based on Speed and Character Height.

Once the total viewing time needed to provide adequate reading time for the CMS is known, the height of the characters needed on the sign to achieve this time can be determined. For example, given a message with two units of information to be displayed on a road with a speed limit of 75 mi/h, a total of four seconds of viewing time is required for this message. Looking at Figure 2, this requires a character height of approximately 13 inches to achieve an adequate viewing time.

A further consideration of font size is stroke width. According to the FHWA (*4*), the stroke width to letter height (SW:LH) ratio should be no greater than 0.13 and the character width to height ratio should be at least 0.7. Both of these ratios should be calculated for a given font on a TMCMS to ensure that adequate legibility distance is achieved for a message.

MESSAGE FORMAT

The order and arrangement of the units of information in a message are important to allow motorists to easily read and interpret the information and make rational decisions based on that information. For TMCMS, a message must usually be divided into two parts and displayed as two phases (in no case should the message be longer than what can be displayed in two phases). Each message phase must be cohesive and understandable by itself, in order not to confuse approaching drivers. Also, when a specific unit of information does not fit on a TMCMS line because of the limitation in the number of characters that can be displayed on a line, it sometimes becomes necessary to use abbreviations. Some abbreviations take longer to read and comprehend and thus must be used with care. Additionally, some abbreviations that engineering and field personnel readily understand are not understood at all by the typical driver. There is a library of words and phrases with acceptable abbreviations for use on traffic control devices contained in Part 1 of the Manual on Uniform Traffic Control Devices (MUTCD) (*5*). For abbreviations not included in this list, the message creator should consider obtaining feedback about the abbreviation from non-engineering or field personnel (friends, office staff, etc.) to verify that it is understood prior to using it in a TMCMS display.

CHAPTER 3: IDENTIFICATION OF ISSUES

As a first step to addressing this project, the research team conducted telephone interviews to gather WYDOT field personnel input regarding the issues or hazards experienced during mobile work operations. During these interviews discussion was aimed at identifying situations where a TMCMS could provide benefits and at determining the state-of-the-practice with regard to current mobile operations and the use of TMCMS. Researchers conducted a total of six phone interviews during this effort. Of the personnel spoken with, two represented WYDOT districts currently using TMCMS, two did not use TMCMS, and two represented WYDOT headquarters.

CURRENT OPERATIONS

When TMCMSs are not used for mobile operations (e.g., striping operations), the current practice is to use an arrow panel on both the shadow and the striping vehicle indicating either passing direction or caution (flashing diamonds) as appropriate for the operation. Additionally, a "Wet Paint" sign is displayed on the shadow vehicle.

In districts that are currently using TMCMSs, the field crews felt that the signs have improved driver communication and understanding during striping operations (the primary use of the TMCMS thus far). The main use of the TMCMS is to display a message that there exists wet paint on a specific lane line to reduce the number of vehicles crossing the wet paint. The interviewees also noted that the messages appeared to have improved the safety and efficiency of passing maneuvers made by motorists (e.g., knowing what side to pass the striping convoy on) and helped motorists avoid wet paint during passing. The personnel believed that the use of these messages instead of basic arrow panels has improved motorists' understanding of the operations. It was also noted that the TMCMS has better attention getting qualities than static signing.

Personnel reported that the following message phrases and graphics are being used on the TMCMS during striping operations:

- YELLOW LINE WET
- WHITE LINE WET
- STAY OFF
- CAUTION STRIPING CREW
- WATCH FOR WET PAINT
- STAY IN LEFT LANE
- STAY IN RIGHT LANE
- ”Arrow“ Graphics
- YELLOW CENTER LINE WET
- WHITE DASHES WET
- WHITE EDGE LINE WET
- SOLID WHITE LINE WET
- LEFT LANE CLOSED AHEAD
- RIGHT LANE CLOSED AHEAD

Beyond the current operational practices, researchers also questioned the interviewees regarding what they believed to be the hazards or safety issues experienced during mobile operations. The following list shows specific hazards or safety concerns that were identified during this discussion:

- Speed differentials.
- High speeds.
- Driver inattention.
- Road rage at construction.
- Driver misunderstanding of passing maneuver.
- Running over wet paint (specifically when passing back into the convoy).
- Passing inappropriately on two-lane, two-way roads (not enough space, no passing zone).
- Drivers reentering a lane between convoy vehicles.

Interviewees believed that TMCMS could assist with many of these concerns by adding target value to the work situation and providing drivers with better information. One person noted that

it was not as necessary to have this type of added information in open areas where there is plenty of sight distance, but that it could be helpful in mountainous terrain or when a convoy is strung out over a longer distance such that approaching motorists cannot see the entire convoy.

EXPANDING TMCMS USE

Researchers asked all of the interview participants to identify other potential work operations (other than striping) where they believed TMCMS could be of use to WYDOT. The following is a list of the operations identified by the participants:

- Special event traffic control.
- Construction.
- Cracksealing.
- Sweeping.
- Patching.
- Signal work.
- Short duration lane closures.
- Reiterating information included on static signs.
- Incident management.

It was specifically noted by participants that truck-mounted changeable message signs (TMCMS) would not be of use during snow removal as the view of the sign would be obstructed by snow kicked up behind the plow.

WYDOT personnel also identified many concerns with regard to the use of TMCMS. The following list highlights these concerns:

- Need standardization of practices.
- Messages must be short and simple.
- Letters must be large enough for adequate sight distance.
- Having to change messages when changing lanes during striping will add extra work burden to crew (currently use caution diamonds and no change is required).

- Viewing angle is a concern in board specification.

Researchers believe that many of these concerns can be addressed through proper message design and took these issues and concerns into account during the human factors studies conducted for this project.

CHAPTER 4: HUMAN FACTORS LABORATORY STUDY

STUDY DESIGN

Based on the input from WYDOT field personnel, TTI researchers developed a human factors laboratory study to determine motorists' understanding and acceptance of the use of TMCMS messages during mobile operations. The study content consisted of three different types of human factors evaluations:

- Phrase comprehension.
- Abbreviation comprehension.
- Message phrasing preferences.

Phrase Comprehension

The initial section of the survey evaluated participant comprehension of the information alternatives identified for this study. Each information alternative consisted of a single message phrase and is considered to be one unit of information that could be included on the TMCMS. A total of 27 phrases were addressed in the survey. Table 1 describes the indentified concerns addressed through this survey, the information needs of a motorist for a given situation, and the roadway type used in the evaluation each phrase. For the effective evaluation of the phrase alternatives, the survey contents were broken into smaller study groups. The study number associated with each of these groups is also identified in Table 1. Each of these groups represents a specific concern that researchers were addressing.

Due to time constraints in the survey administration, not all participants were able to view all of the phrases identified for this study. Additionally, limiting the number of phrases viewed by each participant reduced potential learning effects that could influence the study results. Given these parameters, each participant viewed 7 or 8 of the phrases. To account for all of the phrase variations being evaluated, 6 versions of the survey instrument were created. To avoid the occurrence of primacy bias, the order in which the phrases were displayed was interchanged for

different versions of the survey. An example of the answer form used during this study is provided in Appendix A.

Table 2 is a complete listing of the phrases evaluated by roadway type under which they were tested. As can be seen in this list, there was a significant amount of redundancy between the phrases that were evaluated for two-lane, two-way highways and for multi-lane roadways. However, researchers felt that it would be important to explicitly examine whether any changes in motorist interpretation of a message element existed based on the roadway type it was used on. This is particularly critical in the messages regarding wet paint where specific segments of lines with specific line colors are being identified, and for messages that inform motorists that passing is allowed on multi-lane roadways. Researchers wanted to ensure that appropriate informational components have been identified for use on TMCMS for each of the roadway scenarios.

Table 1. Description of Test Phrase Alternatives by Concerns and Information Needs.

Identified Concern	Information Needs for Motorists	Study #	Test Phrase Alternatives	Roadway Type Used in Study	
				2L2W	Multi-Lane
High speeds of motorists or speed differential between motorist and work crew.	Warn motorist on need to slow down.	1	SLOW	X	X
	Identify why a motorist should slow their travel speed	1	[#] WORK TRUCKS [#] MOVING VEHICLES [#] PAINT TRUCKS	X	X
Drivers do not inherently understand when approaching a mobile work operation that there may be multiple vehicles working as a group (i.e. a work convoy).	Clarify that there is a group of vehicles working together.	2	[#] WORK TRUCKS [#] PAINT TRUCKS [#] MOVING VEHICLES		X
	Identify for motorists that they should not re-enter their original travel lane between trucks within this work group.	3	DO NOT CUT IN KEEP TRKS TOGETHER TRKS STAY TOGETHER		X
When approaching a slow moving convoy on a two-lane, two-way facility, motorists may not always be able to identify how to safely pass the work vehicles.	On a two lane road it is important for a driver to understand that there are multiple vehicles that they will need to pass.	2	[#] WORK TRUCKS [#] PAINT TRUCKS [#] MOVING VEHICLES	X	
	Also on two lane roads, drivers need to know that it is unsafe to pass the convoy one vehicle at a time (i.e. leap-frogging the convoy) until they have passed all of the vehicles.	3	DO NOT CUT IN KEEP TRKS TOGETHER TRKS STAY TOGETHER	X	
At times it may be necessary for a shadow vehicle to stay back beyond a horizontal or vertical curve to alert vehicles of conditions beyond this obstacle.	In these cases, drivers will still need to know that when they pass this single vehicle they have not passed the entire work crew.	4	[#] WORK TRKS AHD	X	X
When approaching a slow moving convoy multi-lane facility, motorists may not always be able to identify how to safely pass the work vehicles.	When there are multiple lanes for a single highway direction, it may be necessary to inform motorists that passing the convoy is acceptable.	5	PASS WITH CARE		X
	Informing a motorist of which lane to use or not use when passing on a multi-lane roadway may further clarify the desired actions of motorists.	6	PASS ON LEFT [RIGHT] STAY IN LFT [RGT] LN RGT [LFT] [CNTR] LANE BLOCKED		X

Table 1 (continued)

Identified Concern	Information Needs for Motorists	Study #	Test Phrase Alternatives	Roadway Type Used in Study	
				2L2W	Multi-Lane
Motorists should know that there is wet paint on certain line segments when painting. This will avoid vehicle damage due to running over the paint and address the concern of tracking newly laid paint before it can dry.	Identify that there is wet paint and possibly provide further details as to which segment of paint is currently wet.	7	WET PAINT YELLOW LINE WET WHITE LINE WET WET CNTRLINE	X	X
	Identify what action a motorist should take to avoid the wet paint.	8	DO NOT CUT IN STAY OFF DO NOT CROSS	X	X
At times it is necessary for workers to be outside of vehicles during a mobile operation (e.g. cracksealing). During these times it is important to identify that these workers are at an added risk during the operation.	Inform motorists that there are workers included with the operation ahead that are not inside of a vehicle.	9	WATCH FOR WORKERS WORKERS IN ROAD WORKERS ON FOOT	X	X
When sweeping operations are active it is possible to create a limited visibility situation.	Inform driver of the type of work ahead to help them understand conditions.	10	SWEEPING AHEAD	X	X
	Warn driver of limited visibility.	10	REDUCED VISION LIMITED VISION	X	X

Table 2. List of Test Alternatives by Roadway Type.

Roadway Type	Test Phrase
Two-lane, Two-way Road	SLOW [#] WORK TRUCKS [#] PAINT TRUCKS [#] MOVING VEHICLES [#] WORK TRKS AHD DO NOT CUT IN KEEP TRKS TOGETHER TRKS STAY TOGETHER WET PAINT YELLOW LINE WET WHITE LINE WET WET CNTRLINE STAY OFF DO NOT CROSS WATCH FOR WORKERS WORKERS IN ROAD WORKERS ON FOOT SWEEPING AHEAD REDUCED VISION LIMITED VISION
Multi-lane Road	SLOW [#] WORK TRUCKS [#] PAINT TRUCKS [#] MOVING VEHICLES [#] WORK TRKS AHD DO NOT CUT IN KEEP TRKS TOGETHER TRKS STAY TOGETHER PASS WITH CARE PASS ON LEFT [RIGHT] STAY IN LFT [RGT] LN RGT [LFT] [CNTR] LANE BLOCKED WET PAINT YELLOW LINE WET WHITE LINE WET WET CNTRLINE STAY OFF DO NOT CROSS WATCH FOR WORKERS WORKERS IN ROAD WORKERS ON FOOT SWEEPING AHEAD REDUCED VISION LIMITED VISION

Survey Administration Protocol

Researchers utilized a laptop computer to display a still image of a work vehicle with a TMCMS. In these images, the TMCMS simulated a message being tested, and asked questions of drivers regarding their interpretation of the phrase presented in the image. Figure 3 shows an example of the type of images (1a. using a two-lane, two-way roadway and 1b. using a multi-lane roadway) that were used during the survey.

a. Image Example on Two-Lane, Two-Way Roadway

b. Image Example on Multi-Lane Roadway

Figure 3. Image Display Examples

In the opening instructions for the phrase comprehension section, researchers first identified for the participant what type of road they would be viewing (i.e., multi-lane or two-lane, two-way) in the image and instructed them as follows:

> "Assume that you are traveling down this road and are approaching the work vehicle. When you press the space bar your first picture will appear on the laptop screen. While the picture is on the screen, I will ask you questions about the information shown. Please give as much detail as you can about your opinion of the information shown."

Participants were then asked two questions for each image they viewed:

1. As a driver, what does this message mean to you or how is it affecting you?
2. In your opinion, why is this information being provided to drivers?

All questions in this study were open-ended and researchers recorded the participant's responses on an answer form.

Abbreviation Comprehension

In the abbreviation comprehension section, three abbreviations used in the message phrases were tested. Each abbreviation was displayed on the computer screen. While displayed, the researchers asked the participant what was meant by the abbreviation. The three abbreviations evaluated were:

- TRK
- CNTRLINE
- RGT

Message Phrase Preferences

In the final section of the study, participants were asked to choose among the different message alternatives being tested within an information group as to which phrase they believed best conveyed the intended information. This approach allowed participants to select their own "best" message for different situations, and has been successfully used in previous studies to

indicate driver preferences for information. Researchers asked participants to select a phrase from within the category displayed that they believe would be the best in addressing the following conditions:

- Wet paint.
- Multiple vehicles participating in the work ahead.
- Driver should not move back into the work lane between a group of multiple work vehicles (i.e. convoy).
- Lane that can be used to drive in and/or pass the convoy.
- Identification of workers outside the vehicles.

Location

A total of 456 laptop surveys were conducted over three locations. Initially, the surveys were to be conducted in Cheyenne and Casper, Wyoming so as to obtain local driving population input and expertise. However, the recruitment of participants took longer than expected, and so a portion of the participants were from Bryan, Texas. Table 3 provides the number of surveys obtained from each location. Given the large number of out-of-state travelers that are on Wyoming interstates and major highways, researchers believe that having a sample of responses from non-Wyoming participants actually makes the results more generalized and useful for WYDOT.

Table 3. Number of Surveys by Location.

Location	Number of Surveys
Cheyenne, WY	228
Casper, WY	108
Bryan, TX	120

Participant Demographics

Participants for this survey were recruited at driver's licensing offices. Researchers recruited a demographically distributed sample of participants based on the gender, age, and educational statistics of Wyoming as identified from the U.S. Census Bureau data of 2006 and the Federal Highway Administration Statistics from 2005. Table 4 shows the desired sample in parentheses compared to the sample obtained in italics. Overall, it is believed that the results obtained in the survey represent Wyoming drivers very well.

Table 4. Percentage of Demographic Sample (n= 456).

Age	Education Level Obtained				Total
	High School Diploma or Less		Some College or More		
	Male	Female	Male	Female	
18-24	*3* (2.25)	*2* (2.25)	*4* (4.25)	*4* (4.25)	*13* (13)
25-54	*11* (12.5)	*12* (12.5)	*17* (15.5)	*16* (15.5)	*56* (56)
55+	*6* (6.75)	*7* (6.75)	*10* (8.75)	*8* (8.75)	*31* (31)
Total	*20* (21.5)	*22* (21.5)	*30* (28.5)	*28* (28.5)	*100* (100)

NOTE: *Numbers in italics represent the sample population obtained*

RESULTS

An initial review of the collected data indicated that there were no significant differences in participant response based on study location (including those obtained from Bryan, TX). Therefore, all participant responses were combined for analysis purposes. The results are divided based on the study groups established in Table 1. This information is then followed by an analysis of the abbreviation comprehension evaluation.

Study #1: Speed Differentials

When mobile work operations are conducted on a roadway the lower speed of the work vehicles as compared to the general traffic stream can create a significant speed differential. This speed differential is of great safety concern as it creates an unexpected situation for motorists of catching up to the work vehicles more quickly than anticipated.

Researchers tested the information phrase SLOW to identify if this would assist in warning motorists of a need to slow down as they approached the rear of the work activity. Additionally,

researchers tested the following three phrases to identify if they would provide information both that the motorist should slow their speed and a reason why the person should slow down (i.e., work activity).

- 3 WORK TRUCKS
- 2 PAINT TRUCKS
- 3 MOVING VEHICLES

The test phrases were evaluated using images portraying both multi-lane and two-lane, two-way roadways; however, researchers determined that there was no effect on interpretation based on roadway type and therefore combined this data for analysis. Each phrase was evaluated by 152 participants.

Comprehension

Table 5 shows that 95 percent of the participants interpreted the phrase SLOW to indicate that there were slow moving vehicles present.

Table 5. Percent of Responses Indicating The Phrase Implied "Work Activity" and/or the Presense of "Slow Moving Vehicles."

Phrase Displayed	Percent of Responses (n=152)	
	Work Activity	Slow Moving Vehicles
SLOW		95
3 WORK TRUCKS	73	50
2 PAINT TRUCKS	76	60
3 MOVING VEHICLES	31	50

NOTE: Multiple responses were possible for each participant. Therefore, percentage will not equal 100.

For the other three phrases evaluated, the phrase 3 PAINT TRUCKS resulted in a slightly higher percentage (60 percent) of participants indicating that the vehicles were traveling slowly as compared to 50 percent for the other two phrases. However, there was no statistically significant difference between these percentages and therefore all three are considered to be understood equally well.

Table 5 also shows that the phrases 3 PAINT TRUCKS (76 percent) and 2 WORK TRUCKS (73 percent) both indicated a work activity to the participants at a much higher level of comprehension than 3 MOVING VEHICLES (31 percent). These results show that very few of the participants interpreted the phrase 3 MOVING VEHICLES to imply work activity and therefore this phrase was not effective in addressing the stated concern.

Recommendations

Given the excellent interpretation results for the phrase SLOW, researchers did not believe there was a need to carry this phrase forward into the field study. Based on the results obtained in this survey, researchers believe it is acceptable to use the phrase SLOW for any scenario where a decrease of vehicle speed (and thereby speed differential) is the primary concern of the work activity.

With regard to the final three phrases, it is suggested that 3 MOVING VEHICLES should not be used for mobile operations as it was not interpreted to indicate work in the roadway or decreasing speeds to a significant percentage. The other two phrases were well understood by the participants as implying work activity. However, the word "paint" in the 2 PAINT TRUCKS phrase may have greater influence on motorists to slow down and to identify that there is work activity. This could be due to the apprehension of the motorists for getting paint on their vehicles as opposed to some other undefined activity implied by the phrase 3 WORK TRUCKS. Consequently, researchers decided to move the two phrases 3 WORK TRUCKS and 2 PAINT TRUCKS into field studies to determine how they affected motorists and what actions are taken to the phrase in a real world scenario.

Study #2: Identifying Multiple Vehicles in a Convoy

Field personnel believe that many drivers do not inherently understand when approaching a mobile work operation that there may be multiple vehicles working as a group (i.e. a work convoy). A misinterpretation of this circumstance could greatly impact the motorist's decisions in passing a convoy and lead to unsafe maneuvers both on two-lane, two-way roads where motorists would need to pass a significantly greater distance than expected, or on multi-lane

roads where they may return to the work lane prematurely and therefore encounter unexpected speed differences and possibly workers in the lane.

To address this concern, researchers evaluated three alternatives that could be used to inform motorists that they are approaching a work operation of multiple vehicles.

- 3 WORK TRUCKS
- 2 PAINT TRUCKS
- 3 MOVING VEHICLES

This evaluation was also conducted using images that portrayed multi-lane roads and two-way, two-lane roadways as depicted in Figure 3. A total of 76 participants viewed each phrase tested for both multi-lane and two-way, two-lane roads. Researchers felt that the roadway type was a factor in the motorist's interpretation of the phrases due to the different impacts on passing maneuvers. As such, this data was not combined for the analysis.

Comprehension

Table 6 shows that the participants had no difficultly in interpreting the phrases to mean more than one work vehicle in the work group for both multi-lane and two-lane, two-way road types. Results show that 82 percent or more of the participants knew the correct number of vehicles in the convoy for each phrase evaluated. In addition, between 1 and 5 percent of the participants stated that there was more than one vehicle in the work group but did not state the exact number (since the responses were allowed to be open-ended, researchers did not explicitly require the participant to state how many vehicles were in the convoy).

Table 6. Identifying Multiple Vehicles in Convoy.

Phrase Displayed	Percent of Responses (n=76)			
	Multi – Lane		2-Lane, 2-Way	
	# in Vehicle Convoy	More than one vehicle (no # specified)	# in Vehicle Convoy	More than one vehicle (no # specified)
3 WORK TRUCKS	88	4	82	1
2 PAINT TRUCKS	84	5	88	4
3 MOVING VEHICLES	87	5	82	4

Recommendations

The comprehension results indicate that all three of the messages work well for identifying that there is more than one vehicle. Based on these results and the previous section, researchers believe that 3 WORK TRUCKS and 2 PAINT TRUCKS would both provide beneficial information for motorists when approaching mobile operations. Researchers included these two phrases in the field test to try and further quantify these benefits.

Study #3: Not Re-entering a Lane In the Middle of a Convoy

The purpose of this study was to evaluate message phrases that attempt to inform motorists not to re-enter their original travel lane between trucks within the mobile work convoy while passing. Re-entering the work convoy is highly dangerous for both motorists (they will still have a high speed differential with the lead work vehicle they pull in behind) and for any workers on foot within the work operation. Thus, this type of behavior is undesirable on both multi-lane roadways and on two-lane, two-way highways. However, the safety concern on two-lane, two-way roads is even greater because drivers are looking for gaps in opposing traffic to make the passing maneuver, and it is imperative that drivers fully understand that they need a gap large enough to pass the entire convoy, not just the vehicle immediately in front of them.

Three phrases were evaluated as options for conveying the need to pass the entire convoy at one time:

- DO NOT CUT IN
- KEEP TRKS TOGETHER
- TRKS STAY TOGETHER

A total of 76 participants viewed each of these phrases for both roadway types. Researchers felt that the roadway type (multi-lane versus a two-lane, two-way) would affect the motorist's interpretation of the phrases due to different driver decision-making processes for each (passes can occur almost anytime on multi-lane roadways whereas on two-lane highways, opposing traffic gaps dictate when a passing maneuver can occur). Therefore, these data were not combined during the analysis.

Comprehension

Table 7 shows that, for multi-lane roads, the message phrase DO NOT CUT IN was correctly interpreted by 58 percent of the participants as indicating the need to pass all of the work vehicles in the convoy at once. Conversely, only 32 and 19 percent of participants responded with this interpretation of the KEEP TRKS TOGETHER and TRKS STAY TOGETHER phrases, respectively.

Table 7. Responses for Not Re-Entering the Convoy Phrases (Multi-Lane).

Responses	Percent of Responses by Phrase (n=76)		
	KEEP TRKS TOGETHER	TRKS STAY TOGETHER	DO NOT CUT IN
Pass all work vehicles	32	19	58
Do not pass work vehicles		1	18
Pass on left			9
Information for tractor-trailer truck drivers	34	55	
Did not know meaning	24	14	11
Other	10	11	4

The phrases TRKS STAY TOGETHER and KEEP TRKS TOGETHER were also often misinterpreted by participants who took the phrases to mean that the information was intended only for tractor-trailer truck drivers (55 and 34 percent respectively). This is a major concern,

suggesting that participants would disregard the information given as not pertaining to them as passenger car drivers.

When these same phrases were evaluated for a two-lane, two-way road, there was again a great deal of confusion on the part of the participants. Table 8 shows the responses of the participants for this evaluation.

Table 8. Responses for Not Re-Entering the Convoy Phrases (Two-Lane, Two-Way).

Responses	Percent of Responses by Phrase (n=76)		
	KEEP TRKS TOGETHER	TRKS STAY TOGETHER	DO NOT CUT IN
Pass all work vehicles	30	39	62
Do not pass work vehicles	4	11	30
Identifies multiple vehicles in work crew	8	16	0
Information for tractor-trailer truck drivers	45	20	0
Did not know meaning	12	14	3
Other	1	0	5

For the KEEP TRKS TOGETHER and TRKS STAY TOGETHER messages, the percentage of participants responding that they needed to pass all of the vehicles together was once again fairly low (30 and 39 percent, respectively). Also, it is evident that many participants again believed that these messages were intended for semi-tractor trailer truck drivers, or simply did not understand the message at all.

For the phrase DO NOT CUT IN, 62 percent of the participants were able to identify that the desired reaction to this message was not to move back into the work lane after passing the vehicle shown on the laptop scenario, but pass all of the work vehicles ahead before returning to that lane. However, 30 percent of the respondents did indicate that this message was telling them not to pass the work vehicles. Although this was not the intended response, it is unclear from the data whether these individuals knew that they could pass and chose not to do so because of the roadway configuration they viewed on the laptop screen, or if they truly believed it was a no passing allowed situation. Researchers believe that this message needed to be evaluated in a field environment to identify which is the true case.

Message Phrase Preference

After assessing comprehension of the various phrases, participants were then asked which phrase best indicates to them that there is more than one work vehicle and that they should not be driving between the vehicles.

As illustrated in Table 9, the preferred phrase for this situation was DO NOT CUT IN, selected by 69 percent of the participants. The other two phrases were selected by a much lower percentage of participants (only 16 percent selected the KEEP TRKS TOGETHER phrase, and only 15 percent selected the TRKS STAY TOGETHER phrase).

Table 9. Preference for Not Re-entering a Lane Between the Work Vehicles.

Phrases	Percent (n=456)
DO NOT CUT IN	69
KEEP TRKS TOGETHER	16
TRKS STAY TOGETHER	15

Recommendations

The results indicate that both the KEEP TRKS TOGETHER and TRKS STAY TOGETHER phrases would not be appropriate for use when trying to inform motorists that they should not reenter the work lane between the work vehicles. Researchers made this determination because a significant portion of the driving population incorrectly interprets these phrases as intended for semi-tractor trailer truck drivers only. Researchers recommend that these phrases not be used on TMCMS.

Although the responses were not always clear for the phrase DO NOT CUT IN, researchers opted to include this phrase in the field studies performed for this project. Researchers believe that many of the participant's reaction to what the message phrase was telling them on the two-lane, two-way road related more about the visual perspective (i.e., they could not see over the hill to assess gaps in oncoming traffic) than on a misinterpretation of the message. Further testing of this phrase in field studies allowed researchers to evaluate the reactions of drivers to this phrase in a real-world environment.

Study #4: Splitting a Convoy Around a Visual Obstruction

At times it is necessary for a shadow or trail vehicle to stay back beyond a horizontal or vertical curve to alert motorists of further work vehicles and/or activity beyond this obstacle. In these cases, motorists need to be made aware that when they pass this single vehicle they have not exited the area affected by the work operation. In fact, for mobile operations they need to know that there is a convoy of work vehicles that they will encounter in the roadway ahead. To address this concern, researchers evaluated the phrase 3 WORK TRKS AHD as a warning of these vehicles that are out of view. Researchers hypothesized that the roadway type used in these images would not affect the driver's interpretation of the phrases. Therefore, participant responses to the message viewed in a two-lane, two-way highway environment and in a multi-lane roadway environment were combined as one data set. This resulted in a total of 152 participants evaluating this phrase.

Comprehension

Participants were asked what the phrase means to them to determine if the drivers realized that there would be 3 additional work trucks ahead of the shadow truck. Table 10 shows that only 19 percent stated the desired response. Researchers also noted the large percentage (71 percent) that indicated there were 3 vehicles in the convoy. This indicates that the participants were using the exact number for the identification of work vehicles given and not reacting to the term "ahead" as implying that these were additional vehicles beyond the one portraying the message. Therefore, it is not believed that the word "ahead" added any benefit to the 3 WORK TRKS phrase.

Table 10. Interpretation of "3 WORK TRKS AHD"

Responses	Percent (n=152)
3 Additional Vehicles	19
More than One Vehicle	5
3 Vehicle Convoy	71
Did not indicate number of Vehicles	4

Recommendations

In cases where it is necessary to let a shadow vehicle "trail behind" at vertical and/or horizontal curves, researchers do not believe it is necessary to add the word "ahead" to a message phrase. It is believed that even with only one vehicle in sight at the point where motorists are reading the message, the fact that there are further vehicles in a convoy for motorists to be aware of is implied.

Study #5: Acceptability of Passing Information

When approaching a slow moving convoy on a multi-lane facility, motorists may not be confident that it is safe or acceptable to pass the work vehicles. Therefore, it may be necessary to inform motorists that passing the convoy is acceptable for the given situation. The purpose of this study was to determine if the phrase PASS WITH CARE would adequately provide this information to motorists. A total of 76 participants viewed the PASS WITH CARE phrase displayed on a TMCMS located on a multi-lane roadway only.

Comprehension

As shown in Table 11, the phrase was understood by a majority of the participants with 96 percent identifying that they could pass the convoy. Also, over half indicated that they would need to slow down when approaching this area and 41 percent identified that a work activity was taking place. Overall, this shows an adequate understanding of the situation and the phrase being portrayed.

Table 11. Interpretation of PASS WITH CARE (Multi-Lane).

Responses	Percent (n=76)
Use Caution When Passing	96
Work – so need to Use Caution	41
Slow Down	53

NOTE: Multiple responses were possible for each participant. Therefore, percentages will not equal 100.

Recommendations

The results indicate that PASS WITH CARE was understood well by most participants and would be appropriate for use on multi-lane roads. No further evaluation of this phrase is needed for multi-lane roadways; however, WYDOT personnel requested that this phrase be included in the field evaluations to determine how motorists would react when given this message on a two-lane, two-way road.

Study #6: Specific Lane Use Passing Information

In some mobile operation situations on multi-lane roadways, it may be desirable to provide motorists with specific information as to which lane to use or not use when going around the work convoy. The following three phrases were evaluated for this purpose.

- PASS ON LEFT [*or RIGHT*]
- STAY IN LFT [*or RGT*] LN
- RGT [*or LFT*] [*or CNTR*] LANE BLOCKED

These phrases were evaluated using only multi-lane roadway scenarios where a suggestion of passing maneuver would be appropriate. Researchers do not believe that this information should be provided unless a designated lane of travel is available to the passing motorist. There were a total of 76 participants that saw each of the three phrases evaluated.

Comprehension

The information shown in Table 12 indicates that all three phrases were well understood, with 99 percent of the participants identifying either the intended open or the blocked lane.

Table 12. Interpretation of Passing Instructions (Multi-Lane).

Phrase Displayed	Percent of Responses (n=76)				
	Work in Right Lane	Must use Left/Pass in Left	Right Lane Blocked	Something going on in Right Lane	Did Not Know
PASS ON LEFT	38	99			
STAY IN LFT LANE	70	99			
RIGHT LANE BLOCKED	17		99	21	5

NOTE: Multiple responses were possible for each participant. Therefore, percentages will not equal 100.

Of the participants that viewed the phrase STAY IN LFT LANE, 70 percent explicitly stated that there was work being conducted in the right lane, compared of only 38 percent who stated similarly for the PASS ON LEFT phrase and 17 percent for the RIGHT LANE BLOCKED phrase. This may imply that motorists believed there was a greater significance to the message based on the words "stay in" as compared to the other phrases. Researchers believe this would have a positive effect on the work zone safety by reducing the number of vehicles re-entering the work lane in the middle of the convoy. However, this phrase was evaluated in the field studies to identify that there are no adverse operational effects for this non-traditional terminology.

Message Phrase Preference

Researchers also gathered participant preference data for the three phrases in this study to determine which one best conveyed which lane was safe to drive in near the work vehicles. The results, shown in Table 13, indicate that almost two-thirds of the participants (63 percent) selected STAY IN LEFT LANE as the best description for the situation. The majority indicated that this phrase gave drivers explicit direction on what action they should take. One of the reasons identified for not selecting RIGHT LANE BLOCKED was that it did not give an action that people could follow as the other two phrases did.

Table 13. Preference for Passing Instructions.

Phrases	Percent (n=456)
PASS ON LEFT	22
STAY IN LFT LANE	63
RGT LANE BLOCKED	15

Recommendations

Based on the results in this study, the phrase STAY IN LFT LANE was selected for inclusion in the field studies. The phrases PASS ON LEFT and RGT LANE BLOCKED are both terms commonly found in current CMS message design guidance literature, and so are acceptable for use on TMCMS without further evaluation. However, the "stay in" phrase segment has not previously been examined in significant detail, and so warranted some observation during field studies.

Study #7: Identifying Wet Paint

To avoid the tracking of wet paint onto both the road surface and onto passing vehicles, it is desirable to inform motorists that wet paint is present on certain line segments during a mobile striping operation. The information to be conveyed regarding this topic is 1) that a paint line is wet, and 2) which lane is the one that is wet. Researchers evaluated the following phrases in this study.

- WET PAINT
- YELLOW LINE WET
- WHITE LINE WET
- WET CNTRLINE

Comprehension

Results shown in Table 14 indicate that all four phrases were understood (at a 95 percent level or better) in identifying the presence of wet paint on the road. The results were similar regardless of whether a multi-lane roadway or a two-lane, two-way highway was shown, and so have been combined in this table.

Table 14. Identification of Wet Paint on Road.

Phrase Displayed	Percent of Responses (n=152)		
	Wet Road Paint	Truck is wet	Not sure
Wet Paint	97	2	1
Yellow Line Wet	100	0	0
White Line Wet	99	0	1
Wet Cntrline	99	0	1

Next, researchers were interested in determining how participants interpreted the phrases in terms of which line(s) were wet (implied in this interpretation would be that the motorist would tend to avoid driving over the line(s)). This required the responses for the multi-lane roadway and the two-lane highways to be examined separately, as lane line colors and their position across the roadway right-of-way differ by roadway type. Figure 4 illustrates the roadway and lane-line configuration presented to participants for the multi-lane roadway scenarios. As shown, the right edgeline and lane dividing line are both painted white, while the left edgeline is yellow.

Figure 4. Multi-Lane Display Illustrating Wet Paint Options.

For this scenario, researchers asked participants basic questions that were intended to identify which line was wet. However, because researchers were not prompting participants and requiring them to select a line there were a significant number of participants who simply repeated the given color/location for the line or did not give information of this sort in their response.

Table 15 shows participant's responses with regard to the identification of the specific line that was being painted for the mobile operation. It can be seen that a significant number of the participants were found to simply repeat the information given or not identify a specific location or line. This is due to limitations within the study design in that researchers were not prompting or requiring participants to select a line in their response.

Table 15. Identification of Wet Paint Location On Multi-Lane Roadway.

Phrase Displayed	Percent of Responses (n=76)						
	Identified Line				Repeated Message*	Truck is wet	Did not indicate where
	White Skip	White Solid	Yellow Solid	White Skip &/or Solid			
WET PAINT						1	99
YELLOW LINE WET	4		38		47		11
WHITE LINE WET	9	23		17	34		17
WET CNTRLINE	56		1		38		5

*Participants correctly repeated whatever was on the display.

However, of the participants who did make the line identification, it can be seen that the majority (38 percent) identified the yellow solid line for YELLOW LINE WET. Additionally, when identifying the location associated with the term CNTRLINE, 56 percent of participants identified this as the white skip line between the two lanes of traffic. This is interesting as it is not what transportation professionals would typically associate with the term centerline (i.e., the yellow line or line separating directions of traffic). Researchers believe this term is acceptable for use in the identification of the skip line and that as transportation professionals we need to be careful about the use of this term with the public.

As expected, participants that viewed WET PAINT did not indicate where the paint would be located in their responses. For those that viewed WHITE LINE WET, there was diversity within the responses between the white skip and/or white solid line as there are two white lines on this road. This indicates that more detail is needed to be included in these messages (other than just white) if specific lines are to be identified.

This same analysis was conducted for the phrases using a two-lane, two-way roadway illustration as shown in Figure 5. As depicted in this figure, both edgelines on the roadway are white with a yellow centerline.

Figure 5. Two-Lane, Two-Way Display Illustrating Wet Paint Options.

Table 16 shows that, just as with the multi-lane analysis, the majority of drivers did not associate "Wet Paint" with a specific line location. However, of those that did identify a line for this phrase, 31 percent believed that the edgeline was wet. When more specific information was given regarding line description, a large number of participants (between 28 and 45 percent) simply repeated the information given in the phrase and did not elaborate in identifying a specific line. However, for those participants who did provide more information within their responses regarding location, the majority of these drivers were able to correctly identify the wet paint location. These responses accounted for approximately 50 percent of responses in this scenario. From this analysis, researchers inferred that drivers can correctly identify wet paint locations based on either color or centerline indications when driving on two-lane, two-way roads.

Table 16. Identification of Wet Paint Location on 2-Lane, 2-Way Roads.

Phrase Displayed	Percent of Responses (n=76)				
	Identified Line			Repeated Message	Did not indicate where
	White Solid (Right)	Yellow Skip (Center)	Right or Left Edge		
WET PAINT	31				69
YELLOW LINE WET		49		29	22
WHITE LINE WET	58		4	28	10
WET CNTRLINE		49		45	6

Message Phrase Preference

Each participant was presented with the following condition for this topic: "A new centerline is being painted on the road and you need to avoid driving on the paint." The five phrases offered for selection were:

- WET PAINT
- YELLOW LINE WET
- WET CNTRLINE
- DO NOT CROSS
- STAY OFF

Table 17 shows that 70 percent of the individuals surveyed felt that "Wet Cntrline" best described the situation stated. Most felt that this phrase was more detailed and told you exactly where the wet paint was located.

Table 17. Preference for Wet Centerline.

Phrases	Percent (n=456)
WET PAINT	7
YELLOW LINE WET	11
WET CNTRLINE	70
DO NOT CROSS	9
STAY OFF	3

Recommendations

Results show that WET PAINT was not descriptive enough for the drivers to know where on the roadway the paint was wet. All of the other phrases evaluated (YELLOW/WHITE LINE WET and WET CENTERLINE) more accurately identify this information for drivers. Based on this data, researchers recommend that when conveying wet paint information, a specific color or location should be identified.

Specifically, researchers believe the use of the YELLOW [WHITE] LINE WET phrases to identify the appropriate line on a two-lane, two-way highway is acceptable. For multi-lane road applications, researchers found that WET CNTRLINE is acceptable to identify the line separating two adjacent lanes of traffic, and YELLOW LINE WET should be used for the inside edgeline. Unfortunately, researchers do not feel that any of the phrases evaluated accurately identify the outside edgeline as the area of wet paint. Intuitively, researchers believe that either RGT LINE WET or WET EDGELINE may be appropriate; however, these phrases were not evaluated for driver comprehension.

Study #8: Actions to Avoid Wet Paint

In some instances where striping is being done, it may be prudent to give motorists an action statement in the message that will further encourage them to avoid driving on the wet paint. Researchers evaluated three phrases that they believed could be used for this purpose, when combined with a wet paint phrase previously discussed.

- DO NOT CUT IN
- STAY OFF
- DO NOT CROSS

These phrases were evaluated in both multi-lane and in two-lane, two-way roadway scenarios. Researchers felt that the roadway type could affect the motorist's interpretation of the phrases. As such, participant responses for each roadway type were analyzed separately.

Comprehension

For the multi-lane roadway scenario, Table 18 shows that 95 and 93 percent of participants indicated that they should not drive on the wet paint when shown a STAY OFF or DO NOT CROSS phrase, respectively. However, they did not indicate what action they would take, if any, and researchers are concerned about queuing if drivers interpret the phrase as not allowing them to leave their current lane.

In contrast, 74 percent of those viewing a DO NOT CUT IN phrase indicated that they should pass all of the work vehicles at once, and 29 percent of participants indicated that they should merge into the left lane. Interestingly, 26 percent of the participants also indicated that felt they should not pass or go around the striping operation based on the DO NOT CUT IN message phrase.

Table 18. Identification of Action to Avoid Wet Paint (Multi-Lane).

Phrases Displayed	Percent (n=76)			
	Don't Drive on Wet Paint	Merge in Left Lane	Pass all at once	Do not Pass or go Around
DO NOT CUT IN		29	74	26
STAY OFF	95			
DO NOT CROSS	93			

NOTE: Multiple responses were possible for each participant. Therefore, percentages will not equal 100

Participant's responses are shown in Table 19 for those who viewed these phrases in a two-lane, two-way roadway scenario. Here, the majority of participants (96 and 99 percent, respectively) again felt they should not drive on the wet paint for both the STAY OFF and DO NOT CROSS phrases. Additionally, 71 percent or participants stated they would not pass or go around the work vehicles when they viewed the STAY OFF phrase. For the DO NOT CUT IN display, 34 percent of the participants stated they would pass all of the vehicles at once, and 69 percent stated that would not pass or go around the vehicles at all. Researchers believe that the passing all at once is a desirable decision in this scenario as it would keep motorists from entering and exiting over wet paint several times as they go around the convoy.

Table 19. Identification of Action to Avoid Wet Paint (2-Lane, 2-Way).

Phrases Displayed	Percent of Responses (n=76)		
	Don't Drive on Wet Paint	Pass all at once	Do not pass or go around
DO NOT CUT IN		34	69
STAY OFF	96		71
DO NOT CROSS	99		

NOTE: Multiple responses were possible for each participant. Therefore, percentages will not equal 100.

Recommendations

For multi-lane roadways, both STAY OFF and DO NOT CROSS message phrases were understood by the majority of participants to mean that motorists should not drive on the paint; therefore, these phrases can be used during striping operations where wet paint behind the shadow vehicle is a concern and personnel wants to instruct motorists to avoid touching this paint. However, it should be noted that the STAY OFF and DO NOT CROSS phrases may result in significant numbers of motorists believing they should not pass the convoy at all when the lane line is being painted (i.e., avoiding this wet area). If such behavior is not desired, these statements should not be used on this road type.

The third phrase, DO NOT CUT IN, was well understood as directing motorists not to go between the work vehicles (i.e., the area where paint is being applied) and would therefore have an influence on drivers avoiding the wet paint area on multi-lane roads. This was also true for the two-lane, two-way scenario and the possibility was even more pronounced for the DO NOT CUT IN phrase as motorists believed it was implying that they should not pass. Although this message will be included in the field studies to further evaluate its positive impact on keeping drivers from reentering the work lane, researchers will also be concerned with identifying if it has the negative impact of creating longer queues behind the convoy.

Study #9: Workers Outside Vehicles

When it is necessary for workers to be outside of their vehicles during a mobile operation (e.g. cracksealing, maintenance, etc.), it is desirable to notify drivers that these workers are there and

at an added risk during the road work operation. The purpose of this study was to evaluate phrases that would indicate to motorists that there are workers that are not inside of a work vehicle included with the operation ahead. The phrases evaluated are shown below:

- WATCH FOR WORKERS
- WORKERS IN ROAD
- WORKERS ON FOOT

The roadway type was not considered to be relevant with regards to motorist interpretation of this topic. Therefore, all data for these phrases were combined and resulted in 152 individuals that viewed each phrase.

Comprehension

For the three phrases of interest, researchers wanted participants to be able to identify that there would be workers in the road ahead. Table 20 shows the participant responses for the phrases. Overall, these phrases were fairly-well understood, although the WORKERS IN ROAD phrase seems most suited to work activities that are limited to the actual travel lanes. Depending on where within the roadway cross-section the workers were located, all three of the alternatives would be adequate for use.

Table 20. Identification of Worker Location.

Phrases Displayed	Percent of Responses (n=152)			
	Road	Shoulder	Road, Shoulder, Anywhere	Did not indicate
WATCH FOR WORKERS	78	6	7	9
WORKERS IN ROAD	93	1	4	2
WORKERS ON FOOT	80	7	11	2

Message Phase Preference

Of the three phrases tested in this study, over one-half of the participants (55 percent) preferred the phrase WATCH FOR WORKERS as the best description for this event (see Table 22). The

main reason given by participants who preferred this phrase was that it indicated that the workers could be located anywhere near the roadway. In other words, the phrase would alert drivers to be aware that workers could be working in several different areas (e.g., on the road, the shoulder, etc.). Interestingly, most human factors studies of driver information preferences on CMS imply a desire for more specific information, not less specific as is indicated here. Whether the results of this study imply that drivers might have a slightly different mindset when traveling next to workers on foot, or simply that they do not find CMS information pertaining to road work activities always credible (and so do not want to be surprised by a worker not where he or she was expected to be), cannot be determined from this study.

Table 21. Preference for Identifying Workers Outside the Vehicle.

Phrases	Percent (n=456)
WORKERS ON FOOT	15
WORKERS IN ROAD	30
WATCH FOR WORKERS	55

Recommendations

The participants demonstrated a high level of understanding of all the phrases evaluated. Additionally, as just discussed, over one-half of the participants preferred the phrase WATCH FOR WORKERS. However, researchers feel that identifying a specific location of the workers is important in contributing to worker safety. Therefore, the general phrase WATCH FOR WORKERS is acceptable when workers will be in several locations on or near the roadway during their work activities; but, the specific location (WORKERS IN ROAD or WORKERS ON SHOULDER) is recommended when workers are exclusively in one location.

Study #10: Sweeping Operations

The final work operation considered for potential use of a vehicle equipped with a TMCMS is as a shadow vehicle for a sweeping operation. During these operations, the TMCMS could be used both to identify the operation ahead (i.e., sweeping) and to warn motorists of upcoming conditions such as reduced visibility due to dust. Three phrases were evaluated related to sweeping operations.

- SWEEPING AHEAD
- REDUCED VISION
- LIMITED VISION

Again, the phrases were evaluated using both multi-lane and two-lane, two-way roadway scenarios, and the results combined, yielding a total sample of 152 participants viewing each phrase.

Comprehension

Table 22 shows the participants' response to the meaning of the phrase SWEEPING AHEAD. As can be seen in the table, this phrase was understood well with 98 percent of the participants identifying the intended operation as sweeping or cleaning of the roadway. Additionally, many of the motorists went on to further identify that the phrase implied that the vehicles were moving slowly (58 percent).

Table 22. Identification of Sweeping Operation.

Responses	Percentage (n=152)
Sweeping-Cleaning	98
Debris	47
Damage windshield	13
Slow	58

NOTE: Multiple responses were possible for each participant. Therefore, percentages will not equal 100.

Having addressed the comprehension of the operation, researchers also wanted to identify for motorists that this operation could be affecting their visibility while driving. With regards to the candidate message phrases pertaining to possible effects of the sweeping operation on visibility, the results shown in Table 23 indicate that the majority of the participants (96 percent) understood the meaning of both phrases evaluated (REDUCED VISION and LIMITED VISION). However, the reasons listed as to why they believed their visibility was reduced indicate that the phrase LIMITED VISION might be understood slightly better. Specifically, Table 23 shows that there were 21 percent of the participants who felt that the work truck

obscuring their vision was the purpose of the REDUCED VISION phrase, compared to 14 percent of those who felt that way when viewing the LIMITED VISION phase. Conversely, the percentage of participants indicating that the reason for the reduction in visibility was likely dust or other debris due to the sweeping operation was higher for the LIMITED VISION phrase than for the REDUCED VISION phrase (42 percent versus 35 percent, respectively).

Table 23. Understanding of Visibility Reduction.

Phrase Displayed	Percent of Responses (n=152)					
	Visibility Impaired	Dust/fog etc. ahead	Geometric (curves, hill, etc. ahead)	Truck obscuring vision	Truck can't see me	Don't know
REDUCED VISION	96	35	9	21	7	3
LIMITED VISION	96	42	11	14	9	2

NOTE: Multiple responses were possible for each participant. Therefore, percentages will not equal 100

Recommendations

The phrase SWEEPING AHEAD was understood well by all the participants and is acceptable for use on a TMCMS, when applicable. Additionally, the results showed that both phrases that pertain to a reduction in visibility were understood, although the LIMITED VISION phrase tended to be associated slightly more often with expectations of dust and debris (a more accurate expectation for this type of operation). Even so, researchers believe that either of these phrases (REDUCED VISION and LIMITED VISION) could be used in conjunction with SWEEPING AHEAD and be well understood by motorists. The use of either of these phrases on a TMCMS is acceptable.

Abbreviation Evaluation

All of the participants were asked to identify what the following three abbreviations meant to them:

- TRK
- CNTRLINE
- RGT

The abbreviation interpretation results are detailed in Table 24. Both TRK and CNTRLINE were understood at a comprehension level of 95 percent of higher. However, the abbreviation RGT was not understood as well with only 78 percent of the participants correctly interpreting it as "right." This result was counter to previous CMS abbreviation research in Texas and elsewhere, which has found this abbreviation to be well understood by drivers (*6, 7, 8*). Researchers attribute the lower level of comprehension in this study to the fact that the abbreviation was evaluated without a prompt word (such as lane) and emphasizes the importance of using this abbreviation with a prompt or descriptor word to ensure comprehension.

Table 24. Abbreviations Evaluation (n=456).

Responses TRK	%	Responses RGT	%	Responses CNTRLINE	%
Truck	95	Right	79	Centerline	98
Track	2	Rig	1	Center lane	1
Train/Train Tracks	1	Regulatory	1	Did not know	0.5
Did not know	2	Other*	4	Other*	0.5
		Did not know	15		

* no individual group exceeded 1 percent

Recommendations

The abbreviations for truck and centerline were well understood and are acceptable for use. It is believed that the abbreviation RGT is a suitable abbreviation as well, especially when used in context of an entire phrase. Consequently, RGT was evaluated during the field studies in the phrase STAY IN RGT LANE to determine if there is any confusion or other operational problems associated with this abbreviation could be observed. .

CHAPTER 5: FIELD EVALUATION

All information elements (or phrases) used in this field evaluation were taken from the human factors laboratory study described in Chapter 4 of this report. The intent of the field evaluation was to validate the usability of some of the different phrases for which the human factors study results were less than conclusive and/or where the responses provided by participants in the lab studies were such that the researchers wanted to first try the phrases out in the field to verify that there are no unintended operational problems that result from their use.

STUDY DESIGN

Field data collection was conducted in WYDOT District 1 at locations near Rawlins, Laramie, and Cheyenne, Wyoming. Researchers observed striping operations on both two-lane, two-way and multi-lane roads. Sites were selected based on current needs for striping. The specific site details are provided in Appendix B.

Mobile Operations Description

The work convoy observed consisted of two vehicles: a lead striping vehicle and a shadow vehicle. These vehicles are depicted in Figure 6 during a mobile operation. Both vehicles used multiple amber warning lights mounted to be seen from both the front and back of the vehicles. The striper had an arrow panel and two orange rectangular signs facing motorists approaching the rear of the convoy. The signs read “WET PAINT” and “PASS WITH CARE”. The arrow panel display was consistent with typical WYDOT operations of this type, and displayed either right or left chevrons (as appropriate for roadway configuration) or flashing diamonds for caution conditions.

The shadow vehicle had a TMCMS facing motorists approaching the rear of the convoy. The display on the TMCMS changed throughout the study. Additionally, this vehicle had a truck-mounted attenuator (TMA) with yellow and black conspicuity markings. During the striping operations observed, the work vehicles moved along the travel lane between 8 and 14 mi/h. Consequently, on the roadways where the evaluations were performed, an average speed differential of approximately 53 mi/h existed between the convoy and traffic approaching the work activity.

Figure 6. Work Convoy Vehicles.

Treatments

Six treatment alternatives were evaluated on the TMCMS. All of the message phrases used are shown in Figure 7. For the messages displayed in the field, researchers selected one of the Phase 1 options and one of the Phase 2 options to use together (i.e., rotating in sequence as a two phase message) to create a full message. Data were collected for all variations of these options (i.e., 6 different messages).

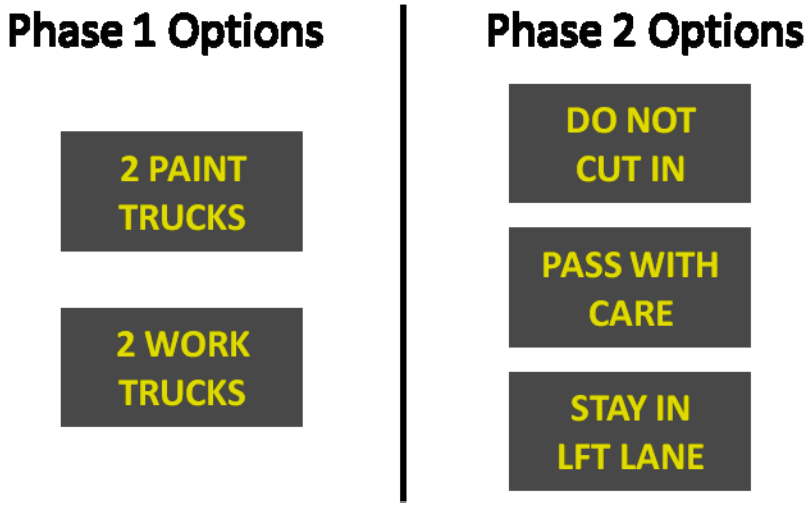

Figure 7. Field Evaluation Message Options

Other than the test messages, researchers also collected data when a standard treatment was being displayed on the TMCMS. This treatment used the text "Caution" on the TMCMS when working on two-lane, two-way roads (this was used in place of either four-corner caution or

flashing diamonds as the TMCMS did not have the capability to display these options) and sequential chevrons when on a multi-lane road.

TMCMS Characteristics

The TMCMS observed in this study was mounted at a height of 4 feet from the ground (to the bottom of the sign). The dimensions of the panel were 3' high by 6'wide. The TMCMS was a full-matrix board and was therefore able to display either text or graphics. Font size was maximized for each of the message phrases used. Table 25 shows the font characteristics for each phrase. Researchers noted that the maximum number of characters that would fit on a line was eight with a single space (this number allowed only for single stroke width).

Table 25. TMCMS Font Characteristics.

Phrase	Height (inches)	Stroke Width
	14 ¾"	Double
	16 ½ "	Double
	16 ½ "	Double
	11 ½" 14 ½"	Pass With – Single Care - Double
	11 ¼"	Double
	11 ¼"	Double

Data Collection Protocol

Two data collection vehicles were used during the field observations. One of the vehicles was positioned to observe passing behaviors at the shadow vehicle and to record free-flow speeds approaching the convoy. The second vehicle was positioned such that the researchers could observe passing behavior along the convoy and to record speeds as the motorist moved around the convoy. The passing behaviors were categorized as follows:

- Passing smoothly (Y or N).
- Hesitating prior to passing (Y or N).
- Passing aggressively on two-lane, two-way roads (Y or N).
- Passing direction (left or right).
- Stopping behind convoy (when not necessary due to other traffic) (Y or N).
- In queue (i.e., no option to pass operation upon arrival).

Researchers in both vehicles also recorded any erratic maneuvers that occurred during the observation times.

Study Results

Table 26 gives information regarding the sites where each message was evaluated along with the amount of time and number of vehicle observations for each message. Data were obtained for a total of 13 hours at 9 different locations. A total of 773 vehicles were observed in passing maneuvers.

Table 26. Message Evaluation Details.

Message	Road Type	Site #	Time Evaluated	# Vehicles Observed
Caution	2L2W	3	1hr, 45 min	72
Chevrons	Multi	5	1 hr, 15 min	104
2 WORK TRUCKS / DO NOT CUT IN	2L2W	8	45min	16
		9	10 min	2
	Multi	5	1 hr, 10 min	140
2 WORK TRUCKS / PASS WITH CARE	2L2W	3	30 min	28
		4	30 min	10
2 WORK TRUCKS / STAY IN RGT LANE	Multi	5	35 min	55
		6	45 min	28
2 PAINT TRUCKS / DO NOT CUT IN	2L2W	3	50 min	35
	Multi	3	20 min	41
		6	35 min	69
2 PAINT TRUCKS / PASS WITH CARE	2L2W	7	1 hr, 15 min	44
2 PAINT TRUCKS / STAY IN RGT LANE	Multi	2	2 hr	17
		6	50 min	112

Unfortunately, researchers were not able to collect a greater number of vehicle observations for each of these messages due to several challenges encountered during data collection including:

- Finding appropriate sites.
- Equipment malfunction.
- Weather cancellations or delays.

This being said, researchers were able to draw several conclusions for the messages evaluated. The following sections detail the information gathered by roadway type.

Two-Lane, Two-Way Roads

When working on two-lane, two-way roads, one of the biggest safety issues identified for mobile operations is the speed differential between the convoy and approaching traffic. Researchers wanted to determine if messages used on a TMCMS would benefit or hinder in slowing motorists down to such a point that this concern was lowered for the workers. Researchers recorded speeds of approaching vehicles both upstream of the work convoy (i.e., before they had begun to slow for the work to any significant degree) and as vehicles were at the rear of, or passing, the convoy.

The data collection showed that speeds at the convoy were not slow enough to alleviate the concern regarding speed differential for any of the evaluated treatments. However, researchers did note that many of the approaching vehicles were able to reach the convoy at crest curves or other roadway sections that allowed them to easily pass the convoy without having to slow down to wait for a gap in opposing traffic. Therefore, the observed speeds were much higher than the convoy speed, but this did not necessarily indicate a hazardous situation.

Researchers also examined the speed data by comparing speeds when the candidate messages were being used to speeds when a standard caution message was being displayed. From the speed data recorded, researchers did not detect a substantial difference in speeds between when one of the test messages was displayed on the TMCMS as compared to when the standard treatment message (i.e., caution) was displayed. This implies that although there was more information for a motorist to take in from the test messages, it was not significantly impacting their decision making process and thereby their driving behaviors. This is a positive result for the evaluated messages as it indicates the motorists did not have to slow down noticeably to take in the information provided.

With regards to passing behaviors on two-lane, two-way roads, it is very difficult to identify changes in behavior as this maneuver is 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 the drivers as compared to desired reactions at the convoy. Table 27 shows the observations recorded for each of the messages evaluated.

Table 27. Erratic Passing Behaviors.

Message	Observed Behavior (% of traffic observed)			
	Pass Multiple Vehicles	**Moved Into Convoy**	**Passed on Left Shoulder**	**Swerving to Observe Passing Distance**
CAUTION	1 %			4%
2 PAINT TRUCKS DO NOT CUT IN	3%			
2 PAINT TRUCKS PASS WITH CARE		26%	2%	
2 WORK TRUCKS DO NOT CUT IN				
2 WORK TRUCKS PASS WITH CARE	15%	33%	3%	

The PASS WITH CARE phrase appeared to be associated with more people moving back into the work lane between the work vehicles than any of the other messages. When paired with either the 2 PAINT TRUCKS or 2 WORK TRUCKS phrases, 26 and 33 percent of motorists, respectively, were observed making this maneuver. Drivers may believe that this action is using more caution when making the passing maneuver; however, if workers had been outside of the vehicle and moving between the trucks this maneuver could have terrible consequences. Also, making this maneuver could track paint across the road surface and onto cars when painting the centerline of a roadway. Moving back into the blocked lane is not a desirable action in many mobile work operations and therefore researchers do not believe that this phrase should be used.

None of the other phrases created significant observable differences in motorist behavior on the two-lane highway sites; therefore it is believed that they were not causing confusion or misjudgments by the motorists. Although all messages created significant queuing behind the convoy, this was mainly attributable to road conditions (e.g., sight distance, traffic volume) and

researchers did not discern any negative impact based on the message used. This is a good indication that the messages did not discourage the desired passing action by drivers when conditions allow. The messages also did not encourage drivers to pass during unsafe conditions as erratic maneuvers did not increase significantly.

Multi-Lane Roads

When observing mobile operations on multi-lane roads, researchers were most concerned with identifying if any of the messages would cause adverse effects that were greater than the standard sequential chevron pattern used to direct traffic. One hypothesis was that in taking away this directional cue (i.e., the chevron pointing towards the open lane) greater confusion may exist with motorists on what action to take. Although all messages were tested for adequate comprehension prior to field testing, the potential did exist for the message display to not always provide adequate legibility distance for conditions (since the sign controller automatically selected character heights, widths, etc.). If some motorists did not have adequate viewing time to read and react to the message presented, improper decisions and resulting driving behaviors could occur.

The first data set evaluated was speeds collected both upstream and at the convoy. Table 28 shows the average vehicle speeds recorded in the field and speed changes observed for both the left (work) lane and the right (open) lane.

Table 28. Multi-Lane Average Speed Analysis.

Message	Speed (mi/h)			Change in Speed Left Lane		Change in Speed Right Lane	
	At the Convoy	Upstream of Convoy		mi/h	Percent	mi/h	Percent
		Left Lane	Right Lane				
Chevrons	63.4	69.7	64.1	6.3	9%	0.7	1%
2 PAINT TRUCKS DO NOT CUT IN	61.7	68.7	65.2	7.0	10%	3.5	5%
2 PAINT TRUCKS STAY IN RGT LANE	61.7	72.2	65.9	10.6	15%	4.3	7%
2 WORK TRUCKS DO NOT CUT IN	62.0	71.3	66.1	9.2	13%	4.1	6%
2 WORK TRUCKS STAY IN RGT LANE	62.5	70.0	68.8	7.6	11%	6.3	9%

Note: All observed operations were working in the left lane on multi-lane facilities.

The data reported above shows no significant differences in speeds based on which message is being displayed. It is interesting to note that the greater speed change percentages were observed for the blocked (left) lane as compared to the open (right) lane traffic. Researchers believe this is mainly attributable to the fact that higher speed traffic typically travels in the left lane and therefore these drivers had to slow down more both for the convoy and to merge with traffic in the open lane.

As a further analysis of the speed data, researchers looked at the standard deviations of the speed samples for each message (Table 29). Researchers conducted this analysis because increases in the variances of speeds between vehicles have been associated with increases in crash rates at a location. Therefore, researchers wanted to determine if any of the messages were causing an operational concern from this stand-point.

Table 29. Multi-Lane Speed Standard Deviation.

Message	Speed Standard Deviation		
	At the Convoy	Upstream of Convoy	
		Left Lane	Right Lane
Chevrons	8.2	6.6	9.5
2 PAINT TRUCKS DO NOT CUT IN	8.4	7.1	9.4
2 PAINT TRUCKS STAY IN RGT LANE	7.2	6.8	6.7
2 WORK TRUCKS DO NOT CUT IN	7.7	6.8	8.0
2 WORK TRUCKS STAY IN RGT LANE	8.6	7.4	6.1

Researchers noted that again there were no significant differences in these values. Particularly, it was pleasing to note that the standard deviations observed at the convoy did not increase for the experimental messages as compared to the standard chevron treatment. This indicates that none of the messages were causing operational concerns with regard to speeds near the work area. In fact, as there was no practical change by message for either average speeds or speed variance, researchers concluded that all messages performed equally well on the multi-lane roads from a speed perspective.

In analyzing the lane changing data for this road type, 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. For the passing distance, researchers used three categories of distance estimations in data collection. These distances were: Region 1) 0-500 feet from convoy, Region 2) 500 – 750 feet, and Region 3) 750+ feet from the convoy. The lane changing information is presented in the next two tables.

Table 30. Erratic Lane Changing Behaviors.

Message	Observed Behaviors (% of traffic observed)				
	Passing Hesitations	Entering Convoy	Erratic Merging	Aggressive Driving	Total Erratic
Chevrons	9%	2%	4%	2%	17%
2 PAINT TRUCKS DO NOT CUT IN	0%	0%	0%	0%	0%
2 PAINT TRUCKS STAY IN RGT LANE	8%	0%	1%	0%	9%
2 WORK TRUCKS DO NOT CUT IN	9%	1%	1%	0%	11%
2 WORK TRUCKS STAY IN RGT LANE	5%	4%	0%	1%	10%

Changing the message did not create a significant increase in the observation of erratic maneuvers during the mobile operation. Again, these results suggest that the messages were not causing drivers any difficulties in making an appropriate driving decision. Researchers were especially interested in the erratic merging or hesitating behind the convoy categories of maneuvers as indicators of possible problems with the content of the test message. Neither of these actions increased as compared to the chevrons condition. Also, looking at the total erratic maneuvers observed for each of the different messages, all were slightly lower than the rate observed for the standard chevrons condition.

Table 31. Distribution of Distance Regions From the Work Convoy Where Lane Change Maneuvers were Made.

Message	% of Lane Changes Made in Each Region		
	0-500 ft from Convoy	500-750 ft from Convoy	750+ ft from Convoy
Chevrons	13	30	57
2 PAINT TRUCKS DO NOT CUT IN	7	26	67
2 PAINT TRUCKS STAY IN RGT LANE	11	36	54
2 WORK TRUCKS DO NOT CUT IN	24	34	42
2 WORK TRUCKS STAY IN RGT LANE	17	33	51

No message caused a significant change in how far away drivers were making their lane change maneuvers. The worst case scenario for the test messages would have been a significant jump in the percentage of drivers waiting until they were closer to the convoy before moving out of the work lane. This would have implied that more drivers were staying in this lane because they needed extra time to read the information prior to making a driving decision, or because they were confused as to the proper driving maneuver. This was not the case and therefore eliminated one of the concerns regarding the use of TMCMS.

CONCLUSIONS

The field evaluations were conducted on both two-lane, two-way and multi-lane facilities. As the operational expectations for these roadways under mobile work operations are not identical, researchers identified several points of interest that are independent and unique to each road type.

First, two-lane, two-way roads will be addressed. The following bullets outline the key findings of the field evaluations for this road type.

- The use of the test messages did not eliminate a speed differential between traffic and the convoy. However, researchers believe this is highly dependent on the sight distance and traffic conditions present on a roadway (i.e., if the left lane is clear and sight distance is good vehicles did not need to slow to convoy speeds to pass).

- Researchers observed that there was no practical impact on driver speeds for the test messages as compared to a caution condition. This is a positive finding for the evaluation as it indicates that motorists did not have to slow down discernibly to take in the information provided.

- The PASS WITH CARE test phrase had more people entering the convoy as compared to the other messages. Researchers believe that the motorist identified this as a safer (or careful) passing behavior. Therefore it is not recommended that this phrase be used for most painting situations where centerline paint is wet or when workers are outside a vehicle and could be working in the lane along the convoy area.

- Significant queuing was observed during all message evaluations; however, this condition is again attributable more to sight distance and traffic conditions and is not entirely dependent on the message content. No message was particularly worse from this perspective. In other words, no message appeared to either discouraged passing (as was a concern for DO NOT CUT IN from the motorist survey) or to encourage passing as a "free" operation (i.e., do not need to wait for a gap, but have the right-of-way in opposite lane).

With respect to the multi-lane evaluation, the following were the key findings.

- The observed speeds of traffic near the convoy were not different and did not create a difference in speed variance for the test messages as compared to the chevron condition.

- There was no disadvantage observed with respect to the distance away from the convoy that motorists were making lane changing maneuvers. In other words, the need to read the message did not encourage motorists to stay in the blocked lane longer than for the chevron treatment.
- The percentage of traffic making erratic maneuvers was slightly lower for all of the test messages as compared to the chevron display, suggesting a possible improvement in safety through the use of these messages.

CHAPTER 6: GUIDELINES

The use of truck-mounted changeable message signs (TMCMSs) for mobile operations is desirable for providing drivers with information to better prepare them for unexpected conditions. Traditionally, temporary traffic control for mobile operations has been limited to arrow panels (i.e. directional arrows and caution displays) and sometimes static warning messages mounted to the back of the work vehicles. The use of warning signs in advance of the work operation itself is usually not practical due to the constant movement or stop-and-go nature of the work operation. TMCMSs are a means of filling an information gap for these mobile operations and providing drivers with better information regarding both the operation and the expected actions based on the operation.

BASIC TMCMS MESSAGE DESIGN PRINCIPLES

The following key points should always be kept in mind when designing and displaying messages on TMCMS:

- The character heights typically used on TMCMS only provide enough sight distance to allow 2 units-of-information (or phrases) to be displayed in a message.
- For most applications, the two critical units that should be displayed on a TMCMS are 1) a problem/roadwork descriptor, and 2) an action statement.
- A message can<u>not</u> contain more than 2 phases.
- Message elements should not flash or scroll.
- Abbreviations should be used when necessary to keep the message to two phases, and should be used in accordance with accepted practices.

Finally, the selection of message elements should be based on the identification of specific concerns for the type of operation and road. These concerns include (but are not limited to):

- Communication of the convoy situation.
- Communication of passing or action information.
- Avoidance of paint tracking during striping.
- Speed differential.

RECOMMENDED PHRASES AND MESSAGES

Based on the findings of this research and basic message design principles, researchers have created a sampling of recommended messages for use on TMCMS during mobile operations. These messages are given in Table 32 and are defined by the type of work, road type, and identified concerns being addressed by the message.

Table 32. Recommended Messages.

Operation	Road Type	Primary Concern	Phase 1	Phase 2
Striping	2-Lane, 2-Way	Convoy recognition	# PAINT TRUCKS	DO NOT CUT IN
		Convoy Recognition & Tracking Paint	# PAINT TRUCKS	YELLOW [*or WHITE*] LINE WET
		Tracking Paint	YELLOW [*or WHITE*] LINE WET	DO NOT CUT IN
	Multi-lane	Convoy recognition	# PAINT TRUCKS	DO NOT CUT IN
		Convoy & Passing Maneuver	# PAINT TRUCKS	STAY IN LFT [*or RGT*] LANE
		Tracking Paint	# PAINT TRUCKS	CNTRLINE [*or EDGELINE*] WET
Sweeping	2-lane, 2-way Or Multi-lane	Debris/Dust obstructing vision	SWEEPING AHEAD	REDUCED VISION
	Multi-lane	Lane encroachment	SWEEPING AHEAD	STAY IN LFT [*or RGT*] LANE
Workers Out of Vehicle	2-lane, 2-way Or Multi-lane	Protection of Workers	# WORK TRUCKS	WATCH FOR WORKERS
		Reducing Vehicles Entering Convoy as protection.	# WORK TRUCKS	DO NOT CUT IN

Where there is a # symbol, the appropriate number of trucks that are present in the convoy should be inserted.

Items in italics are alternatives to be used in place of other similar descriptors shown in the message. For example, Yellow could be interchanged with White.

If the recommended messages provided in the previous table do not address a special circumstance encountered during a mobile operation, there are further message elements that were evaluated and found to be appropriate for use on TMCMS. The following sections identify these elements based on the type of mobile work operation being performed. These elements are listed in priority order, with the element considered the best listed first in the table.

Each column of the table represents the appropriate phrases to use in either the first or second phase of a message. As such, these elements can be mixed-and-matched to create the best possible message for a given circumstance. Note, it is not required that two phases be used; a single phase is acceptable. However, two phases is the upper limit of information recommended for use.

Striping

Two-Lane, Two-Way Roads

Table 33. Message Elements for Striping Operations on 2-Lane, 2- Way Roads.

	Phase 1 Message Elements	**Phase 2 Message Elements**
1	# PAINT TRUCKS	DO NOT CUT IN
2	# WORK TRUCKS	YELLOW [or *WHITE*] LINE WET
3	SLOW	WET PAINT
4	YELLOW [*or WHITE*] LINE WET	

Multi-Lane Roads

Table 34. Message Elements for Striping Operations on Multi-Lane Roads.

	Phase 1 Message Elements	Phase 2 Message Elements
1	# PAINT TRUCKS	STAY IN LFT [*or RGT*] LANE
2	# WORK TRUCKS	PASS ON LEFT [*or RIGHT*]
3	SLOW	DO NOT CUT IN
4	WET CENTRLINE [*or EDGELINE*]	WET CENTRLINE [*or EDGELINE*]
5	LEFT [*or RIGHT, CENTER*] LANE BLOCKED	WET PAINT
6		DO NOT CROSS
7		STAY OFF

Sweeping Operations

Table 35. Message Elements for Striping Operations on 2-Lane, 2- Way Roads.

	Phase 1 Message Elements	Phase 2 Message Elements
1	SWEEPING AHEAD	REDUCED VISION
2		LIMITED VISION
3		STAY IN LFT [*or RGT*] LANE[a]
4		SLOW

[a] use when dust/debris in air is not a concern.

Operations with Employees Out of Vehicles

Examples of mobile operations where employees may need to leave their vehicles would be pothole patching or cracksealing operations.

Table 36. Message Elements for Striping Operations on 2-Lane, 2- Way Roads.

	Phase 1 Message Elements	Phase 2 Message Elements
1	[#] WORK TRUCKS	WATCH FOR WORKERS
2	SLOW	STAY IN LFT [*or RGT*] LANE
3		PASS ON LEFT [*or RIGHT*]
4		DO NOT CUT IN
5		LFT [*or RGT, CNTR*] LANE BLOCKED

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APPENDIX A.
HUMAN FACTORS SURVEY ANSWER FORM

Location: _____	**Participant # ____**
Date: _____	**Researcher: ____**

ANSWER FORM
SURVEY 1

This survey is being conducted by the Texas Transportation Institute, which is part of the Texas A&M System. It is being sponsored by the Wyoming Department of Transportation. The purpose of the survey is to improve driver information needs during road work activities. Now, before we get started we have a few demographic questions, which will used for statistical purposes only

BACKGROUND INFORMATON

Gender: ❒ male ❒ female
Age: ❒ ≤ 24 ❒ 25-54 ❒ 55+
Education: ❒ High School Diploma or less ❒ Some College or greater

Part 1: Comprehension
During the first part of this survey, I am going to show you different pictures of a road where there is a work vehicle shown. Assume that you are traveling down the road and approach the work vehicle shown in the picture. When you press the space bar your first display will appear on the laptop monitor. While the picture is on the screen, I will ask you questions about the information shown. Do you have any questions?

Message 1:

Questions:
1. As a driver, what does this message mean to you? _____

_____

_____

2. In your opinion, why is this information being provided to drivers? _____

_____

_____

_____

Press the space bar to see the next sign.

Message 2:

Questions:
1. As a driver, what does this message mean to you? _____

_____

_____

2. In your opinion, why is this information being provided to drivers? _____

_____

_____

_____

Press the space bar to see the next sign.

Message 3:

Questions:

1. As a driver, what does this message mean to you? _____

_____

_____

2. In your opinion, why is this information being provided to drivers? _____

_____

_____

_____

Press the space bar to see the next sign.

Message 4:

Questions:

1. As a driver, what does this message mean to you? _____

_____

_____

2. In your opinion, why is this information being provided to drivers? _____

_____

_____

_____

Press the space bar to see the next sign.

Message 5:

Questions:

1. As a driver, what does this message mean to you? _____

_____

_____

2. In your opinion, why is this information being provided to drivers? _____

_____

_____

_____

Press the space bar to see the next sign.

Message 6:

Questions:

1. As a driver, what does this message mean to you? _____

_____

_____

2. In your opinion, why is this information being provided to drivers? _____

_____

_____

_____

Press the space bar to see the next sign.

Message 7:

Questions:

1. As a driver, what does this message mean to you? _____

_____

_____

2. In your opinion, why is this information being provided to drivers? _____

_____

_____

_____

Part 2: Abbreviations

Next we are going to look at some abbreviations that may be used on truck-mounted changeable message signs during work operations. Please tell me what you think the following abbreviations mean:

TRK _____ RGT _____

CNTRLINE _____

Part 3: Preference

Finally, we need your advice on selecting phrases to use in messages that would be displayed on these truck-mounted changeable message signs. I am going to describe for you a situation where the DOT would like to provide the driver with additional information about work activities on the roadway. There will be several messages that could be used to provide this type of information displayed on the computer screen. I want you to select the message you think would be best to use for the situation described and why you think that message would be best.

1) *The work ahead is painting the lines on the road and workers want to keep motorists from driving on the wet paint*: # _____
   Why? _____
   _____

2) *Multiple vehicles are participating in the work ahead*: # _____
   Why? _____
   _____

3) *There are multiple work vehicles and drivers should not move back into the work lane between the work vehicles:* # _____
   Why? _____
   _____

4) *Workers want to identify for drivers what lane is safe to use near the convoy:* # _____
   Why? _____
   _____

5) *There are workers outside of vehicles working in the road:* # _____
   Why? _____
   _____

Thank you, that concludes our survey.

APPENDIX B.
FIELD DATA COLLECTION SITE DETAILS

Site #	Location	Speed Limit (mi/h)	# of Lanes/ Direction	Convoy Speed (mi/h)	Work Lane	Evaluated Message
1*	US 287 – In Laramie	N/A	2	N/A	Left	Chevrons (sequential)
2*	US 287 North of Laramie, NB	65	2	8	Left	2 Paint Trucks / Stay in Rgt Lane
3	US 287 North of Rawlins NB & SB	65	Mostly 1, Minimal 2	14	N/A Left	Caution; 2 Paint Trucks / Do Not Cut In 2 Work Trucks/ Pass With Care
4	WY 76 Service Road to Sinclair EB	55	1	N/A	N/A	2 Work Trucks / Pass With Care
5	I-80 , west of Rawlins WB & EB	75	2	14	Left	Chevrons (sequential); 2Work Trucks / Do Not Cut In; 2 Work Trucks/ Stay in Rgt Lane
6	I-80 west of Rawlins WB & EB	75	2	16	Left	2 Work Trucks/ Stay in Rgt Lane; 2 Paint Trucks / Do Not Cut In 2 Paint Trucks / Stay in Rgt Lane
7	WY 230 WB @ Laramie	50 /65	1	14	N/A	2 Paint Trucks / Pass with Care
8	WY 230 EB, west of Laramie	65	1	14	N/A	2 Work Trucks/ Do Not Cut In
9	WY 72, NB outside of Hanna	65	1	11	N/A	2 Work Trucks/ Do Not Cut In

* Researchers were not able to use data collected at this site.