A Systematic Approach to Selection of CMS Messaging During Nonrecurring Events

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FOREWORD

Changeable message signs (CMSs) serve as safe, accessible sources of relevant travel information. Previous research has provided insight into the potential value of CMSs as sources of traveler information.[(1)] However, a gap remains in efforts to document the information and the messaging that effectively promote desired changes in traveler behavior to improve safety and the flow of the transportation system during nonrecurring events.

This report includes a review of the literature on CMSs, and it documents two experiments aimed at exploring the specific CMS messages that are most likely to influence traveler behavior. The researchers designed the study procedures to fill gaps in existing research and thereby obtain information that could be used for generating a systematic approach to the selection of CMS messaging. The results identify the potential value of different CMS messages as well as circumstances in which multiple messages may be equally valuable to drivers.

This report may be of interest to traffic management center operators, agency leadership, transportation engineers, transportation researchers, and others who share an interest in promoting safe and efficient traffic flow.

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Changeable message sign (CMS) messaging can be an important tool for distributing traveler information to drivers. Careful CMS message selection may help drivers make informed travel decisions and increase the safety and usability of roadways, particularly during nonrecurring events. The current work consists of two experiments designed to increase understanding of the ways drivers perceive and respond to different CMS messages. Experiment 1 took an integrative research approach wherein several methodologies targeted open research questions regarding weather, delay, slow down, and intended-audience messages. Experiment 2 used a driving simulator to examine the potential for different CMS messages to elicit changes in route, prompt lane changes, and cause drivers to change speed. The study aims to improve the safety and the flow of the transportation system during nonrecurring events by assessing and documenting specific CMS messages that effectively promote desired changes in traveler behavior.</td></tr>
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SI* (MODERN METRIC) CONVERSION FACTORS				
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 yard	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
		NOTE: volumes greater than 1,000 L shall be shown in m^3		
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2,000 lb)	0.907	megagrams (or “metric ton”)	Mg (or “t”)
		TEMPERATURE (exact degrees)		
°F	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	°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	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa
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	35.314	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 (or “t”)	megagrams (or “metric ton”)	1.103	short tons (2,000 lb)	T
		TEMPERATURE (exact degrees)		
°C	Celsius	1.8C+32	Fahrenheit	°F
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	2.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

*SI is the symbol for International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380.
(Revised March 2003)

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LIST OF ABBREVIATIONS AND ACRONYMS

CMS	changeable message sign
DOT	department of transportation
FHWA	Federal Highway Administration
MUTCD	*Manual on Uniform Traffic Control Devices*
SSQ	Simulator Sickness Questionnaire
TMC	traffic management center

CHAPTER 1. LITERATURE REVIEW

Changeable message signs (CMSs), also referred to as “variable message signs” or “dynamic message signs,” are programmable, electronic message signs capable of displaying multiple alternative messages.[2] Traffic management centers (TMCs) use CMSs to display traveler information to help drivers make informed travel decisions. CMSs offer several advantages as dissemination sources for traveler information. First, information presented on CMSs is accessible to all drivers—even those without radios or personal electronic devices. Drivers can obtain traveler information from CMSs with minimal distraction from the primary driving task.[3] Additionally, information obtained from CMSs is almost always relevant to the current driving situation. The ability of CMSs to serve as safe and accessible sources of relevant traveler information has resulted in CMSs’ being one of the most highly used resources for disseminating traveler information.[3]

Research suggests that traveler information is most needed during nonrecurring events.[4] Nonrecurring events are situations that lead to temporary changes in a roadway’s capacity or travel time reliability. Traffic incidents, roadwork, adverse weather conditions, and planned special events are examples of nonrecurring events that can lead to unexpected and often substantial travel delays. Drivers can use traveler information to avoid the delays and potential safety risks associated with nonrecurring events by making appropriate changes to their travel behavior. Traveler information can provide the greatest reductions in travel time, and drivers value it most during nonrecurring events.[5,6]

Past research on the characteristics of CMS signs has yielded information on such topics as sign and letter visibility, message and phase timing, and use of color and animation.[7] The *Manual on Uniform Traffic Control Devices* (MUTCD), which sets forth national standards for the use of CMSs, has incorporated much of that work.[2]

The current review focuses on CMS messaging during nonrecurring events. Specifically, the review outlines past research on generating CMS messages that drivers can read and understand, that engender trust in CMS messaging, and that encourage appropriate changes in driver behavior.

MESSAGES THAT DRIVERS CAN READ AND UNDERSTAND

Drivers passing a CMS have a limited amount of time to read and process the information displayed on the sign before the sign goes out of view. Drivers read and process the information while also paying sufficient attention to the primary driving task. To aid CMS operators in creating messages drivers have time to read, MUTCD sets forth standards regarding the amount of information for display on a CMS.[2] MUTCD’s provisions indicate that the displayed information be categorized into units of information. A unit of information briefly answers a single question. Table 1 gives examples of various questions whose answers are in the form of single units of information.

Table 1. Examples of single questions and units of information that answer those questions.

Question	Unit of Information
What event is occurring?	ROADWORK
What is the effect of the event?	20 MIN DELAY
What action does the event indicate that the driver take?	USE OTHER ROUTE

Only one unit of information is to appear on each line of a CMS.(2) More than one unit of information on a line decreases processing speed and message comprehension.(8) Separating units of information by line also gives drivers the opportunity to quickly move attention back and forth between the information on the CMS and the roadway. Drivers can read one line of information, return their eyes to the road, and then choose to move their attention back to the second line of the message if traffic conditions permit.(3) That method of moving attention back and forth between tasks is frequently applied in multitasking situations.(9) The back and forth helps ensure drivers maintain adequate attention on the primary driving task by preventing the need to remove attention from the roadway for long periods.

CMSs are limited to three lines, meaning that MUTCD standards permit CMS operators to display only three units of information on a CMS at one time. The operators are allowed to increase the amount of information in a CMS message with a two-phase message—that is, a sign that alternates between two different groups of information. When a message has two phases, some drivers may see only one phase of the message or may see the message in reverse order. Because of such alternating messages, each phase of the message is to be understandable on its own, and drivers' ability to understand the message may not be influenced by the display order of the two phases. MUTCD standards require that an entire message consist of no more than two phases. Additionally, MUTCD stipulates that across those two phases, no more than four total units of information be presented on roads with speeds greater than 35 mph, and no more than five total units be presented on roads with speeds less than 35 mph.(2)

It is suggested that if a CMS has two phases, all units of information should change at least once. Without a change in the first line of a message, drivers are at risk of missing information from one of the phases of the CMS because they do not realize the message has changed. Even when drivers miss no information, research indicates that two-phase messages that repeat the first line in a message take longer for drivers to read.(8) MUTCD standards also define phase durations and interphase intervals.(2)

MUTCD also specifies the maximum length of a CMS message.(2) It is up to CMS operators to decide on optimal CMS message length for a specific nonrecurring event. Drivers have a short time to read and comprehend CMSs, and increases in the size of a CMS message generally lead to increases in the time it takes to read and comprehend that message.(10) As a result, some State CMS manuals tend to encourage the removal of unnecessary words or phrases from a CMS message.(11) But how much information is necessary? Peeta, Ramos, and Pasupathy conducted a survey to assess the CMS message that would make a driver most likely to select an alternate route.(12) The survey asked drivers how willing they would be to divert after viewing a sign that gave information that a crash had occurred, displayed the expected delay time, suggested the best alternate route, or conveyed some combination of those units of information. Participants exposed to at least two of the three units of information indicated greater willingness to change routes than did those who viewed messages with only one unit of information, thereby suggesting that having more information may be advantageous. However, when Jeihani and Ardeshiri asked participants to rate how likely they would be to take an alternate route in response to different CMS messages, higher ratings resulted for a message with two units of information (e.g., ACCIDENT AHEAD / TAKE THE DETOUR) than for a message with three units of information (e.g., ACCIDENT AHEAD / 20 MIN DELAY / TAKE THE DETOUR).[13]

The authors speculated that too much information on a CMS could cause confusion. Conflicting findings on the value of information quantity may be results of the specific messages on the CMSs. Some CMS phrases may carry more weight than others such that the appearance of those phrases reduces the quantity of required information.[14] Indeed, in a stated-preference study, Madanat, Yang, and Yen found that the proportion of participants who indicated they would divert in response to CMS messages describing a nonrecurring event tended to increase as the number of units of information included in the CMS message increased from one to four.[15] However, the researchers also found that the highest rates of route diversion resulted from a message that contained only two units of information when one of those units was an action suggestion urging the reader to use an alternate route. Thus, the level of effectiveness of a specific CMS message in influencing driver behavior may depend more on the message's content than on its length.

One danger of providing too much information on a CMS is that drivers may reduce their speed to ensure they can read the entire message. Drivers who slow down while approaching a CMS can cause traffic bottlenecks and become safety hazards. Erke, Sagberg, and Hagman noted that on a congested highway, braking by even a small number of drivers can trigger chain reactions wherein one vehicle's sudden braking to read a CMS can force following vehicles to brake or change lanes, which can in turn lead to additional braking by other upstream vehicles such that the average speed of traffic approaching the CMS becomes significantly reduced.[16]

Past research has split regarding whether drivers reduce their speed to read CMS messages. In a driving simulator study, Harder, Bloomfield, and Chihak found reductions in speed at the point at which CMS messages became legible—particularly on the parts of older drivers.[17] Field studies conducted by Erke, Sagberg, and Hagman and Jamson, Tate, and Jamson reported similar reductions in speed—but only for CMS messages that had four lines of text—a message length not endorsed by MUTCD.[2,16,18] A number of other researchers have failed to find reductions in driving speed for CMS messages that follow MUTCD provisions.[3,14,19] For example, Wang, Keceli, and Maier-Speredelozzi failed to detect significant reductions in speed in an assessment of loop detector data collected as traffic approached different CMS messages.[20] Interestingly, in a survey of drivers in the same area, 90 percent of drivers self-reported that they either always or sometimes slowed down when approaching an active CMS, suggesting that drivers may feel that slowing down is an appropriate response to encountering a CMS. Indeed, Alm and Nilsson saw slowdowns by all drivers who received on-road traveler information in advance of a nonrecurring event—even by those who received the information in the form of a flashing red light that did not offer any text to read.[21] The authors concluded that slowing down may be the default reaction to receiving traveler information. If so, then the reductions in speed seen among some drivers in response to CMS messages may be responses to the information about the upcoming nonrecurring event rather than reactions to some kind of difficulty in reading the message.

Both the number of words displayed on a CMS and the specific words used for conveying the information influence drivers' CMS comprehension and reading speed. Words a driver is unfamiliar with or does not expect take longer to read, are less well understood, and are less likely to change behavior than are words a driver is accustomed to seeing on a CMS.[16,22,23] Literate adults read words as whole units rather than as groups of letters, such that reading speed is influenced more by familiarity and context than by word length. The implications for CMS message design are twofold: First, CMS operators would do well to avoid using abbreviations. Abbreviations that are unfamiliar to drivers or difficult to interpret take longer to read than their unabbreviated counterparts despite their having fewer letters. MUTCD lists abbreviations it considers appropriate for use on CMSs.[2] Second, to the greatest extent possible, operators help drivers when they strive to be consistent in their uses of specific words and phrases. CMSs serve in unique information contexts, and if messaging is consistent, drivers can use that context to read and process the information on CMSs more quickly.

MESSAGES THAT PROMOTE TRUST IN CMS USE

A driver's trust in CMS information influences the driver's use of that information.[24,25] The relationship between trust and use of CMS information is likely to be circular.[24] Drivers who trust the traveler information messages they see on CMSs are more likely to use the information to make appropriate changes in their behavior. Likewise, drivers who successfully use CMS messaging to avoid a delay increase their trust in CMS messages due to their positive experiences. Trust in and use of CMS messaging seem to be parts of larger cycles of trust in and use of traveler information in general. Drivers who seek out traveler information can use the information they gather to form a more complete picture of the road network. Those drivers will then be both in a position to take advantage of the alternate routes available within that network and more likely to use the alternate routes after encountering a CMS message about a delay on their current route.[25]

Cultivating and maintaining trust in CMS messaging may be important goals. Dudek and Ullman emphasize ensuring that information on CMSs remain up to date.[11] Drivers who view incorrect or out-of-date information lose trust in messaging.[10,26] Drivers are somewhat tolerant of occasional errors in CMS messages; however, repeated inaccuracies lead to mistrust and disuse.[10]

One potential source of perceived CMS inaccuracies is outdated messaging. Even small changes in the frequency with which CMS messages get updated can have large impacts on the accuracy of those messages.[27] Including time stamps that indicate when a message was last updated has been proposed as one means of maintaining drivers' trust in CMS messaging.[28] However, the effect that that practice would have on drivers is unclear. On one hand, drivers do tend to show increased responsiveness to a message when they a watch a message change and therefore infer that the message is up to date.[29] However, when Lerner et al. directly assessed the effects of time stamps on participants' reactions to CMS messages, time stamps failed to influence drivers' behavior, although they did increase the time it took to read the messages.[10] A more beneficial solution may be to reduce the frequency with which messages get updated by avoiding CMS messages that are overly specific.[30]

Richards and McDonald argued that another potential source of mistrust in CMS messaging may come from misinterpretation of blank CMSs—that is, CMSs that do not display any information.[26] In the Richards and McDonald study, drivers kept travel journals about their encounters with CMSs during the course of a workweek. On one of the days, a CMS along the route malfunctioned and remained blank throughout the day. Drivers interpreted the blank sign as an indication that the road ahead was clear and became displeased when they encountered an incident downstream from the malfunctioning sign. For that reason, some operators choose to never leave a CMS blank. Haghani et al. endorse displaying travel times in the absence of information about a nonrecurring event.[31] If travel times can update automatically, they can warn about a developing delay even prior to the time that a CMS operator could verify the event triggering the delay and create a message about the event.

Other options are to display all-clear or safety messages on CMSs when no nonrecurring events have been reported.[32,33] However, universal support for these practices is lacking. First, research has found that all-clear messages reduce diversion rates relative to blank signs, which could increase route congestion.[34] Moreover, proponents of blank message signs argue that drivers who typically encounter messages that are not relevant to their commutes may come to ignore CMS messaging altogether. Chatterjee et al. blamed that learned inattention to CMS messages for the extremely low (0.03 percent) rate of compliance with CMS messages that they found in their study of drivers in London.[35] The authors noted that CMSs in the city were typically used to warn drivers about events planned for the future. As a result, drivers became highly unlikely to respond to messages about events currently occurring on the roadway. Choosing to leave a sign blank can prevent drivers from becoming overloaded with uninformative messaging and can reduce CMS energy and maintenance costs.[32]

Dudek and Ullman warn that drivers lose trust in CMS messaging if they are exposed to vague, overly simplistic messages or displays of information that can be easily observed instead.[11] For example, information about adverse weather conditions that are not visible (e.g., BLACK ICE) can help drivers take appropriate action, whereas information about an event that is already visible on the roadway (e.g., FALLING SNOW) does not provide any new information. Similarly, messages about the length of a delay (e.g., 20 MIN DELAY) can help drivers make travel decisions. However, travel information about a general delay or congestion is beneficial only if the information is distributed far enough upstream that drivers cannot already see the congestion associated with the delay.[36] Limiting CMS use to informative and helpful messaging can help maintain driver trust in and use of CMSs.

MESSAGES THAT ENCOURAGE APPROPRIATE CHANGES IN DRIVER BEHAVIOR

Creating messages drivers can read and trust is only the first step in CMS message generation. Multiple studies have demonstrated that simply having access to or having positive attitudes about CMSs is not always sufficient to induce behavioral change.[35,37] Consider the findings of Lerner et al., who conducted a series of focus groups in three U.S. cities.[10] While most participants indicated that they liked to see traveler information and felt the information was helpful, most did not feel the information influenced their route choices. Data from daily driving logs a portion of the participants kept confirmed the lack of influence. Regarding traveler information, legibility and trust are necessary but not always sufficient to encourage behavioral change.

In some instances, low rates of behavioral change in response to CMS messages are acceptable. Even drivers who do not make changes in their driving behavior can still benefit from receiving traveler information via CMSs. Weaver, Balk, and Arnold found that participants who received traveler information before encountering a nonrecurring event reported less stress during their drive than did drivers who did not receive any information.[14]

Traveler information seems to reduce the potential frustration associated with driving during nonrecurring events. Indeed, many drivers report feeling better informed after viewing traveler information on a CMS.[26] Drivers also report using the information to confirm that they are on the correct route and feeling safer after viewing CMS messages because they know that other drivers on the roadway have been informed about an upcoming nonrecurring event.[38,10] Thus, using CMSs simply to inform drivers about a nonrecurrent event, without anticipating any overt change in their behavior, is a valid and appreciated use of CMS messaging.

In other instances, the goal of CMS messaging is to encourage drivers to act. When encouragement is the goal, the specific words and phrases the CMS message uses can affect how likely drivers are to make changes in their behavior. The remainder of this review outlines research on specific words and phrases CMS messaging uses and discusses the impact that those units of information have on driver behavior. Specifically, this section assesses research on the following units of information:

- Event type.
- Effect of event.
- Location of event.
- Suggested action.
- Signal words.
- Intended audience.
- Time and duration of event.

Event Type

Event type refers to the type of nonrecurring event currently affecting travel. CMS messages can convey information about a number of different types of nonrecurring events, including incidents, such as crashes or disabled vehicles; roadwork, such as pavement repair or construction; weather events, such as ice or flooding; planned events that cause excess traffic, such as concerts or athletic events; and planned events that block roads, such as street fairs or parades. Past research suggests that including event type in a CMS message leads to increased changes in driver behavior compared with CMS messages that do not include event information.[34,39] For example, Huo and Levinson found that a CMS message indicating a delay was due to a nonrecurrent event was more effective than a message indicating a delay was due to congestion.[40] However, the impact of specific event types is not consistent across all studies.

Jindahra and Choocharukul found that information about road construction increased diversion rates, but information about crashes did not.[22] In contrast, Wardman, Bonsall, and Shires found that crash information was more effective in influencing diversion rates than was information about roadwork.[34] In a comparison of the influence of messages about 10 different types of nonrecurring events, Weaver et al. found that only three of the events were associated with diversion ratings higher than those found for messages that did not include event information.[14] The authors concluded that whether or not event information affects a driver's response to a CMS message depends on the perceived severity of the event. They suggested that event type be included in CMS messages if drivers perceive that the event is likely to have a severe impact on the roadway or if the event itself informs drivers of the appropriate response to the event.

One of the classes of events that drivers likely perceive as severe and informative is a nonrecurring event involving weather. Drivers usually view weather events such as snow, ice, fog, heavy wind, and flooding as having severer impacts on roadways than do other types of nonrecurring events such as incidents and roadwork.[14] Such weather events affect entire roadway systems rather than specific routes and often have fairly long durations. Weather events are likely not only to increase congestion but also to affect visibility and traction directly. As a result, the safety impacts of a weather event often exceed impacts associated with other kinds of nonrecurring events.

Drivers seem to understand the special status of weather events and make more significant changes to their travel plans in response to weather information than they do in response to other types of nonrecurring events—particularly when they get traveler information in advance of the event.[14,41,42] For example, Luoma et al. found that many drivers reduced their speed and increased their following distance after viewing a message warning of a slippery roadway.[38] Drivers also reported testing the slipperiness of a road, increasing their attention to the road, and reducing overtaking as a result of the traveler information. CMS messages about a weather event can result in multiple positive effects on driving behavior as drivers make the changes they feel are most appropriate for dealing with that event. The specific phrases used to display an event type in a CMS message can influence drivers' perception of event severity. For example, Ullman et al. found that focus group participants perceived the message ROAD FLOODED as referring to a severe event in which a road was impassable due to flooding, whereas the message WATER ON ROAD indicated a less severe flooding event in which the road was still functional.[43] Weaver et al. found a similar result.[14] Drivers asked to evaluate the effectiveness of different CMS phrases rated the message ROAD FLOODED as more effective in conveying an event that is affecting traffic than they did other messages like FLOODING, STANDING WATER, or WATER ON ROAD. In addition, messages that indicated an event was possible rather than definite (e.g., FLOODING POSSIBLE and POSSIBLE BLACK ICE) or that an event was occurring in only some areas (e.g., ICY SPOTS and AREAS OF DENSE FOG) were seen as less effective than similar messages that did not include qualifiers. In attempts to encourage behavioral change, including qualifying information as part of the event type description on a CMS is likely to be counterproductive.

Weather event messages like SNOW, ICE STORM, or BLACK ICE convey a sense of severity that can increase a driver's likelihood of changing behavior. Information about fog or heavy winds, though often viewed as less severe, are informative regarding the type of change that might be beneficial to driving behavior (i.e., reduced speed). In each case, the event itself conveys information about the potential threat associated with the nonrecurring event and is therefore likely to be helpful to drivers. In contrast, specifying the event type is less crucial for events that are perceived as less severe or that do not provide information about specific changes to be made in driving behavior. For example, knowing a crash has occurred does not provide specific information about the effect the event is having on the roadway, since crashes can be of different severities and have different effects on traffic. Likewise, drivers might find it helpful to react similarly to a lane closed for pavement repair and a lane closed due to a disabled vehicle. In that situation, knowing the lane is closed is more critical than knowing the source of the lane closure. In such instances, CMS operators would do well to prioritize the effect of event information over the event type.

Effect of Event

Effect of event information advises drivers about the impact a nonrecurring event is having on a roadway and can provide a reason to change driving behavior. Some of the most common effects of nonrecurring events are road or lane closures and travel time delays.

Road Closed

Nonrecurring events that have the severest impact on travel plans are those that result in road closures. Closing a road forces all travelers who had intended to use that road to change their travel plans. Dudek and Ullman advise that the ROAD CLOSED effect of a nonrecurring event is the most efficacious piece of information that can be included in a CMS message, and CMS operators would do well to always give them priority.[(11)] Participants given road closure information tend to have diversion rates that are nearly 100 percent, such that additional information about event type or suggested actions provide little additional effect.[(14,16)] When asked to rate different road closure messages based on their effectiveness, participants rated messages that used the term “closed” (e.g., ROAD CLOSED or ALL LANES CLOSED) as more effective than messages that used the term “blocked” (e.g., ALL LANES BLOCKED).[(14)] When a nonrecurring event results in a road closure, researchers recommended that that information be prioritized and placed on the first line of the CMS message and, to prevent ambiguity, that the message include the word “closed.”[(11)]

Lane Closed

When a nonrecurring event results in a lane reduction, the nature of the CMS message indicating the lane closure can influence the action drivers take. Schroeder and Demetsky found that CMS messages indicating the location of a lane closure (i.e., right lane or left lane) led to reduced route diversion rates relative to messages that indicated either the number of lanes that were closed or that had no lane closure information.[(19)] Drivers who receive information about the direction of a lane closure change lanes earlier than do drivers who do not receive the information and, as a result, are less likely to consider other possible actions, such as taking an alternate route. Information about a lane closure can also have an effect on drivers’ speed. Alm and Nilsson found that participants who received CMS instruction to move into the open lane (e.g., USE LEFT LANE) not only changed lanes earlier than those who did not receive instruction but also retained higher speeds throughout the lane closure than those who did not receive any information.[21] Thus, the specific message that warns drivers about a lane closure should consider the behavior that the message is trying to encourage.

When the goal is to encourage an early merge, researchers recommended indicating the location of the lane closure, which typically means using the terms "right" or "left." Ullman found that when multiple lanes are closed, drivers prefer CMS messages that lead with such directional or locational information (e.g., RIGHT 2 LANES CLOSED), as opposed to messages that lead with number of lanes closed (e.g., 2 RIGHT LANES CLOSED).[43] The terms "right" and "left" seem to have some difficulty in directing attention due to the inconsistent mapping of those directions when speakers and listeners are not sharing the same reference point.[44] Inconsistent messaging has the potential to exacerbate that problem. As a result, variations in directional words are to be avoided—particularly within the same sign (e.g., RIGHT LANE CLOSED / MERGE LEFT).[45] So far, attempts to assess whether it is better that a CMS message indicate a lane closure in reference to the lane that is closed (e.g., RIGHT LANE CLOSED) or to the lane that is open (e.g., LEFT LANE OPEN) have been inconclusive, whereas assessments of the potential benefit of more commanding messages (e.g., USE LEFT LANE or MERGE LEFT) have not yet been explored.[19]

Delay

One common effect of nonrecurring events is that they produce delays in travel time. Drivers who receive information about a delay are more likely to select an alternate route.[12,26,40] Delay messages often attempt to specify the magnitude of the delay—a practice that helps drivers understand the severity of the nonrecurring event and that promotes changes in driver behavior.[10,34,46] Such delay messages can be broadly divided into quantitative and qualitative messages.

Quantitative delay messages use numbers to calculate the magnitude of the expected delay. Stated-preference surveys suggest that participants are sensitive to small changes in the magnitude of a delay, such that a positive linear relationship exists between delay length and the proportion of drivers who divert from the delayed route.[34,47] However, examinations of actual diversion rates in field and simulation studies indicate that drivers are less sensitive to small variations in delays. Instead, diversion rates tend to follow a more stepwise pattern wherein a large increase in diversion rates results once a particular delay threshold has been reached.[47,48]

CMS operators can quantify delays with regard to queue length, traffic speed, total travel time, and delay time.[10,47,48] While all of these methods of indicating a quantitative delay influence driver behavior, some methods have proved more effective than others. Lerner et al. found that drivers could process delay messages that included time more quickly than they could messages involving speed.[10] Moreover, drivers processed more quickly messages that included time if the message included a unit of measurement (e.g., MINS). When CMSs use time to inform drivers about a nonrecurring event, Dudek and Ullman recommend that the time displayed specify length of the delay rather than total trip time.[11] The authors found that drivers informed about a nonrecurring event expect the time that accompanies the message to specify the additional delay the event is causing rather than the total travel time. Furthermore, trip travel time can be more difficult for CMS operators to estimate and easier for drivers to invalidate. Using added delay time instead of estimated trip time could help engender driver trust in CMS messages.

If CMS operators cannot accurately estimate the precise timing associated with a delay, they may prefer to display a qualitative delay message. Qualitative delay messages use adjectives to describe the magnitude of a delay. Research suggests that drivers are sensitive to qualitative delay descriptions. Drivers are more likely to divert in response to a message about a long delay than they are in response to a message about a short delay, and they rate MAJOR DELAY as more effective in indicating that a nonrecurring event is affecting traffic than they do DELAY.(14,26)

Some research has attempted to assess whether drivers associate different qualitative messages with specific quantitative values. For example, Weaver, Balk, and Arnold found that drivers ranked MAJOR DELAY as more effective than other qualitative messages and equivalent to 20 MIN DELAY.(14) However, this study used only one quantitative message, so the way drivers would have compared this message with even longer quantitative delays (e.g., 30 or 40 MIN) is unclear. On Toronto's Highway 401, which has a speed limit of 62 mph, MOVING WELL describes speeds greater than 46 mph; MOVING SLOWLY describes speeds of 25–46 mph; and VERY SLOWLY describes speeds less than 25 mph.(33) Dudek and Ullman indicate that drivers interpret MAJOR DELAY to mean a 45-min delay, whereas they interpret HEAVY DELAY to mean a delay of 25–45 min, although the authors do not specify how they arrived at those estimates.(11) Wardman, Bonsall, and Shires created a traffic simulation model to assess the perceived lengths of different quantitative messages.(34) The authors concluded that LONG DELAY was an estimate of 35–47 min, whereas DELAYS LIKELY was an estimate of 10–31 min.

Whether drivers prefer qualitive or quantitative information remains unclear. Madanat, Yang, and Yen reported increased diversion rates based on quantitative messages relative to qualitative messages; however, in this study, message type was confounded with the amount of information displayed, such that the preferred, quantitative messages contained more information than the less preferred, qualitative messages.(15) Jindahra and Choocharukul found that more participants indicated they would divert in response to qualitative information (e.g., EXPECTED LONG DELAY) than in response to quantitative information (e.g., 15 MIN DELAY).(22) However, the authors attributed the difference to the limited use of quantitative information on CMSs in the study area of Thailand and were unsure whether the results would transfer to other areas that use quantitative delay information more regularly. In a study of drivers in the United States, Benson found that participants were evenly split between wanting CMSs to display delays in words (e.g., MAJOR DELAY) or in numbers (e.g., 15 MIN DELAY).(28) In presentations of information about delays, presentations of consistent and accurate information may be more important than the specific words used to convey the information.

Location

CMS messages frequently include location information. Location information tells drivers where an event is occurring and gauges drivers' opportunity for making changes to their driving behavior before reaching the event. When surveyed about the type of information they wish to see on CMSs, drivers report valuing location information, and they cite being unsure of where an event is located as one reason for not changing their behavior after seeing a CMS message.(12,35,49) However, including location information in a CMS message does not always influence the ways drivers react to the message.(12) The usefulness of location information in a

CMS message is likely to vary as a function of the availability of alternate routes on the road network, the actual distance between the CMS and the event, and the event type.[14,26]

CMS operators can convey location information by using a specific place, such as an exit or cross street, or by specifying the distance between the CMS and the nonrecurring event. Ullman et al. conducted an examination of the ways drivers interpret CMS messages about specific locations.[43] Participants first read CMS messages about a freeway closure that used different location messages. The participants then used a map to indicate the location they believed the message was referring to. The researchers then calculated the number of participants who believed they could use the exit specified in the location portion of the CMS message for four different location phrases. Table 2 displays the proportion of participants who, after viewing each message, believed the exit mentioned in the CMS message was open. For three of the four messages, most participants indicated that the exit referred to on the CMS was open. Even for the final BEFORE EXIT X, more than a third of participants indicated that they could use exit X to leave the highway to avoid the road closure.

Table 2. Percentage of participants who believed each CMS location phrase indicated that exit X was open.

CMS Location Phrase	Percent of Participants
PAST EXIT X	99
BEYOND EXIT X	95
AT EXIT X	86
BEFORE EXIT X	34

Location messages that used range information found similar results. As indicated in table 3, when range information specified the location of a road closure, the majority of participants believed they could exit and reenter the highway by using the locations specified in the CMS message. The results suggest that when a CMS includes specific locations, CMS operators would do well to reference locations upstream from the nonrecurring event and, when possible, refer to open exits or streets a driver can use to avoid the nonrecurring event.

Table 3. Percentage of participants who believed each CMS location phrase indicated that the first and second locations in the message were open.

CMS Location Phrase	First Location (%)	Second Location (%)
FROM X TO X	86	97
BETWEEN X AND X	94	97
BEYOND X TO X	79	97

When the location phrase in a CMS refers to distance, drivers can sometimes mistakenly interpret a message that includes, say, “5 MILES” as indicating the length of the nonrecurring event rather than the distance to the event—especially for nonrecurring events such as roadwork, which can persist for several miles.[14] Adding the preposition “IN” to the beginning of the phrase (e.g., IN 5 MILES) or adding “AHEAD” to the end of the phrase (e.g., 5 MILES AHEAD) can help eliminate such confusion.

While the word “AHEAD” can provide clarity when it is part of a location phrase that specifies distance, it is not advisable to use “AHEAD” as a substitute for more detailed location information (e.g., ROADWORK AHEAD). Dudek and Ullman refer to “AHEAD” as a “dead” word to remove from CMS messages whenever possible.(11) Because drivers always assume that an event described on a CMS is occurring ahead of them, the word “AHEAD” increases a message’s length—and thus its reading time—without providing the driver with any valuable information. Dudek and Ullman also advise that CMS messages not use the name of the roadway the driver is currently on.(11) Drivers assume that CMS messages are relevant to their current roadway unless the message specifies an alternative audience. As a result, naming the current roadway is unnecessary and can cause confusion.

Suggested Action

Providing drivers with a direct-action suggestion is an effective way of influencing travel behavior.(19,46,50) Following are two of the most frequently studied action suggestions: change route and change speed.

Change Route

A frequent goal of CMS messaging is to alleviate the traffic backup a nonrecurring event generates by encouraging a portion of drivers to divert to an alternate route. Increasing rates of route change are frequently reported effects of CMS messaging, such that increased alternate-route use has been reported in response to various messages such as ones that report road closure,(16,17) delays,(10,40,51) congestion levels,(10,48) and travel times.(29) However, the highest rates of diversion result from CMS messages that directly suggest a driver change routes.(14,15,22,39)

Schroeder and Demetsky demonstrated that increases in the specificity of a suggested action displayed via CMS can lead to increases in the proportion of vehicles that comply with that suggested action.(19) Specifically, messages indicating an incident or delay was present without suggesting an alternate route were associated with low diversion rates. Messages suggesting drivers take an alternate route without specifying the specific alternate route to be used led to moderate diversion rates. Messaging that suggested drivers use a specific alternate route was associated with the highest diversion rates. As long as drivers are familiar with the suggested route, the highest levels of diversion can be obtained by instructing drivers to take a specific alternate route.(22)

Dudek and Ullman caution that CMS operators suggesting a specific alternate route also ensure the suggested route can accommodate the diverting drivers, since encouraging drivers to take the alternate route will benefit the roadway system only if the number of drivers does not exceed the capacity of the alternate route.(11,52) Worries that diverting traffic may exceed the capacity of a specific alternate route prevent many TMCs from suggesting specific roadways on CMSs.(19,32,41)

Some research has suggested that CMS operators who wish to encourage drivers to change routes select the specific CMS message that would encourage the optimal diversion rate based on the capacity of the road network. For example, Srinivasan and Krishnamurthy proposed a framework wherein specific CMS messages associate with specific diversion rates.(27) CMS operators then choose messages for display based on the diversion rates that a traffic simulation indicates would optimize travel time within the network. While such an approach could lead to optimal network performance in theory, still it depends on assumptions that may not be true in practice. First, the approach assumes that the specific CMS message displayed can reliably estimate the proportion of drivers who divert. Past research on CMS messaging has proved valuable in predicting which messages are likely to be more effective or less effective in encouraging alternate-route use.[13,17] However, it is difficult to accurately predict the percentage of drivers who divert in response to any specific CMS message. In their model, Srinivasan and Krishnamurthy based diversion estimates on survey data;[12,27] however, the rates are unlikely to be accurate because research has repeatedly found that stated-preference data overestimate the actual diversion rates found in fieldwork and revealed-preference data.[47,50,53] Accurate diversion rates are difficult to estimate because a number of factors influence them, such as personal driver characteristics like age, gender, personality, and familiarity with the road network, as do external variables like time of day, weather conditions, and visible congestion levels. (See references 4, 13, 17, 24, 34, 37, and 47.) Research on CMS messaging is likely to be more informative in determining the relative effectiveness of different types of messages than it is in providing specific estimates of the percentage of drivers who divert in response to a message.

Change Speed

Researchers have found reductions in speed in response to various CMS messages, including messages that warn against potential hazardous conditions on the road ahead.[21,38] However, a specific suggested action message can be a more effective method for eliciting a change in speed. For example, Weaver, Balk, and Arnold found that participants who drove beneath a CMS displaying the message WATER ON ROAD / 5 MILES / SLOW DOWN reduced their speed after viewing the message, whereas participants who saw the same message without the suggested action message (i.e., WATER ON ROAD / 5 MILES) did not.[14] That the researchers did not find reduction in speed for both messages suggests that the potential safety implications of the nonrecurring event described in the message were not sufficient to influence speed. The result points out the value of including specific action suggestions in CMS messages—particularly because drivers may have limited time and resources for drawing safety inferences while driving.

Research has examined the specific phrases that are most effective in encouraging drivers to reduce their speed. Weaver, Balk, and Arnold reported that participants rated the messages SLOW DOWN, REDUCE SPEED, and MAX SPEED 35 MPH as more effective than either SLOW or ADVISE 35 MPH.[14] Garber and Patel found that the messages HIGH SPEED / SLOW DOWN and YOU ARE SPEEDING / SLOW DOWN were more effective at reducing speed within a temporary work zone than were the messages EXCESSIVE SPEED / SLOW DOWN, or REDUCE SPEED / IN WORK ZONE.[54] Chaurand, Bossart, and Delhomme conducted a field study to assess the effect of framing on compliance with a CMS safety message on speeding.[55] Based on social psychology research on the effects of framing on behavioral change, the authors hypothesized that speeding messages that were framed as a gain (e.g., respected speed limit equals fewer crashes) would be more effective than messages framed as a loss (e.g., exceeded speed limit equals more crashes). A CMS presented gain and loss speeding messages for fixed intervals, and an experimenter, located out of view of drivers, recorded vehicle speeds downstream from the CMS. Among drivers in the two leftmost lanes, speeds were higher when no message displayed than when a loss message displayed and were higher when a loss message displayed than when a gain message displayed. The results suggest that CMS messages can influence driver speed and that messages framed as a gain may be more effective than those framed as a loss.

CMS messages suggesting that drivers slow down can be effective in reducing drivers' speeds.(14,54,55) However, speed reduction messaging can sometimes have unexpected consequences. For example, Boyle, and Mannering found that drivers reduced their speed directly after viewing CMS messages that warned about upcoming fog or snowplows but increased their speed afterward to compensate for the reductions, such that the messages did not produce an overall reduction in speed.(56) Weaver, Balk, and Arnold found another unexpected result of CMS messages that suggested a change in speed.(14) In a stated preference study, CMS messages that included the suggested action SLOW DOWN led to reduced diversion ratings. The authors speculated that it is likely that drivers typically perform only one action in response to a CMS message. As a result, action requests that do not instruct a driver to change routes may, in effect, prevent route diversion.

Signal Words

Signal messages such as USE CAUTION or WARNING sometimes display as part of a CMS message. However, the acceptability of that practice is unclear. Signal messages help convey the severity of a nonrecurring event and thus increase the amount of attention directed toward the message.(45) However, Proffitt and Wade suggested avoiding signal words because they increase the length of the message without verified benefit to travelers.(45) Lichty et al. also advised against the use of signal messages such as CAUTION and WARNING at the start of a message but indicated the phrase USE CAUTION at the end of a message is acceptable.(57) Weaver, Balk, and Arnold examined the actual effect of signal words on traveler behavior.(14) In that study, signal words did not increase participants' stated diversion rates regardless of whether the words appeared at the beginning or the end of a CMS message. That lack of influence is not surprising given basic research on selective attention. Surface characteristics such as color, size, or sudden onset are capable of capturing attention; however, semantic processing can occur only after drivers have attended to a word or phrase. The context of CMS messages means that drivers would have to have directed their attention to the CMS to read the signal word, at which point the capture of attention with a signal word would no longer be necessary.

Intended Audience

Sometimes the information on the CMS is applicable to all drivers on a particular roadway, while other times it is intended for a specific audience. When a message applies to a specific audience (e.g., METRO TRAFFIC), Dudek and Ullman suggested specifying the audience in the CMS message.(11) However, very little research has been done on the effects of this practice. Whether audience information is of any additional benefit to drivers beyond that provided by event location is unclear.

Time/Duration of Event

While the majority of CMS messages describe events currently occurring on roadways, CMS messaging can also warn drivers about planned events that will happen in the near future.[43] Research suggests that drivers can better determine the time and duration of a planned event when the CMS uses days of the week. For that reason, Dudek and Ullman suggested that CMS messages about planned events be displayed no more than 6 d prior to a planned event.[11] If a sign displays an advance warning about an event to occur more than a week in the future, the sign must use dates rather than days of the week. Ullman, Ullman, and Dudek assessed the ideal way of displaying dates on CMSs.[58] The authors found that month names (e.g., APR 21) led to greater message recall than did numbers (e.g., 4/21) and were easier to recognize as corresponding to today's date, and participants preferred them. A message referring to a range of dates and including the name of the month twice (e.g., APR 21–APR 25) did not improve recall or comprehension beyond the levels found when the month was listed only once (e.g., APR 21–25), and participants preferred messages that listed the month only once. The authors also assessed the value of including times of day in CMS messages (e.g., 10 a.m.–6 p.m.). While participants preferred messages that included times of day, such information did not improve recall or comprehension. In fact, only 39 percent of participants were able to accurately recall time-of-day information. The results support Dudek and Ullman's suggestion that drivers should not be expected to have complete memory and comprehension regarding events planned for more than 6 d in the future.[11]

CONCLUSIONS

CMS messaging can be an important tool for distributing traveler information to drivers. The specific messages used for conveying traveler information can affect the ways drivers respond to that information. CMS operators would do well to select message content based on the content's ability to influence driver behavior, cultivate and maintain trust in CMS messaging, and be easily understood by drivers. Careful CMS message selection can help drivers make informed travel decisions and increase the safety and usability of roadways.

CHAPTER 2. EXPERIMENT 1

Past research on the characteristics of CMSs has uncovered information that CMS operators can use to help them select CMS messages that encourage desired changes in drivers' behavior during different nonrecurring events.(14) However, some research gaps remain. Specifically, during the literature review completed in chapter 1, the authors identified a number of open research questions as follows, which motivated experiment 1.

WHAT ARE THE PERCEIVED SEVERITIES OF DIFFERENT WEATHER MESSAGES?

As chapter 1 notes, CMS messages may be particularly useful to drivers during adverse weather events. The message used to describe a weather event can have an impact on the way drivers perceive the event and thus also on the types of changes drivers are likely to make after viewing the message. For example, during a flooding event, a driver's perceived severity of the flood as conveyed through a CMS message can affect whether or not the driver decides to proceed down a roadway. Drivers may perceive the phrase "road flooded" as referring to a severe event requiring the driver to change routes, whereas they may perceive the phrase "water on road" as referring to a less severe flooding event in which the road was still functional.(43) Drivers likely view other weather-related messages as indicating varying levels of severity or impact on a road. Iowa Department of Transportation (DOT) guidelines specify use of the phrase "snowstorm warning" to indicate "life-threatening severe winter conditions have begun or will begin within 24 h," whereas the phrase "winter driving conditions" indicates winter conditions when snowplows are active but the National Weather Service has not issued a warning.(61) Do drivers correctly perceive the differences in severity intended by those two messages? That question is one of several open questions regarding how drivers interpret and react to different weather-related phrases.

WHAT IS THE VALUE IN INCLUDING QUALIFIERS IN MESSAGES DESCRIBING WEATHER EVENTS?

Weather events displayed on CMSs have the potential to provide drivers with pertinent information drivers can use to make appropriate changes in driving behavior.(38) However, predicting the precise duration, severity, and location of a weather event can be difficult. For instance, sudden changes in the location or severity of a storm can cause inaccuracy in weather information displayed via CMS. Research suggests that drivers who view inaccurate CMS messages lose trust in CMS messaging and grow less likely to use the information.(10) To prevent lack of trust, some CMS operators choose to temper CMS messages about weather events by including qualifiers such as "possible," "intermittent," or "spots."(57,61) However, drivers report that messages that indicate an event is possible rather than definite (e.g., FLOODING POSSIBLE or POSSIBLE BLACK ICE) or that an event is occurring in only some areas (e.g., ICY SPOTS or AREAS OF DENSE FOG) are less effective than similar phrases that do not include qualifiers.(14) The value of qualifiers in descriptions of weather events remains an open research question. Specifically, how does a weather message with qualifiers influence behavior relative to the same weather message without qualifiers? When drivers do not actually experience a predicted weather event, do they view weather messages with qualifiers as more accurate than messages without qualifiers? Do inaccurate weather messages result in changes in trust in CMS messaging similar to changes with regard to inaccurate messages about other types of nonrecurring events? Future research may be able to directly assess how qualifiers influence both perceived accuracy and the effectiveness of weather messages.

WHICH IS MORE EFFECTIVE: QUANTITATIVE DELAY MESSAGES OR QUALITATIVE DELAY MESSAGES?

Drivers who receive information about the presence of a delay are more likely to select an alternate route.(12,26,40) Two different types of delay messages exist: If the specific length of a delay is known, then CMS operators can use quantitative delay messages, which use numbers to quantify an expected delay length (e.g., 20 MIN DELAY). When the length of the delay is difficult to estimate, CMS operators may consider qualitative delay messages, which use adjectives to describe the magnitude of a delay (e.g., MAJOR DELAY), as more appropriate. Past research has been inconclusive about whether drivers prefer quantitative or qualitative delay messages.(15,22) For example, Benson compared preference ratings for qualitative messages (e.g., MAJOR DELAY) and quantitative messages (e.g., 15 MIN DELAY) and found no significant differences in preferred message type.(28) Whether U.S. drivers prefer qualitative or quantitative information remains an open question.

DO QUALITATIVE MESSAGES HOLD QUANTITATIVE VALUE?

Some research has attempted to assess whether drivers associate different qualitative messages with specific quantitative values. For example, a simulated traffic model created by Wardman, Bonsall, and Shires seemed to indicate that DELAY LIKELY was interpreted as referring to a delay of 10–31 min, and LONG DELAY to a delay of 35–47 min.(34) Weaver, Balk, and Arnold found that drivers ranked MAJOR DELAY as equivalent to 20 MIN DELAY; however, since MAJOR DELAY was the study's only quantitative message, how drivers would have compared the message with longer delays is unclear.(14) Indeed, Dudek and Ullman reported that drivers typically interpret MAJOR DELAY as referring to a delay closer to 45 min, whereas they interpret HEAVY DELAY as a delay of 25–45 min; however, the study did not report the procedures used for creating the estimates.(11) More research would assess whether drivers associate different qualitative delay phrases with specific delay times and, if so, whether those times are consistent across different drivers.

DO DESCRIPTOR WORDS CARRY THE SAME WEIGHT ACROSS DIFFERENT EVENTS?

Adding descriptor words to a message may increase the perceived severity of a nonrecurring event and thus increase the likelihood of behavioral change. Drivers rate MAJOR DELAY as more effective in indicating that a nonrecurring event is affecting traffic than does DELAY, and they rate MAJOR CRASH as more effective than CRASH.(14,26) Dudek and Ullman suggested that drivers associate descriptor words (e.g., HEAVY or MAJOR) with quantitative delay values (e.g., MAJOR equates to a 45-min delay), and those values remain constant regardless of whether the descriptor describes a delay (e.g., MAJOR DELAY) or an event (e.g., MAJOR CRASH).(11) However, this hypothesis does not appear to have been tested.

HOW DO DRIVERS INTERPRET AND RESPOND TO "SLOW" MESSAGES?

Research indicates CMS messages suggesting that drivers slow down can be effective in reducing drivers' speeds.(14,54,55) A number of different phrases can encourage drivers to reduce speed during a nonrecurring event (e.g., SLOW, SLOW DOWN, REDUCE SPEED, PREPARE TO STOP, SLOW TRAFFIC AHEAD, ADVISE SPEED XX, and MAX SPEED XX). Which message is most effective? Past research has tended to focus on whether or not a message is associated with a speed reduction by drivers without comparing differences in speed reduction between messages.(14) When researchers have directly compared messages, the specific numbers and types of messages in the comparison have been limited.(14,54) Which phrase is most effective among all those that TMCs typically use in encouraging drivers to reduce speed and whether drivers see different speed messages as requiring different changes in speed remain open questions.

ARE MESSAGES THAT SPECIFY AN INTENDED AUDIENCE MORE EFFECTIVE THAN MESSAGES THAT INCLUDE ONLY LOCATION INFORMATION?

Often, the information on a CMS is applicable to all drivers on a particular roadway. Other times, the message is intended for a specific segment of road users. When a specific segment is the case, CMS operators can add intended-audience information to the CMS message to specify whom the message is for (e.g., BRIDGE TRAFFIC).(11) Current research on the potential effectiveness of intended-audience information is limited. The current experiment extends that research to assess whether targeted-audience information is of additional benefit to drivers beyond that provided by event location, but it remains uncertain.

THE CURRENT STUDY SET

CMS messaging can be an important tool for distributing traveler information to drivers. Careful CMS message selection can help drivers make informed travel decisions and increase roadways' safety and usability. Additional research could determine specific phrases that would be most effective during different nonrecurring events. The current experiment took an integrative research approach that uses multiple methodologies to target the preceding outlined questions. Table 4 outlines the specific procedures the researchers applied to each research question.

Table 4. Matrix of research questions and experimental procedures.

Research Question	Open-Ended Responses	Likert Scale Responses	Message Ranking	Time or Speed Estimates	Fly-by Drive
What are the perceived severities of different weather messages?	X	X	X	–	–
Does the inclusion of qualifiers in weather messages have value?	–	X	–	–	X
Are quantitative or qualitative delay messages more effective?	X	X	–	–	–
Do qualitative messages hold quantitative value?	–	–	X	X	–
Do descriptor words carry the same weight across different events?	–	X	–	X	–
How do drivers interpret and respond to “slow” messages?	X	X	X	X	–
Are messages that specify an intended audience more effective than messages that include only location information?	X	X	–	–	–

X symbolizes it was applied; – symbolizes it was not applied.

To learn drivers’ perceived severity of different types of weather messages, the researchers used the open-ended question, What would you do in response to this message? to gauge participants’ initial reactions to specific CMS messages. Researchers can interpret messages that cause a driver to return home or select an alternate route as more severe than messages that do not cause a change in behavior. Scaled responses to such questions as How likely would you be to continue on the current route? and How easy would it be to continue driving on the current road? allowed for a numerical assessment of the perceived severity of these same messages. The researchers made direct comparisons of different messages by having participants engage in a message-ranking task. The researchers used the open-ended responses, scaled responses, and message-ranking procedures to assess the effect of adding qualifiers to weather messages, to compare the effectiveness of qualitative and quantitative messages, to differentiate between drivers’ reactions to different “slow” messages, and to compare the effects of a message containing intended-audience information with the effects of a message that included only location information.

When assessing the potential value of including qualifiers in weather messages, CMS operators may find it important to learn not just the perceived severity of each message but also the impact that inaccurate weather messages may have on drivers’ trust of CMSs. To do that, the current study included a flyby drive procedure wherein participants watched a recording of a short route that included a CMS. Some participants saw a CMS display a message about a weather event, some saw a message about a different nonrecurring event (e.g., roadwork), and some saw a CMS that was blank. Messages either did or did not include qualifiers. For some participants, the route included the hazard warned about in the sign; for others, the route was clear. Afterward, participants were asked to rate both the helpfulness and the accuracy of the signs they had seen along the route. Their ratings assessed changes in trust in CMSs as a function of sign accuracy.

Of specific interest was whether messages with inaccurate weather information had led to a loss of trust at the same rate as had messages about nonrecurring events and whether qualifiers were able to prevent trust loss.

The most direct way to determine whether or not qualitative messages hold quantitative value is to ask participants to assign a numerical value to different qualitative messages and determine whether participants generate consistent time estimates. The current study used that simple time-estimation procedure to assess the perceived delay associated with different delay messages and to assess whether that delay time varies across contexts. A similar speed estimation procedure assessed whether drivers associate different "slow" messages with the need to reduce speeds by specific amounts.

The researchers designed the multiprocedure approach the current study used so they could further the understanding of specific CMS messages that are most effective in helping drivers make informed travel decisions.

METHOD

Participants

Seventy-two licensed drivers participated in the study. All participants were at least 18 yr of age, and approximately half were older than 45 yr. The study comprised equal numbers of male and female participants.

Apparatus

Data collection sessions took place remotely using virtual conferencing software. Participants' computer screens displayed stimuli, and participants could respond to questions by using a mouse and keyboard or by giving verbal responses to a researcher, whom they could watch input their responses in realtime.

Stimuli

The research team contacted State DOTs to obtain lists of CMS messages currently used by transportation agencies. The team supplemented the lists with examples of CMS messages found during the literature review conducted in chapter 1. CMS messages were then sorted into relevant units of information. The researchers prioritized for use as experimental stimuli those messages used by multiple transportation agencies or literature sources and deemed best able to answer the questions of interest.

Procedure

Each session began with participants' reviewing and signing a virtual informed consent form. Participants then verified that they had a valid driver's license before responding to the following question types.

Open-Ended and Likert Scale[62] Responses

This portion of the study assessed participants' responses to messages displayed on CMSs. Each trial presented one CMS and asked participants to imagine they had encountered the presented CMS while driving in a familiar area. The trial then asked participants to describe what they would do in response to the sign, and the open-ended responses were recorded. Participants then answered additional questions based on sign type. Questions included, What is the likelihood of continuing on the current route? How easy or difficult would it be to drive on the road described in the message? and Who should respond to this message? Ratings were made on a four-point scale.

Message Rankings

During this portion of the study, participants ranked the effectiveness of different CMS messages. Participants saw a series of messages that have been used by different CMS operators to convey the same information and ranked the messages from most effective to least effective.

Time or Speed Estimates

This portion of the study assessed the quantitative values that drivers assign to specific CMS messages and phrases. On each trial, participants saw a specific CMS message and estimated the time or speed value the message referred to.

Flyby Drive

This portion of the study examined the perceived accuracy of different types of messages. Participants viewed a video displaying a drive down a simulated roadway. The drive included a CMS sign that could either be blank or include a CMS message. The drive sometimes included an event (e.g., a flooded road or roadwork) and sometimes did not. After viewing the video, participants rated the accuracy of the signs seen along the route and rated how helpful the signs were.

Analysis

After data collection, trained coders read and categorized open-ended responses to compare the effects of different messages. The researchers analyzed scaled responses, response times, and likelihood ratings by using linear mixed models.[63] Friedman rank tests[64] (nonparametric analyses of variance) assessed sign rankings and speed and time estimates.

RESULTS

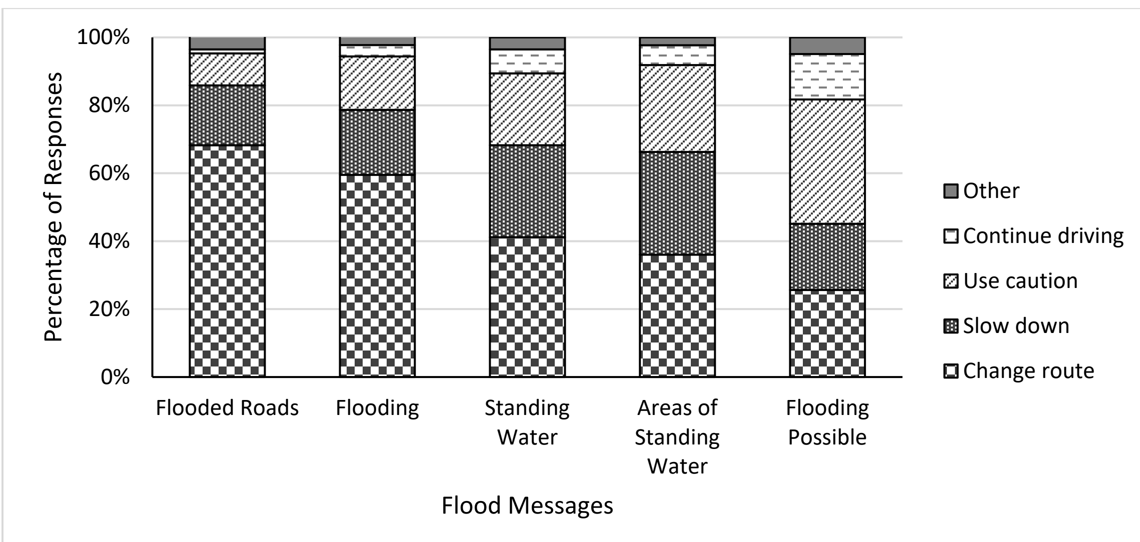
What Are the Perceived Severities of Different Weather Messages?

The question assessed six different types of weather events: floods, ice, snow, wind, low visibility, and winter weather. The researchers compiled stimuli for each event based on relevant literature[43,57,61] and input from State DOTs on the messages currently used on CMSs in their States. Four questions assessed the perceived severity of the different weather messages.
First, participants answered what they would do in response to a CMS displaying the message

and recorded their open-ended responses. Trained coders then categorized each message. The researchers combined into an "other" category those message categories that included less than 5 percent of total responses. Next, participants answered two Likert questions about each message.(62) Participants rated how likely they would be to continue on their current route on a scale from 1 (very likely to continue on the current route) to 4 (very likely to take an alternate route). Participants then rated how easy it would be to continue on their current route on a scale from 1 to 4, where 1 indicated very easy, 2 indicated somewhat easy, 3 indicated somewhat difficult, and 4 indicated very difficult. Finally, participants ranked each message from most severe to least severe on the severity of the condition the message described.

Flood Messages

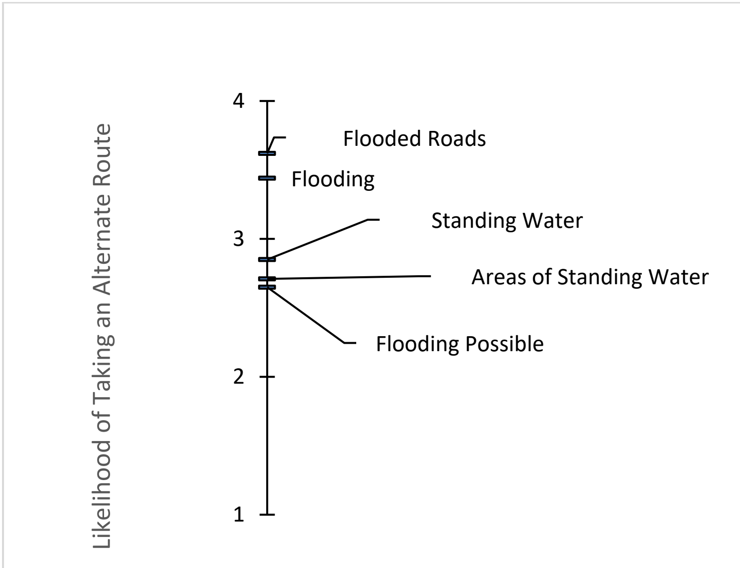
When asked what they would do in response to each flood message, participants most commonly responded across all messages that they would change routes (46.6 percent), followed by slow down (22.7 percent), use caution (21.5 percent), and continue driving (6.1 percent). Figure 1 displays the proportion of those responses to each of the five flood messages. Changing routes was the most common response for the FLOODED ROADS and FLOODING messages. Slowing down and using caution were more common for STANDING WATER, AREAS OF STANDING WATER, and FLOODING POSSIBLE messages.



Source: Federal Highway Administration (FHWA).

Figure 1. Graph. Open-ended responses to flood messages.

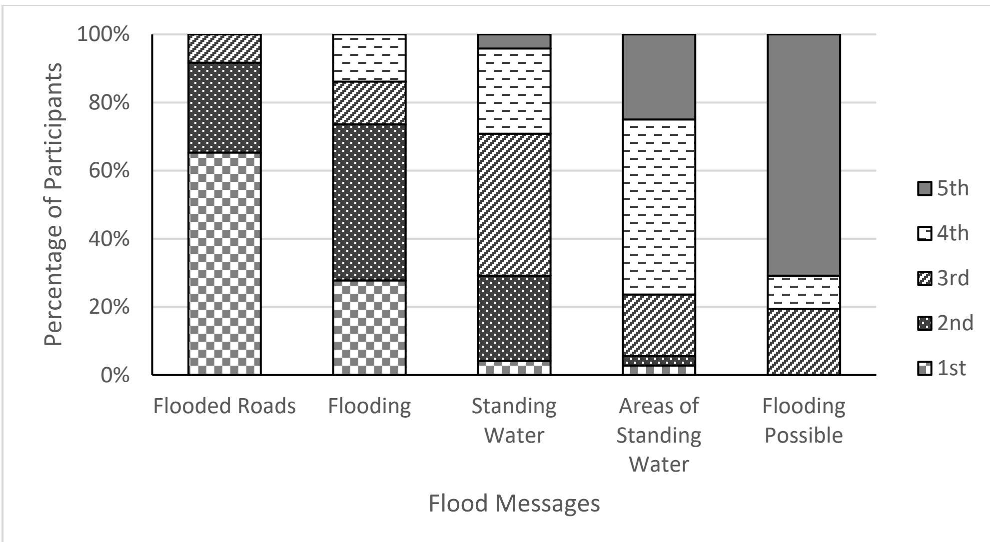
Participants rated how likely they would be to take an alternate route. Figure 2 displays mean responses. Significant differences in responses resulted across sign messages, $\chi^2(4) = 71.05$, $p < .001$. Post hoc tests found that the messages FLOODED ROADS and FLOODING received higher ratings than the three other responses.



Source: FHWA.

Figure 2. Graph. Mean likelihood of taking an alternate route for each flood message.

Next, participants rated how easy it would be to continue on their current route. A significant effect of message resulted, $\chi^2(4) = 78.95$, $p < .001$. Higher difficulty ratings resulted for the messages FLOODED ROADS (Mean (*M*) = 3.58) and FLOODING (*M* = 3.38) than for the three other messages (STANDING WATER: *M* = 2.94, AREAS OF STANDING WATER: *M* = 2.88, FLOODING POSSIBLE: *M* = 2.71). Message ranking results were consistent with that finding. As shown in figure 3, the majority of participants ranked FLOODED ROADS and FLOODING as the first and second severest messages, respectively. The results suggest that participants viewed messages indicating flooding has occurred as severer, that such messages about flooding make participants more likely to select an alternate route, and that such messages about flooding make participants more likely to view proceeding on the current route as difficult than messages that mention water or that flooding is possible.

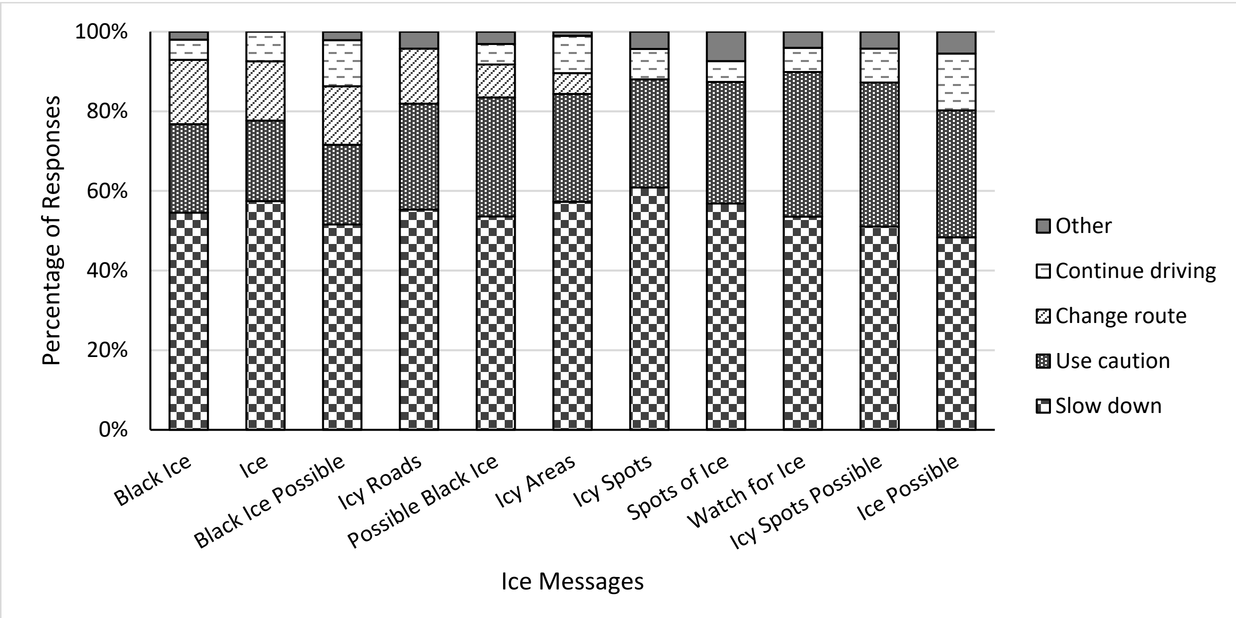


Source: FHWA.

Figure 3. Graph. Flood message rankings.

Ice Messages

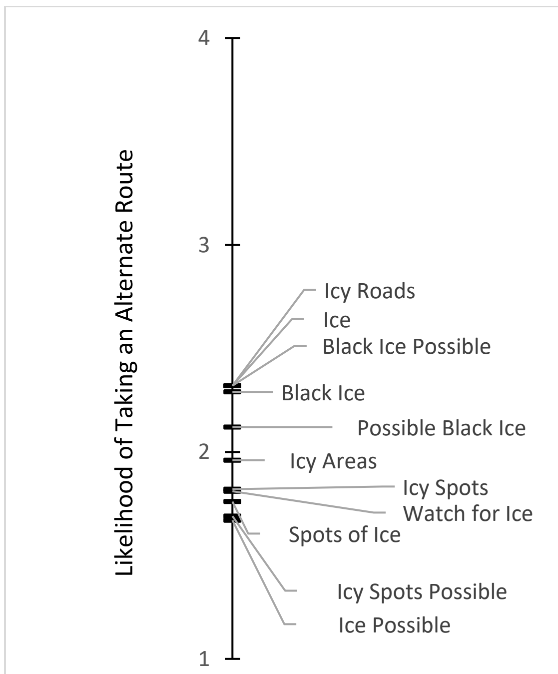
The most common responses to open-ended questions about ice messages were slow down (54.6 percent), use caution (28 percent), change routes (8.2 percent), and continue driving (7.3 percent). Figure 4 displays responses to specific ice messages. Slowing down was the most common response across each of the ice messages, followed by use caution. Drivers responded that they would change route in response to 6 of the 11 messages, including ICE, ICY ROADS, ICY AREAS, and the three messages that included the phrase "black ice" (i.e., BLACK ICE, BLACK ICE POSSIBLE, and POSSIBLE BLACK ICE).



Source: FHWA.

Figure 4. Graph. Open-ended responses to ice messages.

When participants rated their likelihood of changing routes, their responses were low (*M* = 2.01), suggesting that participants are unlikely to change their route in response to messages about ice. Nevertheless, significant differences in ratings resulted across different messages, $\chi^2(10) = 112.2$, $p < .001$. Figure 5 displays the messages ICY ROADS, ICE, and BLACK ICE POSSIBLE, which elicited higher ratings than ICY SPOTS POSSIBLE and ICE POSSIBLE. BLACK ICE was also rated higher than ICE POSSIBLE. Participants also rated BLACK ICE (*M* = 2.88), ICY ROADS (*M* = 2.85), and ICE (*M* = 2.85) as referring to roads that were significantly more difficult to drive on than were roads with the messages ICE POSSIBLE (*M* = 2.21) and ICY SPOTS POSSIBLE (*M* = 2.19), $\chi^2(10) = 143.9$, $p < .001$. When ranking ice messages from severest to least severe, most participants (76.3 percent) selected BLACK ICE as the severest ice message. ICY ROADS ranked as severest by 20.8 percent of participants. No other message was selected as severest by more than one participant.

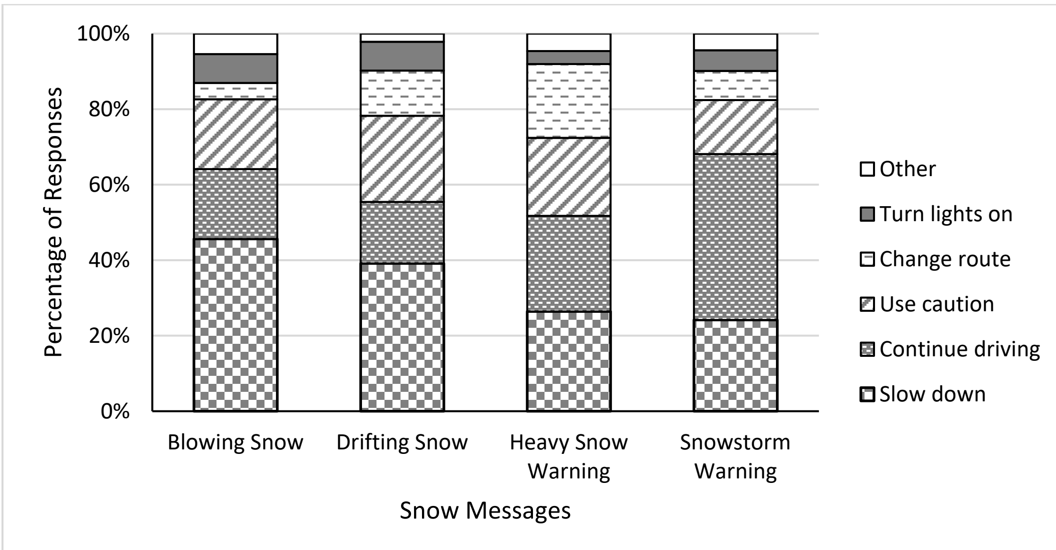


Source: FHWA.

Figure 5. Graph. Mean likelihood of taking an alternate route in response to ice messages.

Snow Messages

When asked what they would do in response to messages about snow, participants responded slow down (33 percent), continue driving (25.2 percent), use caution (18.5 percent), change routes (10.5 percent), and turn on lights (5.9 percent). Figure 6 shows that slow down was the most common response to BLOWING SNOW and DRIFTING SNOW, whereas SNOWSTORM WARNING resulted in the most common response of continue driving.



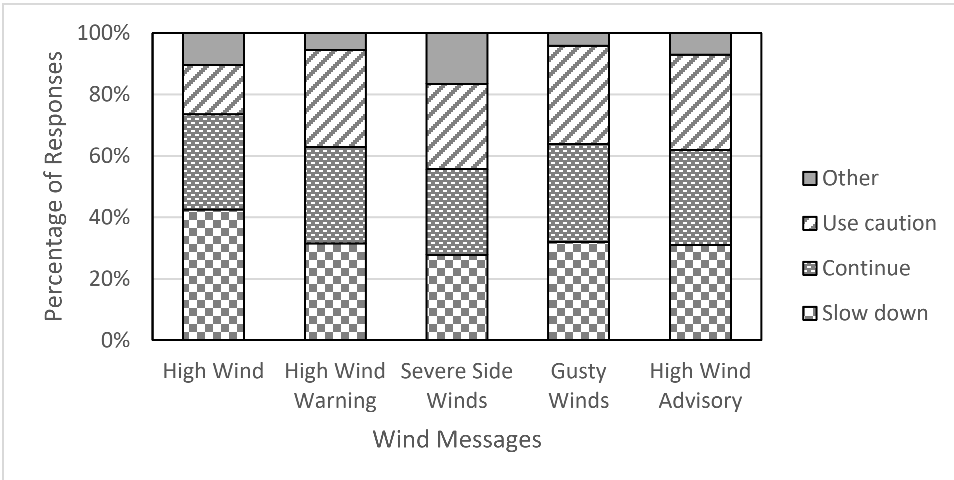
Source: FHWA.

Figure 6. Graph. Open-ended responses to snow messages.

When asked to rate the likelihood of changing routes in response to each snow message, participants tended to rate the probability as low (*M* = 1.9). Significantly higher ratings or route change resulted for HEAVY SNOW WARNING (*M* = 2.33) than for BLOWING SNOW (*M* = 1.79) or SNOWSTORM WARNING (*M* = 1.74). Likewise, when asked to rate how easy it would be to continue on their current route, participants indicated it would be more difficult to continue driving after seeing HEAVY SNOW WARNING (*M* = 2.86) than after seeing BLOWING SNOW (*M* =2.32) or SNOWSTORM WARNING (*M* = 2.28). In addition, 81 percent of participants ranked HEAVY SNOW WARNING as the severest of the four snow messages.

Wind Messages

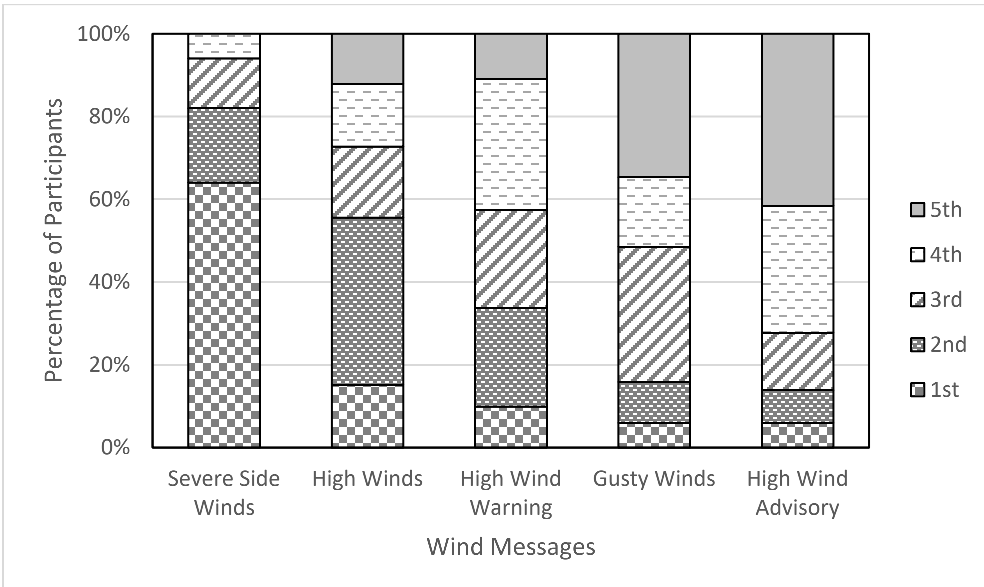
The researchers assessed five wind messages. When asked what they would do in response to wind messages, drivers most commonly responded slow down (38.7 percent), continue driving (31.9 percent), and use caution (18.7 percent). Figure 7 shows responses distributed fairly evenly regardless of the message presented.



Source: FHWA.

Figure 7. Graph. Open-ended responses to wind messages.

Across all wind messages, participants rated the likelihood of changing routes fairly low (M = 1.63). In a comparison of the likelihood of changing routes and the ease of continuing on the current routes for the different wind messages, SEVERE SIDE WINDS rated highest on both measures (M = 1.94 and M = 2.4, respectively). However, no differences in message ratings remained significant during the post hoc tests after accounting for multiple comparisons. When asked to rank the wind messages, most participants (64 percent) ranked SEVERE SIDE WINDS as the severest wind message (figure 8).

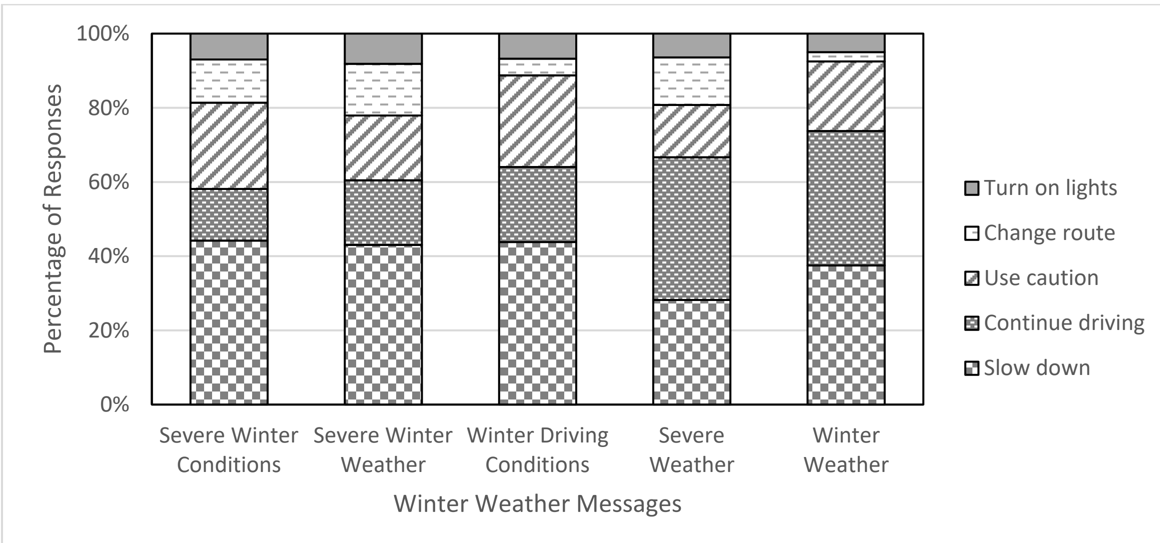


Source: FHWA.

Figure 8. Graph. Wind message rankings.

Winter Weather Messages

Figure 9 shows participants' open-ended responses to different winter weather messages. Slowing down was the commonest response across all message types. Using caution was the second commonest response to SEVERE WINTER CONDITIONS and WINTER DRIVING CONDITIONS, whereas continue driving was reported more often in response to SEVERE WEATHER and WINTER WEATHER.



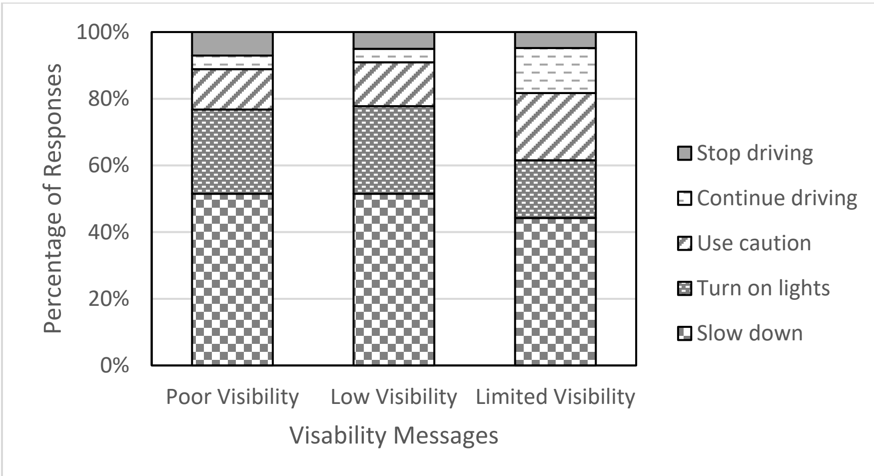
Source: FHWA.

Figure 9. Graph. Winter weather message rankings.

In participants' ratings of how likely they would be to change routes, researchers found significant differences between messages, $\chi^2(4) = 74.1$, $p < .001$. Ratings were higher for the messages SEVERE WINTER CONDITIONS ($M = 2.35$) and SEVERE WINTER WEATHER ($M = 2.31$) than for WINTER DRIVING CONDITIONS ($M = 1.65$) or WINTER WEATHER ($M = 1.47$). Participants also rated SEVERE WEATHER ($M = 2.04$) higher than WINTER WEATHER ($M = 1.47$). Similarly significant differences in ratings of the ease of continuing on the current route resulted, $\chi^2(4) = 68.15$, $p < .001$, such that SEVERE WINTER CONDITIONS ($M = 2.89$) and SEVERE WINTER WEATHER ($M = 2.83$) were rated higher than WINTER WEATHER ($M = 2.14$). A similar pattern of findings resulted in responses to the ranking tasks. Participants tended to rate messages that included the word "severe" as severer than messages that did not.

Visibility Messages

When asked what they would do in response to different visibility messages, participants most commonly responded across all message types to slow down (46.69 percent), followed by turn on lights (21.77 percent), and use caution (14.51 percent) (figure 10).



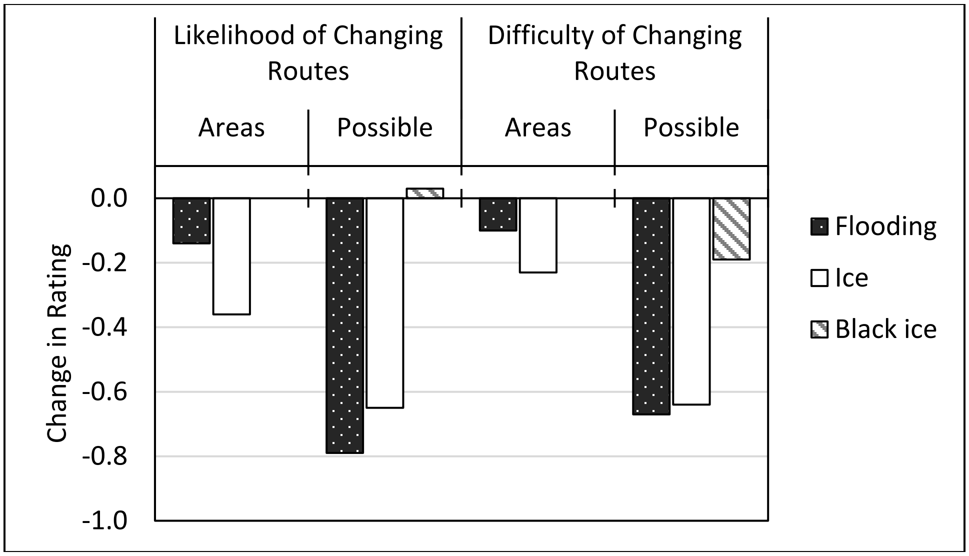
Source: FHWA.

Figure 10. Graph. Open-ended responses to visibility messages.

Participants rated the likelihood of changing routes in response to visibility messages as low (M = 1.78), and the responses did not vary significantly as a function of message type. Neither was ease of continuing on the current route influenced by message type. However, when asked to rank the three visibility messages, most participants (69 percent) ranked POOR VISIBILITY as the severest message, and most participants (53 percent) ranked LIMITED VISIBILITY as the least severe message.

Does Including Qualifiers in Weather Messages Have Value?

To assess the extent to which qualifiers influence weather messages, the researchers created messages with different types of qualifiers for flood and ice messages. Specifically, they included two types of qualifiers: a qualifier to indicate the weather event was possible rather than definite (e.g., ICE POSSIBLE) and a qualifier to indicate the weather event was happening in only some, rather than all, locations (e.g., ICY AREAS). Figure 11 shows the reduction in ratings that occurred with the addition of each type of qualifier for the three weather events tested. Addition of the qualifier “areas” resulted in only small, nonsignificant reductions in the perceived need to change routes and ease of continuing on the same route across both the flood and ice messages. However, the addition of the qualifier POSSIBLE led to significant reductions in ratings of the likelihood of opting to change routes and the perceived difficulty in continuing on the current route for both the flood and ice messages. The addition of POSSIBLE did not influence ratings for BLACK ICE. As noted in the preceding section, participants rated BLACK ICE as the severest of all the ice events, and the addition of the qualifier POSSIBLE did little to reduce the perceived severity of this weather event.



Source: FHWA.

Figure 11. Graph. Change in ratings after the addition of "area" and "possible" qualifiers to flood, ice, and black ice messages.

Due to the temporary and mobile natures of weather events, some drivers who see a CMS message about a weather event may not actually experience that weather event. Therefore, some transportation agencies prefer to use qualifiers when describing weather events because they believe that doing so may increase drivers' trust in CMS messages when drivers do not actually experience the event described on a CMS. The current study sought to assess the perceived value of that practice by comparing the perceived accuracy and helpfulness of CMSs that described an event (e.g., FLOODING), described an event using a qualifier (e.g., FLOODING POSSIBLE), or were blank. After passing the CMS, the participant would either encounter the described event or not. Further, the weather event was compared with a nonweather event (e.g., ROADWORK). The result was a 2 (Hazard: present or not present) by 2 (Event Type: flood or roadwork) by 3 (CMS message: event message, event plus qualifier, no message) design. Researchers manipulated event type within subjects and manipulated hazard and CMS messages between subjects. The researchers then assessed the ratings of both the helpfulness and accuracy of each sign (table 5).

Table 5. Mean helpfulness and accuracy ratings as a function of event type, message type, and presence of hazard.

Event and Message Type	Helpfulness Rating: Hazard Present	Helpfulness Rating: Hazard Not Present	Accuracy Rating: Hazard Present	Accuracy Rating: Hazard Not Present
Flood: No message	2.18	2.42	2.00	2.00
Flood: Message with qualifier	2.17	2.00	2.17	1.83
Flood: Message without qualifier	2.00	1.92	2.00	2.08

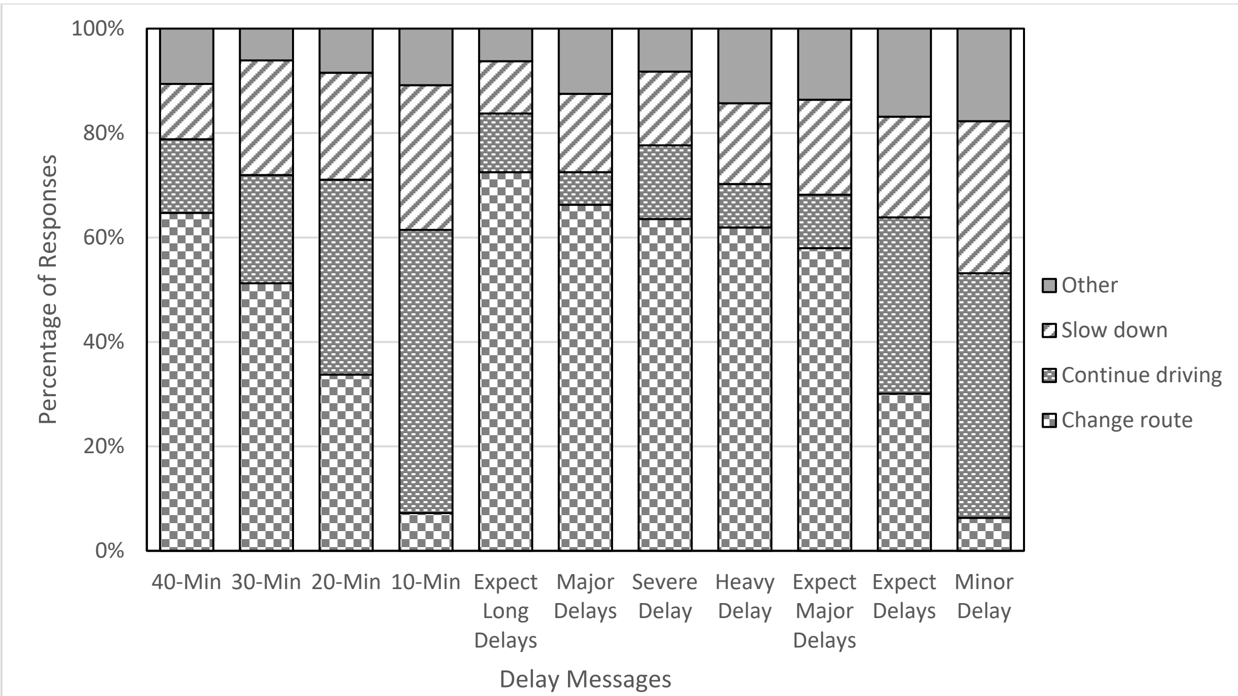
Event and Message Type	Helpfulness Rating: Hazard Present	Helpfulness Rating: Hazard Not Present	Accuracy Rating: Hazard Present	Accuracy Rating: Hazard Not Present
Roadwork: No Message	1.92	1.18	1.83	2.00
Roadwork: Message with qualifier	3.17	2.33	3.08	2.08
Roadwork: Message without qualifier	3.08	1.67	3.58	1.58

The researchers evaluated the ratings of each sign's helpfulness on a scale from 1 (not at all helpful) to 4 (very helpful). A comparison of helpfulness ratings revealed a main effect of hazard. As expected, participants rated a sign as more helpful when the hazard was present on the roadway ($M = 2.42$) than when the hazard was not present ($M = 1.92$). However, that effect was qualified by a significant hazard-by-event interaction, such that the effect of hazard was found only for the roadwork condition, $F(1, 65) = 8.10$, $p = .005$. Whereas participants rated a flood message as equally helpful regardless of whether flooding was present on the roadway (hazard present: 2.12; hazard not present: 2.11), they rated a roadwork message as more helpful when roadwork was present on the roadway ($M = 2.72$) than when no roadwork was present ($M = 1.73$). An event-by-message type interaction was also found, $F(2, 65) = 9.09$, $p < .001$. Message type did not influence helpfulness ratings for flood events. For roadwork events, participants viewed signs that contained no roadwork message as less helpful than signs that contained messages with qualifiers. Overall, participants rated a sign in flooding conditions as not very helpful regardless of what the message said or whether the flood hazard was actually present on the roadway. Participants saw signs about roadwork condition as more helpful—but only if the sign contained a message and only if roadwork was actually present on the roadway.

The researchers evaluated accuracy ratings on a scale from 1 (not at all accurate) to 4 (very accurate). All three main effects were significant. Participants rated roadwork messages as more accurate than flood messages, $F(1, 65) = 5.8509$, $p = .01$. Participants rated signs that contained event or event-plus-qualifier messages as more helpful than signs that were blank, $F(2, 65) = 3.91$, $p = 0.02$. They rated a sign as more accurate when a hazard was present than when the road was clear, $F(1, 65) = 10.48$, $p = .001$. Three-way interaction was also significant, $F(2, 65) = 5.30$, $p = .007$. Participants rated a sign in the flood condition as not very accurate regardless of what the sign displayed and whether or not the hazard was present on the roadway. Participants deemed a sign in the roadwork condition as accurate only if the sign displayed a message and the hazard was present in the roadway.

Which Are More Effective: Quantitative Delay Messages or Qualitative Delay Messages?

Researchers presented participants with four different quantitative delay messages and seven different qualitative delay messages. When asked what they would do in response to each delay message, participants most commonly responded across all messages to change routes (47 percent), continue driving (23.2 percent), and slow down (18.3 percent). Figure 12 displays the proportion of those responses that participants made to each of the delay messages. For quantitative messages, the proportion of participants who indicated they would change their route was a direct function of the length of the expected delay. For qualitative messages, messages that contained the descriptor “long,” “severe,” “major,” or “heavy” elicited the change-route response at rates similar to those seen for the 40 MIN DELAY message. EXPECT DELAY had a range similar to the 20 MIN DELAY message, whereas the rate for MINOR DELAY was similar to that seen for 10 MIN DELAY.



Source: FHWA.

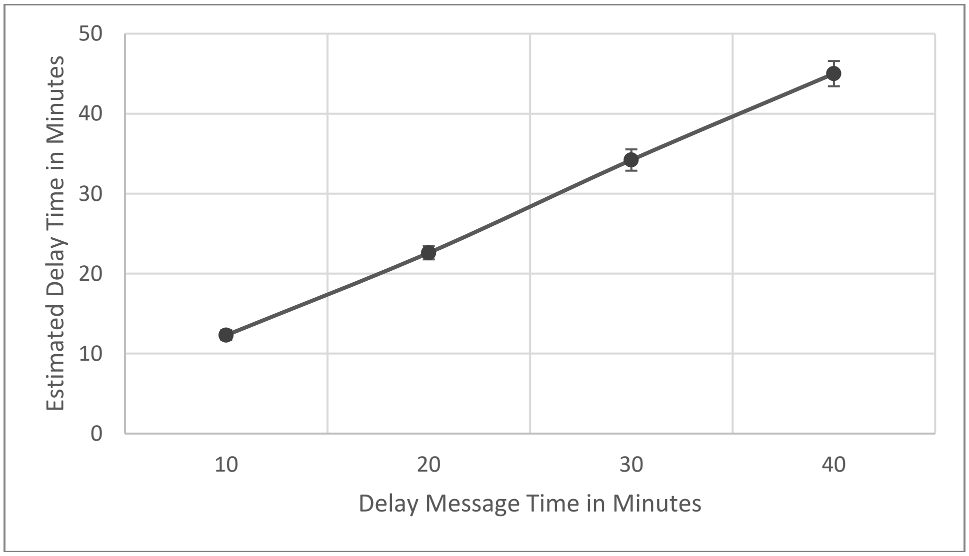
Figure 12. Graph. Open-ended responses to delay messages.

A similar pattern resulted when participants were asked to rate their likelihood of taking an alternate route in response to each delay message. The researchers found significant differences across message types, $\chi^2(10) = 453.25$, $p < 0.001$. For quantitative messages, the likelihood of changing routes in response to the 40 MIN DELAY message ($M = 3.56$) was significantly higher than for any other quantitative delay message. Ratings for the 30 MIN ($M = 2.76$) and 20 MIN ($M = 2.28$) DELAY messages did not differ from each other, but both were significantly higher than the rating for the 10 MIN DELAY message ($M = 1.42$).

Among qualitative messages, ratings for MINOR DELAY were significantly lower than for all other qualitative messages ($M = 1.39$) and were similar to that seen for 10 MIN DELAY. The message EXPECT DELAY had the second-lowest rating ($M = 2.25$) and was similar to that seen for the 20 MIN DELAY and 30 MIN DELAY messages. All the other qualitative messages tested had ratings that were not significantly different from one another and that were equivalent to that of the 40 MIN DELAY message.

Do Qualitative Messages Hold Quantitative Value?

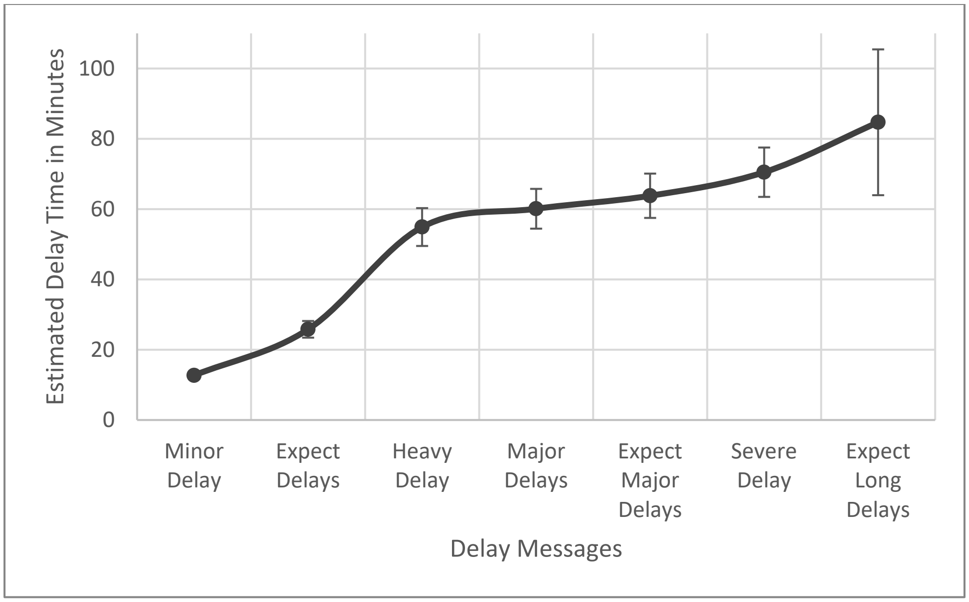
To further explore the relationship between qualitive and quantitative messages, the researchers asked participants to estimate how long the participants would be delayed after seeing each message. Figure 13 displays the mean expected delay time for each of the quantitative messages. As expected, a linear relationship resulted between the time displayed in the message and the amount of time respondents expected to be delayed. However, respondents tended to expect the time they would actually be delayed to be 2–to 5 min longer than the time the message actually displayed.



Source: FHWA.

Figure 13. Graph. Mean expected delay time for quantitative delay messages.

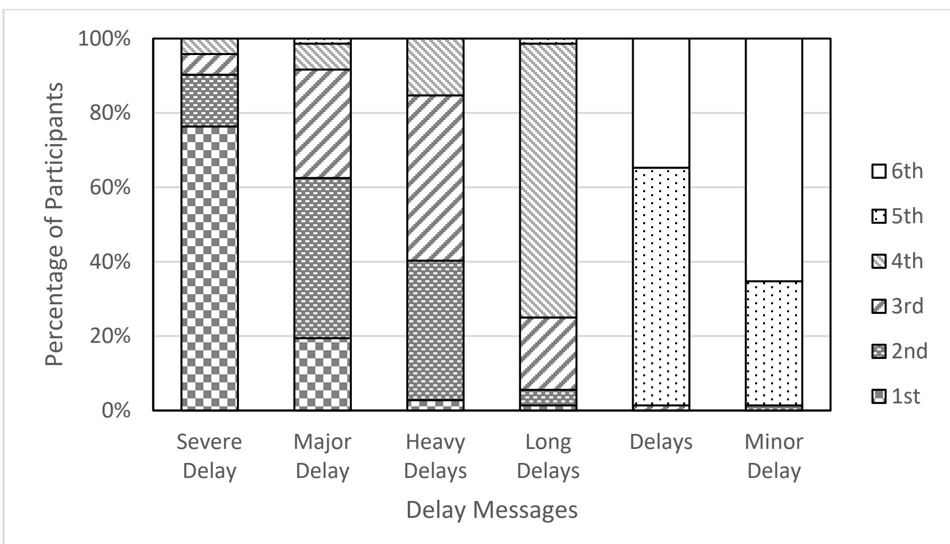
Figure 14 displays the mean expected delay times for qualitative delay messages. Significant differences in expected delay time resulted across message type, $\chi^2(10) = 440.18$, $p < 0.001$. EXPECT LONG DELAY had an expected delay time significantly longer than all the quantitative messages as well as both MINOR DELAY and EXPECT DELAY. However, this message also had the highest variability of all the messages, suggesting that EXPECT LONG DELAY is likely to result in different delay expectations by different drivers. The next four highest delay messages (i.e., SEVERE DELAY, EXPECT MAJOR DELAYS, MAJOR DELAY, and HEAVY DELAY) had expected delay times that were higher than both EXPECT DELAY and MINOR DELAY but that did not differ significantly from one another or from the 40 MIN DELAY message. EXPECT DELAY had a significantly higher delay time than MINOR DELAY and 10 MIN DELAY but was significantly lower than all other messages except 20 MIN DELAY. Although the expected delay time was only half a minute longer than the estimated delay time, for MINOR DELAY, the expected delay was significantly higher than for 10 MIN DELAY.



Source: FHWA.

Figure 14. Graph. Mean expected delay time for qualitative delay messages.

The researchers used message rankings to further assess the perceived severity of different qualitative messages. In figure 15, the message SEVERE DELAY ranked as severest followed by MAJOR DELAY, HEAVY DELAYS, and LONG DELAYS.

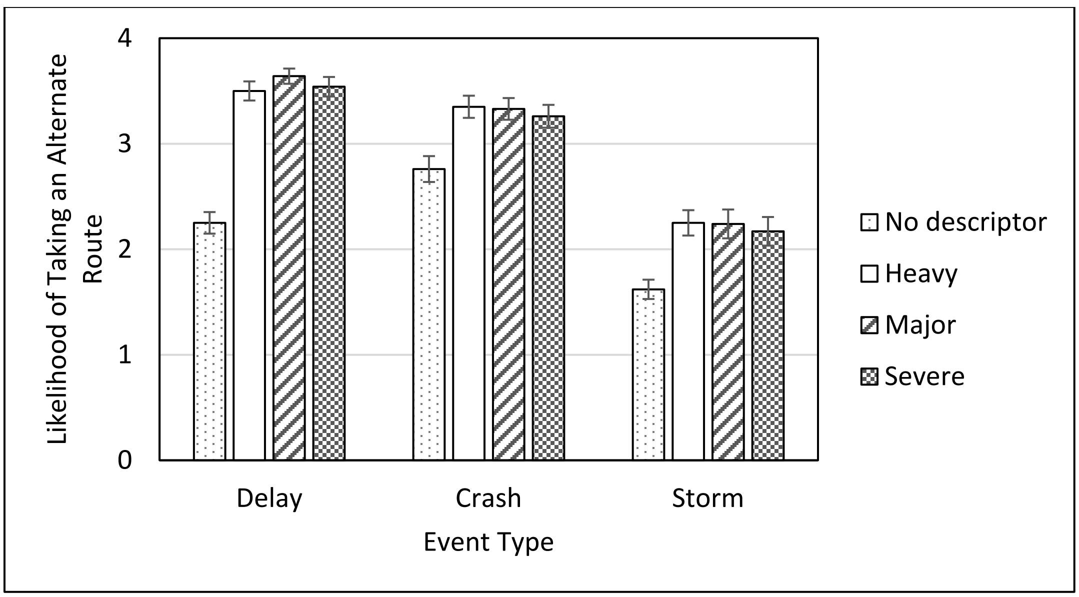


Source: FHWA.

Figure 15. Graph. Rankings of delay messages.

Do Descriptor Words Carry the Same Weight Across Different Events?

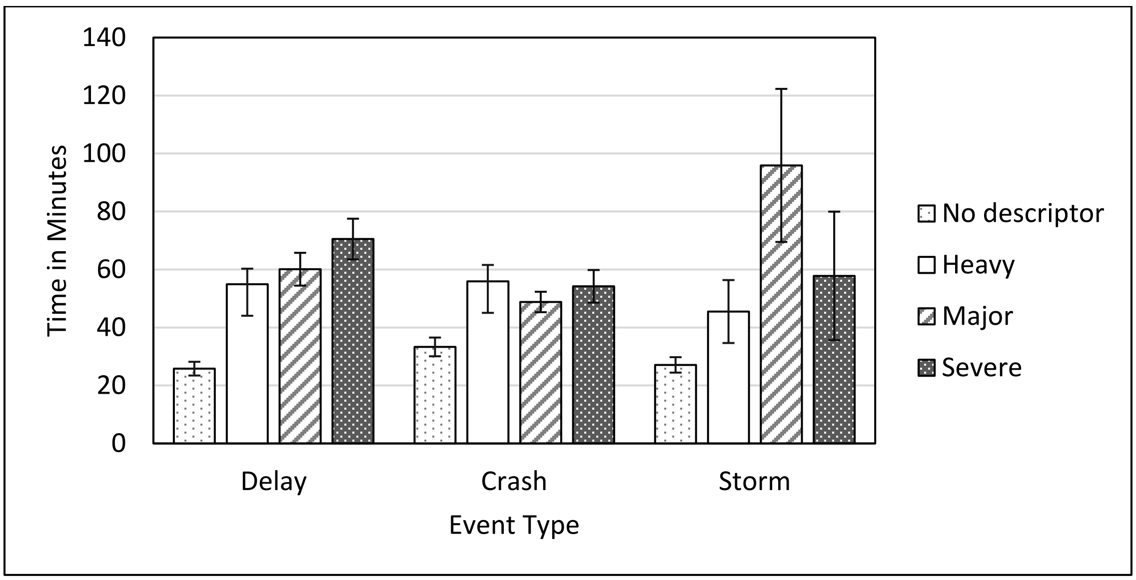
The same descriptor words can often describe different types of events (e.g., MAJOR DELAY or MAJOR STORM). To assess whether participants perceived descriptor words similarly across different events, they rated how likely they would be to change routes in response to CRASH, STORM, and DELAY events that were described either without a descriptor or as HEAVY, MAJOR, or SEVERE. A main effect of event resulted, $F(2) = 167.96$, $p < 0.001$. Participants indicated they were less likely to change routes in response to a storm ($M = 2.07$) than in response to a delay ($M = 3.23$) or a crash ($M = 3.18$). A main effect of descriptor also resulted, $F(3) = 58.37$, $p < 0.001$, such that events that did not include a descriptor ($M = 2.21$) received lower ratings than events that did include a descriptor (HEAVY: $M = 3.03$, MAJOR: $M = 3.07$, SEVERE: $M = 2.99$). The interaction between event and descriptor was also significant, $F(6) = 3.76$, $p = 0.001$. As figure 16 shows, relative to the baseline message that contained no descriptor, adding descriptors to a delay message had a larger impact on participants' ratings than it did for crash or storm messages. However, the specific descriptor message applied to each event message had little effect on ratings.



Source: FHWA.

Figure 16. Graph. Likelihood of taking an alternate route as a function of descriptor and event type.

Participants also estimated how long they would expect to be delayed after seeing a message that included those same descriptors and events. As expected, participants believed messages that included a descriptor (HEAVY: $M = 52.10$ min, MAJOR: $M = 68.27$ min, SEVERE: $M = 60.83$ min) would result in longer delays than those that did not ($M = 28.73$ min), $F(3) = 71.72$, $p < 0.001$. A main effect of event also resulted, $F(2) = 655.39$, $p < 0.001$. However, that effect was qualified by an event-by-descriptor interaction, $F(6) = 5.91$, $p < 0.001$. Figure 17 shows that for both crash and delay events, all messages that included a descriptor were estimated to result in significantly longer delays than messages that did not include the descriptor, but none of the descriptors varied significantly from one another. For the storm event, MAJOR STORM was estimated to result in a much greater delay than all other messages, and variability was also higher than for other event messages, such that the only significant difference between storm messages was between the MAJOR STORM and the no-descriptor message.

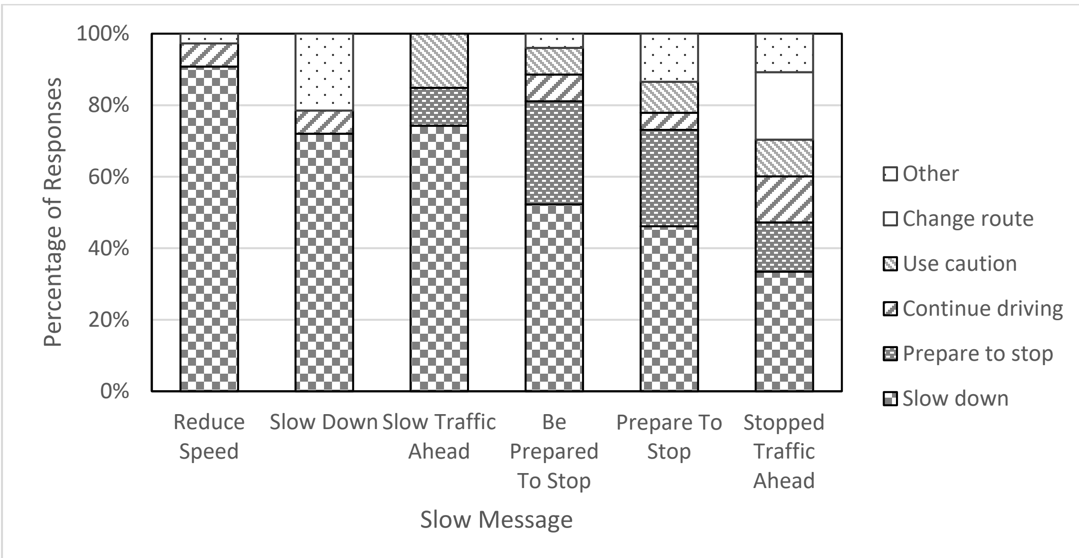


Source: FHWA.

Figure 17. Graph. Time estimates as a function of descriptor and event type.

How Do Drivers Interpret and Respond to "Slow" Messages?

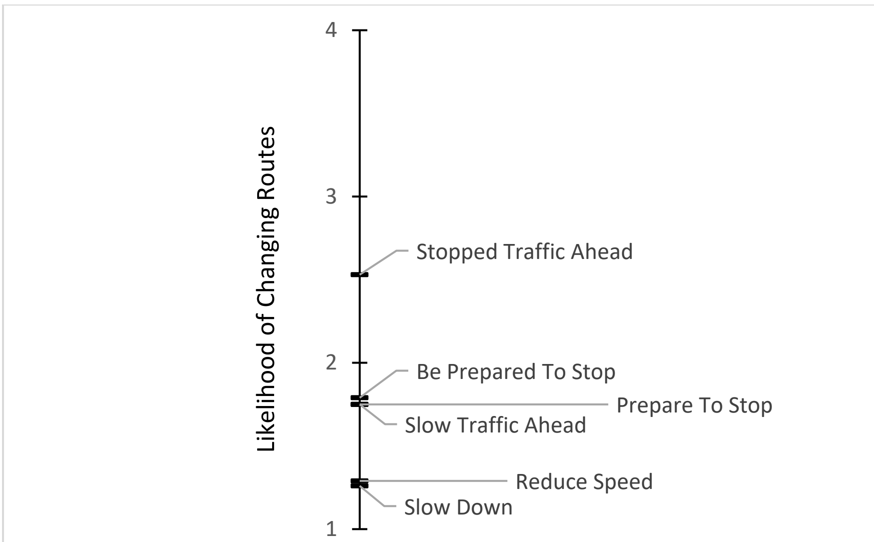
When asked what they would do in response to each "slow" message, the commonest responses across all messages were to slow down (61.7 percent), prepare to stop (15.1 percent), continue driving (7.9 percent), use caution (7.7 percent), and change routes (5.6 percent). Figure 18 shows the proportion of those responses that participants made to each of the six "slow" messages. The slow-down response was commonest for messages that were direct commands (i.e., REDUCE SPEED and SLOW DOWN). Only one message, STOPPED TRAFFIC AHEAD, caused participants to say they would change routes.



Source: FHWA.

Figure 18. Graph. Open-ended response to "slow" messages.

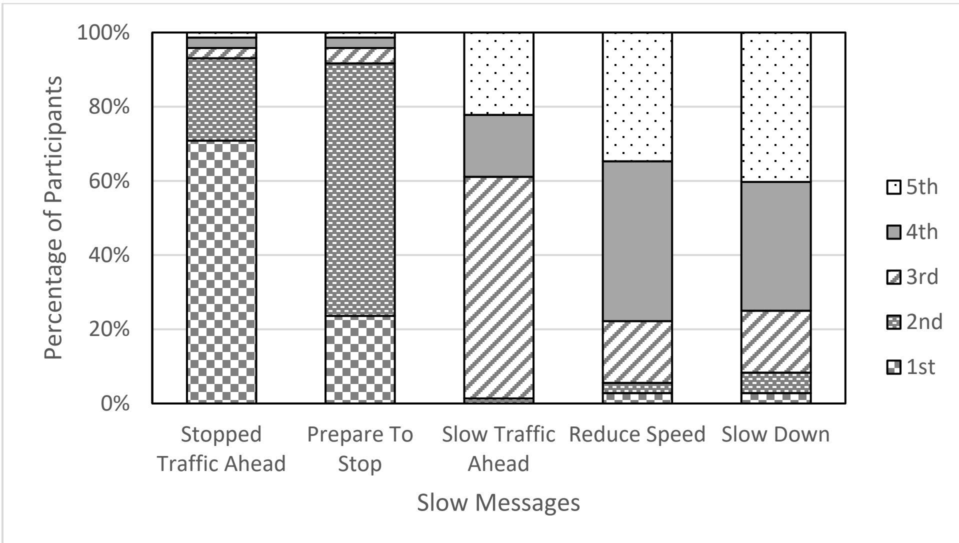
When asked to rate how likely they would be to change routes in response to each “slow” message, participants showed significant differences in ratings across message type, $\chi^2(5) = 125.20$, $p < 0.001$. Figure 19 shows STOPPED TRAFFIC AHEAD as rated highest. All other messages had low ratings, indicating that participants were unlikely to change their route in response to these messages. The messages REDUCE SPEED and SLOW DOWN had ratings that were significantly lower than all other messages.



Source: FHWA.

Figure 19. Graph. Likelihood of changing route in response to “slow” messages.

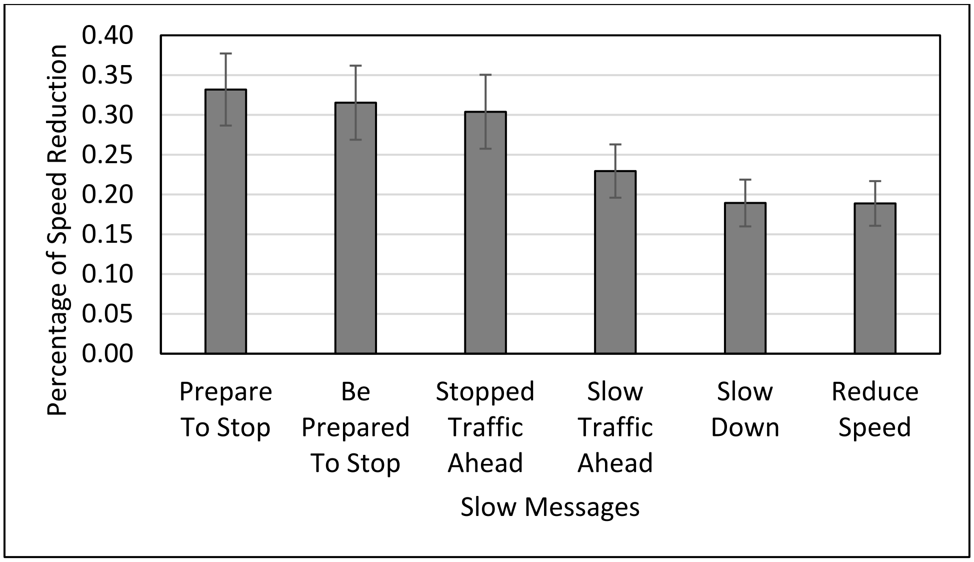
Figure 20 shows the rankings for each of the "slow" messages. The ranking follows the same pattern seen in the data for likelihood of changing routes. STOPPED TRAFFIC AHEAD was ranked as severest, while messages that included a direct command tended to be ranked as least severe.



Source: FHWA.

Figure 20. Graph. "Slow" message rankings.

For each "slow" message, participants imagined seeing the message on a road with a speed of 55 mph, and they estimated what speed the message was requesting that drivers drive at. The estimation allowed for a calculation of the mean percentage of speed reduction estimated for each message (figure 21). Differences in speed estimates resulted across message type, $\chi^2(5) = 41.77$, $p < 0.001$. Despite being most likely to elicit a change in speed, the command messages REDUCE SPEED and SLOW DOWN resulted in the smallest speed reductions.



Source: FHWA.

Figure 21. Graph. Mean percentage of speed reduction estimated for each "slow" message.

Are Messages That Specify an Intended Audience More Effective Than Messages That Include Only Location Information?

To compare the effectiveness of messages that contain information for an intended audience with those that instead include location information, the researchers constructed two messages about a crash. The first included information about the location of the crash: CRASH / AT BRIDGE / USE OTHER ROUTES. The second used intended-audience information to target drivers who would be affected by the crash: CRASH / BRIDGE TRAFFIC / USE OTHER ROUTES. When asked how they would respond to each message, participants had very similar responses (table 6), and the mean ratings for the likelihood of changing routes were high for both the location information message ($M = 3.92$), and the intended-audience message ($M = 3.90$).

Table 6. Open-ended responses for each message type.

Message Type	Change Route (%)	Slow Down (%)	Other (%)
Location information	86.4	9.5	4.1
Intended audience	88.3	9.1	2.6

When asked how likely they would be to change their route in response to each message, participants showed no difference between the message that contained location information ($M = 3.93$) and the intended-audience messages ($M = 3.90$). When asked who each message was for, 73.6 percent of respondents were able to correctly identify the target audience for the location information message, while 81.9 percent correctly identified the audience for the intended-audience message.

DISCUSSION

What Are the Perceived Severities of Different Weather Messages?

The findings suggest a tendency toward differences in the perceived severity of different weather messages. For instance, participants viewed flood messages that included the word "flood" as severer than messages that included the word "water." Participants tended to view ice messages that contained qualifiers as less severe than messages that did not. For snow messages, ratings for HEAVY SNOW WARNING, which participants tended to rank as severer, were higher for changing route, whereas BLOWING SNOW and DRIFTING SNOW appeared more likely to elicit changes in driving speed and increased caution. For winter weather messages, participants viewed messages that contained the term "severe" as severer than those that did not.

Responses to messages that did not warn about precipitation were less influenced by message type. For both wind and visibility messages, participants tended to indicate they would be unlikely to change their route in response to these types of messages. The rates at which they would engage in other driving responses, such as slowing down and using caution, seemed to be similar across message options.

Does Including Qualifiers in Weather Messages Have Value?

The researchers assessed the potential influence of qualifiers by using both a Likert scale response and a flyby technique.[(62)] The findings from the Likert response questions indicated that qualifiers tended to make messages appear less severe and, as a result, made drivers less likely to change their behavior compared with the same message that did not include a qualifier. BLACK ICE was a notable exception to that finding. BLACK ICE tended to be viewed as a very serious weather condition, and the presence of the qualifier POSSIBLE did not reduce the perceived severity of the event.

Researchers used the flyby procedure to assess the effect of qualifiers on the perceived helpfulness and accuracy of CMS messages. Participants' perceptions of weather messages tended to be less affected by both message type and hazard presence than their perceptions of nonweather message were. The results suggest that drivers may understand the potentially temporary nature of weather events and be more tolerant of inaccuracies in weather messages than of inaccuracies in nonweather messages. However, readers should interpret that result with caution, since the study was limited to only one weather event type, and participants did not appear to view the specific hazard in this experiment as particularly severe.

Which Are More Effective: Quantitative Delay Messages or Qualitative Delay Messages?

In the researchers' comparison of quantitative and qualitative messages, qualitative messages appeared to be more effective at conveying long delays— that is, delays that were expected to last for 40 min or longer. All messages that included descriptors, such as LONG, MAJOR, or HEAVY, tended to elicit a desire to change routes at rates similar to rates seen for the 40 MIN DELAY message.

Do Qualitative Messages Hold Quantitative Value?

In this study, qualitative messages with strong descriptors were seen as referring to rather long delays (45 min to an hour and a half). When asked to estimate the time related to each delay, participants gave EXPECT LONG DELAY the highest time ranking. In contrast, when asked to rate the severity associated with each message, they ranked the message with the descriptor SEVERE as the highest, followed by MAJOR, HEAVY, and, finally, LONG. However, the specific message used for delays of this length may not be important because there seems to be a ceiling of approximately 40 min on the extent to which a delay message causes drivers to change routes such that additional delay times are unlikely to yield additional changes in behavior.

Do Descriptor Words Carry the Same Weight Across Different Events?

When considering changing routes, drivers seem to consider both the event itself and whether or not the CMS included a descriptor to describe the event. Participants indicated they were less likely to change routes in response to a storm compared with a delay or a crash. Use of a descriptor increased ratings for changing route more for delay messages than for crash or storm events. However, the specific descriptor that emphasized the severity of the event did not affect route-change ratings. A similar finding resulted for both delay and crash events when participants were asked to estimate the time associated with the delay. The presence of any descriptor was sufficient to increase the estimated delay time. However, a different finding resulted for the storm event, such that MAJOR STORM was associated with estimated delay times that were longer and more variable than the findings for other descriptors. Interestingly, the long delay estimated for MAJOR STORM contrasts with the descriptor severity that resulted for other weather messages and for delay messages, in which the descriptor SEVERE tended to be associated with higher perceptions of event severity. Such variability across different events and even within subjects for the same event suggests that descriptor words, while able to increase the perceived severity of an event, do not carry similar weights across different event types.

How Do Drivers Interpret and Respond to "Slow" Messages?

Responses from this study suggest that "slow" messages can cause drivers to either slow down or change their route. Specifically, participants rated messages that included a direct command (e.g., SLOW DOWN or REDUCE SPEED) as most likely to result in a change of speed and least likely to result in a change in route. The messages BE PREPARED TO STOP, PREPARE TO STOP, and SLOW TRAFFIC AHEAD also were associated with increased likelihood of slowing down and reduced likelihood of changing routes. However, the frequency of those responses was not quite as high as it was for messages that were direct commands. Finally, STOPPED TRAFFIC AHEAD was less likely to result in slowing and more likely to result in a change of route. Surprisingly, when asked what speed each message was suggesting the driver drive at, the expected speed reduction seemed to be inversely related to the likelihood of slowing down, such that participants rated the direct command messages as requiring the smallest reductions in speed. Direct command messages also tended to be ranked as least severe.

Are Messages That Specify an Intended Audience More Effective Than Messages That Include Only Location Information?

Participants were slightly better at identifying the intended audience for a message that directly contained intended-audience information than they were at identifying the intended audience for messages that did not. However, that knowledge did not have a significant effect on their intended response to each message. The results suggest that location information may be a sufficient substitute for intended audience information in some circumstances, but intended-audience information is more appropriate in situations in which the potential target audience of the message is unclear.

CHAPTER 3. EXPERIMENT 2

The current experiment used a driving simulator to examine how different combinations of phrases displayed on a CMS influence driving behavior. Specifically, the team compared the potential for specific sets of CMS messages to elicit drivers' changes in route, lane, and speed.

ROUTE CHANGES

A typical goal of CMS messaging is to alleviate the congestion a nonrecurring event generates by encouraging drivers to use an alternate route. Assessing the potential for CMS messages to lead to route change in a driving simulator can be challenging, however.

First, the actual rate at which drivers take an alternate route suggested by a CMS in the absence of a complete road closure is often quite small.[(2)] In fact, Schroeder and Demetsky found diversion rates of only 8.7–9.5 percent in response to CMS messages on a Virginia highway.[(19)] Participants may be even more reluctant to change routes in a driving simulator. For example, Weaver et al. found that none of the 120 participants who completed their driving simulator experiment took the available alternate route despite attempts to encourage participants to do so.[(14)] On actual roadways, research suggests, drivers are more likely to divert from their routes in response to traveler information, such as that displayed on a CMS, when driving in a familiar area.[(16,17,18)] Studies that have taken steps to make the simulated routes participants drive within a driving simulator familiar to participants have been successful in eliciting route diversion. For example, some studies have simulated a local route so that potential participants would be familiar with the route prior to the start of the study.[(39,53)] Jeihani, Narooienezhad, and Kelarestaghi used a simulated Global Positioning System–based in-vehicle guidance system to give participants more information about the route.[(59)] Finally, some researchers have had participants gain familiarity by driving through the route multiple times.[(39,47,59)] This experiment used multiple drives through a simulated route to enable participants to gain familiarity with the simulated route options and thereby improve the potential for route change in response to CMS messages.

Eliciting Route Change During Congestion

Research has suggested that the highest rates of route diversions result from CMS messages that explicitly tell drivers to change routes. (See references 14, 15, 22, and 39.) Schroeder and Demetsky demonstrated that messaging suggesting drivers use a specific alternate route were associated with higher diversion rates than were more generic messages, such as USE OTHER ROUTES.[(19)] Nevertheless, such generic messages are often favored by CMS operators who do not want to risk exceeding the roadway capacity of any single, specified route.[(19,32)]

Increased rates of route change have also resulted in responses to messages that describe high congestion levels and lengthy travel times.[(10,29,48)] When asked how likely they would be to change routes in response to different CMS messages, Weaver et al. found that messages including the phrase MAJOR DELAY often prompted change rates similar to rates seen for messages including the phrase USE OTHER ROUTES.[(14)] The results of the first experiment in the current project (discussed in chapter 2) also highlighted the potential for MAJOR DELAY to lead to route diversion. When asked how they would respond to different delay messages, more than half of participants (58 percent) answered that they would change routes after seeing a MAJOR DELAY message. MAJOR DELAY gives drivers a potential reason to change routes, and as such may be an effective alternative to USE OTHER ROUTES when congestion is delaying traffic. This experiment tested that hypothesis by comparing rates of route change in response to the two messages.

Eliciting Route Change Using Two-Phase Messages

MUTCD specifies that a CMS display no more than three units of information at one time.(60) That content limitation helps ensure that drivers can read and process the message without undue distraction from the primary driving task. CMS operators can increase the amount of information that can display on a CMS by use of a two-phase message or a sign that alternates between two different groups of messages. Two-phase signs give drivers more information, which may aid them in making appropriate travel decisions during a nonrecurring event. For example, when an event results in a lane closure, a one-phase message could enable CMS operators to convey information about the event type, the event location, and the lane closure itself. A two-phase message can also instruct drivers to take an alternate route. Since drivers who are preparing for a lane change appear less likely to change routes, the addition of the instruction to change routes could increase diversion rates.(14) However, increasing the number of phases also increases the probability that a driver may miss some of the information. Therefore, whether the extra information presented in a two-phase message produces a net benefit in traveler behavior when drivers are required to process information from both phases while driving remains unclear. The current experiment addressed that issue by comparing diversion rates after exposure to a one-phase message and a two-phase message.

LANES

When a nonrecurring event results in a lane closure, CMS messages can prepare drivers for the lane closure and prompt them to enter the open lane. Schroeder and Demetsky reported that individual CMS operators in Virginia use both RIGHT LANE CLOSED and LEFT LANE OPEN to indicate lane reductions.(19) That type of inconsistent lane reduction messaging has the potential to cause confusion among drivers. Basic attentional research has demonstrated the difficulty of directing attention by using the words “right” and “left”—due to the inconsistent mapping of those directions when speakers and listeners do not share the same reference point.(44) Proffitt and Wade warn that use of variations in directional values within the same sign (i.e. RIGHT LANE CLOSED, MERGE LEFT) can increase message processing time and reduce comprehension rates.(45) Consistency in CMS messaging with regard to lane reductions could help speed drivers’ processing time and compliance. However, the specific phrase most effective at encouraging drivers to merge remains to be determined. The phrase RIGHT LANE CLOSED is used on work zone signing (i.e., W20-5R).(60) As a result, the phrase is likely to be familiar to drivers and consequently may speed lane-changing responses. However, the phrase MERGE LEFT is a shorter message, with the potential to focus drivers’ attention on the action to perform and the direction to move in. Therefore, drivers might process and respond to that phrase more easily. The current study directly compared the speed at which participants respond to the phrases RIGHT LANE CLOSED and MERGE LEFT to assess which message is more effective in eliciting a prompt lane change before arrival at a lane closure.

Lane Change Prior to a Road Closure

Lane changes may also be necessary in situations in which a road is completely blocked and drivers must follow a detour or take a suggested route. In instances in which the first step in changing routes is a change in lane, researchers can evaluate the effectiveness of road closure messages by learning how promptly a participant changes lanes after seeing the road closure message. Dudek and Ullman advise that the message ROAD CLOSED is the most explanatory piece of information to include in a CMS message and, as such, that that message always appear on the first line of the CMS.(11) However, that strategy would run counter to the usual practice of placing event information on the first line of the CMS.(60) Further, the inclusion of event information, which gives drivers a reason for the road closure, may make drivers feel more informed and less stressed about the road closure. The current experiment directly compared the effects of including event information in a road closure message.

SPEED CHANGES

When a nonrecurring event results in congestion, one way to help alleviate the congestion is to have drivers reduce their speed prior to reaching the bottleneck. CMS messages can be effective in reducing drivers' speeds.(3,18,19) The command message SLOW DOWN is commonly used for encouraging such behavior. For example, Weaver et al. found that participants who drove beneath an overhead CMS that included the CMS phrase SLOW DOWN drove at slower speeds than did those who received a similar CMS message that did not include the phrase SLOW DOWN.(14) Likewise, Garber and Patel found that the phrases HIGH SPEED / SLOW DOWN and YOU ARE SPEEDING / SLOW DOWN were more effective at reducing speed in a temporary work zone than was REDUCE SPEED / IN WORK ZONE.(54) Nevertheless, SLOW DOWN may not always be the most effective message to encourage speed reductions. In Garber and Patel's study, EXCESSIVE SPEED / SLOW DOWN was less effective in slowing traffic than were the other messages that contained the phrase SLOW DOWN. the first experiment in the current study also saw potential limits to the effectiveness of SLOW DOWN. SLOW DOWN was tied with REDUCE SPEED for being the lowest ranked of the five "slow" messages tested. Similarly, when asked what they would do in response to each "slow" message, only 64 percent of participants responded that they would slow down, whereas 93 percent of participants said they would slow down in response to the phrase SLOW TRAFFIC AHEAD. The current experiment compared speed reductions among participants after exposure to the messages SLOW DOWN and SLOW TRAFFIC AHEAD.

METHOD

Participants

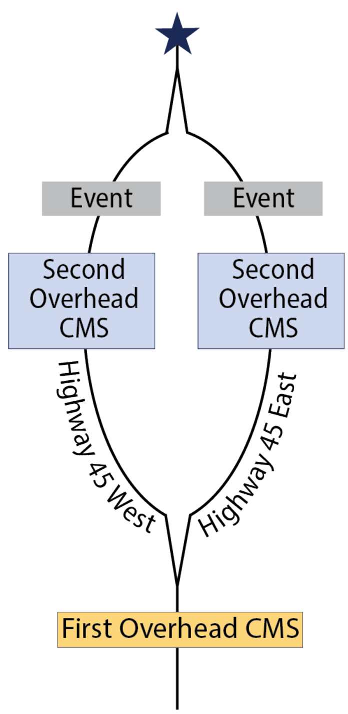
The researchers recruited 98 licensed drivers from the Greater Washington, DC, metro area. Data from three participants was lost due to a technical error. Of the remaining 95 participants, 49 were male and 48 were older than 45 yr.

Simulator

The team conducted the study by using National Advanced Driving Simulator Quarter Cab miniSim.™ Three 48-inch-wide high-definition liquid crystal display screens depicted the forward roadway and side and rearview mirrors. An additional, 12-inch-wide screen displayed dashboard information. The simulator was fixed base and used a subwoofer beneath the driver's seat to generate road feel.

Simulator Scenario

Figure 22 depicts the experimental scenario. The route was just under 4 mi and had a speed limit of 55 mph. Participants began each drive on a highway of four lanes, all of them traveling in the same direction. An overhead CMS was positioned approximately 0.5 mi downstream from the start point. One mile downstream from the CMS, the highway split such that two lanes extended to the right (Highway 45 East) and two lanes to the left (Highway 45 West). A second set of overhead CMS was positioned approximately 0.5 mi downstream from the highway split, so that each participant encountered two CMSs—one before the highway split and one after the split—regardless of the direction participants choose to travel. Each arm of the highway continued for 1.5 mi. Depending on the experimental condition, participants sometimes encountered a nonrecurring event that delayed their travel time on this portion of the roadway. Approximately 3.25 mi from the start of the route, the two arms of the highway merged back together. Participants traveled an additional 0.25 mi before reaching their destination. Because the specific message, event, and default driving direction varied based on participant and condition, this study required several simulator scenarios. The full list of scenarios is in the appendix.



Source: FHWA.

Figure 22. Diagram. Experimental route.

Experimental Design

The study used a series of drives to examine various questions of interest related to how drivers respond to CMS messages. Specifically, the team assessed rates of route diversion, changes in speed, and locations of lane changes that occur after drivers viewed different CMS messages. The specific messages each participant saw varied by condition. Table 7 shows the different message sets compared, grouped by the dependent variable of most interest for that message set. During the experiment, each participant saw either message option A or message option B. The specific set of sign combinations was counterbalanced.

Table 7. Message options and variables of interest.

Dependent Variable of Interest	Message Option A	Message Option B
Diversion rate	TRAFFIC INCIDENT HWY 45 EAST ONE LANE CLOSED	TRAFFIC INCIDENT HWY 45 EAST/ONE LANE CLOSED USE OTHER ROUTES
Diversion rate	GAME DAY TRAFFIC HWY 45 EAST USE OTHER ROUTES	GAME DAY TRAFFIC HWY 45 EAST MAJOR DELAY
Lane-change location	ROAD CLOSED TAKE HWY 45 WEST	FLOODING ROAD CLOSED TAKE HWY 45 WEST
Lane-change location	TRAFFIC INCIDENT RIGHT LANE CLOSED	TRAFFIC INCIDENT MERGE LEFT
Speed change	GAME DAY SLOW DOWN	GAME DAY SLOW TRAFFIC AHEAD

HWY = highway.

Procedure

Each session began with participants reviewing and signing an informed consent form. The team then assessed participants' vision to ensure a minimum acuity of 20/40 with correction, which is the minimum acuity required to obtain a driver's license in most States. Finally, participants completed a Simulator Sickness Questionnaire (SSQ) as a screen for symptoms of simulator sickness that could have prohibited them from participation.

Next, participants completed a practice drive to familiarize themselves with the simulator controls. During the practice drive, participants practiced accelerating, braking, and changing lanes. After the practice drive, participants completed the SSQ a second time.

Prior to beginning the experimental drives, participants received instructions explaining that the researchers had designed the study to mimic situations in which drivers had to drive to the same location multiple times, such as caused by the need to commute to work daily. They saw a map of the experimental route, with the starting location and destination marked, and were given time to become familiar with the route map before completing a series of five experimental drives.

During the first drive, all CMSs were blank, and no events were present on the roadway. Light traffic throughout the route added realism to the drive. That first drive served as a baseline condition with which the team could compare the other drives. The first drive also determined each participant's default drive preference, which dictated some of the features of that participant's next two drives. Specifically, drivers who chose to take Highway 45 East for their first drive began their next two drives in the rightmost lane and were exposed to nonrecurring events taking place on Highway 45 East. Participants who chose to take Highway 45 West for their first drive began their next two drives in the leftmost lane and were exposed to nonrecurring events taking place on Highway 45 West.

The second drive used a closed road to force participants to take their alternate route, or the route they did not take during their first drive. Participants were exposed to a road-closed message that either included information about the event causing the road closure (e.g., FLOODING / ROAD CLOSED / TAKE HWY 45 WEST) or did not include event information (e.g., ROAD CLOSED / TAKE HWY 45 WEST). When they reached the split in the highway, barrels prevented them from proceeding in their default direction.

The order of the drive that contained an incident was counterbalanced such that it occurred as the third drive for half of participants and as the fifth drive for the other half of participants. The incident drive examined messages preceding a traffic incident. First, participants were exposed to either a one-phase message warning them about the location of a traffic incident (e.g., TRAFFIC INCIDENT / HWY 45 EAST / ONE LANE CLOSED) or a two-phase message that warned them about the location of the traffic incident and instructed them to use an alternate route (e.g., TRAFFIC INCIDENT / HWY 45 EAST / ONE LANE CLOSED / USE OTHER ROUTES). Participants who did not divert but instead chose to proceed on their default route encountered a second CMS, which provided information about the road closure by way of either the message RIGHT LANE CLOSED or the message MERGE LEFT. They then reached a congested lane closure. Participants who chose to divert to the alternate route passed a blank CMS and traveled in free-flowing traffic.

The fourth drive was a repetition of the first baseline drive, in which no CMS messages or events had been encountered. This drive reset each participant's default route as needed.

The drive that included congestion was also counterbalanced, such that it could be either a participant's third or fifth drive. This drive examined reactions to messages preceding congestion resulting from a planned nonrecurring event. Participants were exposed to one of two messages regarding game day traffic. One message warned participants that event traffic was causing a major delay (e.g., GAME DAY TRAFFIC / HWY 45 EAST / MAJOR DELAY). The other instructed participants to use an alternate route (e.g., GAME DAY TRAFFIC / HWY 45 EAST / USE OTHER ROUTES). Participants who chose to remain on their default route encountered a second CMS about game day traffic that either instructed them to SLOW DOWN or indicated that there was SLOW TRAFFIC AHEAD. Participants then encountered a high density of traffic traveling at slow speeds. Participants who chose to divert to the alternate route passed a blank CMS and traveled in free-flowing traffic.

After each drive, the team asked participants to rate the amount of stress they felt during the preceding drive from 1 to 10, where 10 indicated the highest level of stress and 1 the lowest. Once they had finished all drives, participants completed a brief questionnaire about how much they trust CMS signs and how frequently they change their driving behavior in response to CMS messages.

Analysis

After data collection, the team further processed data from each participant such that only meaningful observations were left to derive variables of interest that would enable the team to assess rates of route diversion, changes in speed, and locations of lane changes that occurred after drivers viewed different CMS messages. The team selected and applied hypothesis-testing methods depending on data characteristics. The main statistical tests the team used were, in alphabetical order, the Friedman test,(64) Mann–Whitney *U* test,(65) McNemar test,(66) paired-samples *t*-test,(67) Pearson's chi-squared test,(68) Skillings–Mack test,(69) Welch two-sample *t*-test,(70) and Wilcoxon signed-rank test.(71)

RESULTS

This section describes the results of each of the four drive types and responses to the postdrive questionnaire.

Baseline Drive

The experiment had two baseline drives during which no CMS messages were displayed. The two drives served as a baseline for comparing the drives with CMS messages. During their first drive, only 11 percent of drivers took the alternate route. On the fourth drive, which served as the second baseline drive, 62 percent of drivers took the alternate route. The large increase in drivers who took the alternate route during the second baseline drive suggests that drivers felt comfortable using both routes. Stress ratings were low for both the first drive ($M = 2.25$) and the fourth drive ($M = 2.18$).

Road-Closed Drive

During participants' second drive, one of the routes was closed such that all participants were forced to take the route they had not taken during their first drive. The team manipulated the CMS that warned participants about an upcoming road closure such that half of participants saw a message with information about the event causing the road closure (e.g., FLOODING / ROAD CLOSED / TAKE HWY 45 WEST), while the other half of participants saw the same message but without event information (e.g., ROAD CLOSED / TAKE HWY 45 WEST). Participants who saw event information got closer to the lane closure before changing lanes ($M = 3512.31$) than did participants who saw ROAD CLOSED on the top line of the CMS ($M = 3779.48$); however, that effect was not significant. Stress was low among both participants who saw event information ($M = 2.64$) and those who did not ($M = 2.56$).

Incident Drive

During the drive with messages that included the incident, participants saw a CMS message warning them about the incident ahead. For half of participants, the message contained only one phase (e.g., TRAFFIC INCIDENT / HWY 45 EAST / ONE LANE CLOSED). Remaining participants saw a two-phase message (e.g., TRAFFIC INCIDENT / HWY 45 EAST / ONE LANE CLOSED / USE OTHER ROUTES). Diversion rates for both the one-phase message (69.57 percent) and the two-phase message (75.51 percent) were high and did not vary significantly from each other. Likewise, the point at which participants who chose to divert changed lanes did not vary as a function of message type.

To assess the potential impact of multiphase messages on drivers' speed, the team calculated mean speed for the distance between when the first CMS became visible and when participants passed under the sign. The team found no difference in speed between one-phase ($M = 56.22$ mph) and two-phase ($M = 56.34$ mph) messages. The results suggest that drivers did not reduce their speed to read the two-phase message.

The team examined stress ratings as a function of the type of message each participant saw and whether or not the participant diverted to avoid the incident. As expected, participants who did not divert rated stress higher ($M = 3.08$) than those who did divert to the alternate route ($M = 2.08$), $F(1,90) = 7.94$, $p < 0.01$. Participants who saw the two-phase message ($M = 2.67$) also rated stress higher than those who saw the one-phase message ($M = 2.03$).

Participants who did not divert during the incident drive encountered a second CMS that warned them about an upcoming lane closure. Participants who viewed the message RIGHT LANE CLOSED merged into the open lane farther downstream from the lane closure ($M = 1641.12$) than did participants who saw MERGE LEFT ($M = 1378.86$). Participants who saw RIGHT LANE CLOSED also took less time to drive through the event ($M = 196.69$ s) than did participants who saw MERGE LEFT ($M = 201.17$ s). Overall, stress ratings were low for both those who saw RIGHT LANE CLOSED ($M = 3.25$) and those who saw MERGE LEFT ($M = 2.80$).

Congestion Drive

During the drive that included congestion, participants first passed a CMS that either encouraged them to take an alternate route (i.e., GAME DAY TRAFFIC / HWY 45 EAST / USE OTHER ROUTES) or warned them about an upcoming delay (GAME DAY TRAFFIC / HWY 45 EAST / MAJOR DELAY). Diversion rates were high for both other-route messages (87.23 percent) and delay messages (83.33 percent) and did not vary significantly from each other. Each group also changed lanes at a similar distance from the road split so as to prepare to divert (delay: $M = 4956.45$, other route: $M = 4813.63$). Stress was higher among participants who did not divert ($M = 3.08$) than among participants who did divert ($M = 2.08$), $F(1,90) = 7.69$, $p < 0.01$, but did not vary as a function of message type.

Participants who did not divert encountered a second CMS that warned them to slow down by either a direct command message (GAME DAY / SLOW DOWN) or a warning about the speed of upcoming traffic (GAME DAY / SLOW TRAFFIC AHEAD). To assess the effect of those messages on drivers' speed, the team calculated mean speed between the location of the CMS and the location where participants encountered the event (congestion) for participants that diverted. The team compared that speed with mean speed in the same location during the baseline drives. Participants drove slower after seeing a CMS message (M = 51.00 mph) than when the CMS was blank (M = 54.67 mph), $F(1,13) = 7.78$, $p = 0.02$. However, the SLOW DOWN (M = 51.57 mph) or SLOW TRAFFIC AHEAD (M = 50.23 mph) message elicited no difference in speeds. The result suggests that both messages were successful in reducing speed. Stress ratings did not vary as a function of message type (SLOW DOWN: M = 3.36, SLOW TRAFFIC AHEAD: M = 2.87).

Postdrive Questionnaire

When asked to rate on a scale of 1 (very infrequently) to 10 (very frequently) how frequently they encountered CMS messages in their daily lives, participants responded with a mean rating of 5.74. The rating did not vary as a function of gender or age-group. The team then asked participants how accurate they deem the CMSs they encounter in everyday life and how often they make changes in their driving behaviors based on messages on those signs. Accuracy ratings tended to be high (M = 8.04), and participants indicated that they change their behavior more than half of the time (M = *6.83)*. Ratings did not vary as a function of age-group or gender.

DISCUSSION

Experiment 2 used a driving simulator to assess the extent to which specific CMS messages affected drivers' behaviors. The team designed the experiment to elicit potential changes in route in response to different CMS messages. To that end, both routes were the same length, and participants could familiarize themselves with both routes by seeing a map of the simulated road network and participating in multiple study drives. To further encourage the potential for route change, the team forced all participants to take different routes in their first and second drives. The procedure was successful in eliciting route change. Even during the second baseline drive (the fourth drive), in which all CMSs were blank, 62 percent of participants chose to take the alternate route. Diversion rates were even higher for drives during which the CMS warned of either an incident (73 percent) or congestion (85 percent) on the default route. The rates of diversion found in the current study appear much higher than would be expected on an actual roadway, where diversion rates are typically closer to 10 percent.(19) Those high diversion rates present a potential concern for some of the analyses conducted in the current experiment. Responses to the second CMS could be evaluated only for participants who did not divert to the alternate route. Thus, the number of participants who could be included in these analyses was less than originally planned, and as a result, the findings from these analyses are to be interpreted with some caution.

The team assessed diversion rates as a function of message type. One goal was to compare the potential influence of the command message USE OTHER ROUTE with the message MAJOR DELAY on diversion rates when event-related congestion was present on the roadway. The current findings suggest that both messages were equally successful in eliciting route diversion. That both messages could elicit route change is consistent with previous research assessing the influence of CMSs on diversion rates.(14,19) Earlier research has shown that USE OTHER ROUTES is effective in eliciting route change.(19,32) In the current study, that effect was likely amplified, since the specific route the team expected participants to divert to was made obvious by the experimental procedure. The team found MAJOR DELAY to be rated as likely to cause participants to change route both in previous work and in experiment 1.[14] The current experiment builds on those findings by demonstrating that MAJOR DELAY can lead not only to ratings of route change similar to those seen for USE OTHER ROUTES but also to similar changes in driving behavior in a driving simulator.

The research team also assessed rates of diversion in response to one- and two-phase messages and found high diversion rates for both message types. Neither the specific rate at which participants changed routes nor the speed at which they drove under each message varied as a function of the number of phases included in each message. Drives that included the two-phase message did produce slightly higher stress ratings than those that included only one phase. However, all stress ratings tended to be low. In the current study, phase number had little influence on drivers' behaviors. However, drivers may be more sensitive to phase number when driving on actual roadways. Traffic condition was light in the present study, giving drivers plenty of time to monitor the roadway and read both phases of the CMS. Previous work has noted that drivers consider one-phase messages easier to understand than two-phase messages.[7] In conditions in which participants have less opportunity to monitor CMSs, it may behoove TMC operators to select the one-phase message if possible.

The effect of CMS messages on lane changes was also of interest. The drives required lane changes at two points during the experiment, the first in response to a route closure during the second drive. Before this lane closure, participants saw a message that either included or did not include event information. Previous research has found that messages that include event information tend to be associated with higher diversion rates than messages that do not.[34,39] However, some work has suggested that when a road is closed, event information in the CMS describing the road closure may not be necessary.[14,16] In fact, Dudek and Ullman advise that when a road is not accessible, ROAD CLOSED always appear on the first line of the CMS.[11] The current findings were somewhat consistent with that recommendation. Participants who saw ROAD CLOSED on the first line of the message changed lanes slightly more quickly and had stress ratings that were slightly lower than those who saw event information as the first line of the CMS. However, those slight differences did not reach statistical significance. Nevertheless, since event information increases the size of the CMS message without providing a benefit with regard to reduced stress or prompter lane changes, researchers may prudently not include event information on a CMS conveying information about a road closure. Instead, ROAD CLOSED should appear on the first line of the CMS.

The team also assessed speed of lane change in response to a single-lane closure. Of interest was whether RIGHT LANE CLOSED or MERGE LEFT is better in eliciting prompt lane changes. RIGHT LANE CLOSED was associated with slightly prompter lane changes and slightly faster times for clearing an incident. However, the results were not significant, and those somewhat inconclusive findings are similar to those by Schroeder, and Demetsky, who found similar responses to both RIGHT LANE CLOSED and LEFT LANE OPEN.[19] While more compact and a direct command message, MERGE LEFT is likely to be slightly less familiar to participants than is RIGHT LANE CLOSED, since MUTCD sign W20-5R includes either the phrase RIGHT LANE CLOSED along with either the distance in feet or miles at which the closure will occur or the word AHEAD.[2] Since consistency in messaging typically leads to reduced processing times and more consistent driving behavior, the use of RIGHT LANE CLOSED on CMSs may be advisable.

Finally, the study also assessed the potential for CMS messages to elicit changes in speed. Specifically, the researchers compared responses to SLOW DOWN and SLOW TRAFFIC AHEAD. Both messages successfully elicited mean speeds approximately 5 mph slower than those found in the baseline conditions, in which no CMS message was present. Neither the mean speed nor mean stress ratings varied significantly as a function of message type. However, as indicated in the preceding, the high diversion rate found during the congestion drive (85 percent) may have influenced that lack of significance. An examination of mean responses by participants who did not divert revealed slightly lower speeds and slightly lower stress ratings for SLOW TRAFFIC AHEAD relative to SLOW DOWN. While the lack of power in the current analysis indicates that these results be interpreted with caution, the findings are somewhat consistent with those found in experiment 1, wherein participants rated SLOW TRAFFIC AHEAD as more effective and as requiring a greater reduction in speed than SLOW DOWN. When slow or stopped traffic is occupying a roadway, messages that describe that traffic may result in greater reductions in speed than command message SLOW DOWN.

CHAPTER 4. CONCLUSIONS

CMS messaging may be an important tool for distributing traveler information to drivers. Careful CMS message selection can help drivers make informed travel decisions and increase the safety and usability of roadways—particularly during nonrecurring events. As noted in the literature review, CMS messages are most beneficial when drivers can read and understand the messages, have trust in CMS messaging, and view messages that encourage appropriate changes in driver behavior. Previous research has yielded insights into how CMS operators can design and implement messages drivers can read, understand, and trust. The current work aims to improve the safety and the flow of the transportation system during nonrecurring events by assessing and documenting specific CMS messages that effectively promote desired changes in traveler behavior.

MUTCD provisions specify that CMS messages be broken down into units of information or brief, one-line phrases that give a simple answer to a single question.(1) Dudek and Ullman have produced State CMS manuals that describe different types of units of information that a CMS may include.(11) The series of experiments conducted for this report provide additional information about the utility of phrases that can serve as units of information. First, the research team contacted State DOTs and obtained lists of CMS messages that transportation agencies are currently using. Examples of CMS messages used in the literature supplemented the list, and then the researchers sorted the list into units of information: event type, effect of event, suggested action, and intended audience. The researchers used the message lists to generate the stimuli for experiment 1 and thereby help motivate the research questions that experiment 2 assessed. The following sections apply the findings from the two experiments to the broader research on each of the four types of units of information.

EVENT TYPE

"Event type" refers to the type of nonrecurring event that is currently affecting travel. Past research suggests that including event type in a CMS message often increases changes in drivers' behaviors.(34,39,40) However, some events tend to be more likely to elicit changes than others tend to.(14,22,34) Whether or not event information affects a driver's response to a CMS message appears to depend on the perceived severity of the event as well as the availability of actions the driver can take to respond to the event. Events viewed as severe and to which an appropriate response is apparent are likely to have the largest impact on driver behavior and thus are most important to include in CMS messages.

One class of event type that is frequently perceived as both severe and informative is a nonrecurring event involving weather.(14,41,42) CMS messages about a weather event can result in multiple positive effects on driving behavior because drivers make changes they feel are most appropriate for dealing with that event.(38) Previous research indicates that the specific phrases used for describing a weather event can influence drivers' perceptions of event severity and that CMS operators sometimes use specific weather messages to denote more severe and less severe versions of the same type of weather event.(43,61)

Experiment 1 further explored that idea by attempting to assess the perceived severities of different weather messages currently in use. The findings indicate that drivers do perceive some weather event messages as more difficult to drive in than others and that those perceptions influence the actions drivers are likely to take when encountering a CMS with different event messaging. For example, with regard to messages that describe a snow event, drivers viewed HEAVY SNOW WARNING as the severest; and it was the only snow message that drivers said they would respond to by changing routes. With regard to all other snow messages, drivers indicated they would reduce speed and drive more cautiously. With regard to flooding events, drivers interpreted messages that included the word FLOOD as severer and more likely to elicit changes in behavior than would messages that described the presence of water on the road. For winter weather events, the descriptor SEVERE led to the highest ratings of behavioral change. For ice events, drivers associated the use of qualifiers (e.g., POSSIBLE) with reduced ratings of severity and behavioral change.

However, drivers do not perceive all weather-event messages as referring to events of different severity. With regard to events that do not involve precipitation, such as wind events and events that reduce visibility, participants tended to indicate they would slow down or use caution. The frequency of that response and the perceived severity of the event were similar across message types. Thus, event information about fog or heavy winds is informative regarding the type of change a driver should make to driving behavior (i.e., reduce speed), but different event messages are less effective in conveying differences in event severity.

Predicting the precise duration, severity, and location of a weather event can be difficult. As a result, some CMS operators choose to temper CMS messages about weather events by including qualifiers such as "possible," "intermittent," or "spots."(57,61) Both previous research and the current work indicate that weather messages that include qualifiers are less likely to promote behavioral change than those that do not.(14) The current work also demonstrates that the perceived helpfulness and accuracy of weather messages tended to be less affected by the use of qualifiers and the presence of the hazard than were nonweather messages. That is, qualifiers may not be necessary to preserve drivers' trust in weather messages, because drivers seem more tolerant to inaccuracies in weather messages than they are to nonweather messages. Further research might confirm that finding.

EFFECT OF EVENT

Effect of event information advises drivers about the impact a nonrecurring event is having on a roadway and can provide a reason to change driving behavior. Some of the commonest effects of event are road closures, lane closures, and travel time delays.

Road Closed

A road closure is the most impactful of the effects of event because it affects all travelers who had intended to use that route. Dudek and Ullman advised that ROAD CLOSED is the most informative piece of information to include in a CMS message and as such that it always appear as the first line on a CMS message.(11) The findings of experiment 2 seem to confirm that recommendation. Participants who saw ROAD CLOSED on the first line of a message changed lanes slightly more quickly and had stress ratings slightly lower than those who saw event information as the first line of the CMS. Even though those effects did not reach significance in the current study, the findings do demonstrate that including event information in a road closure message did not benefit drivers. Since event information increases the size of the message without providing benefit, CMS operators would do well to exclude event information from messages warning about a road closure. Instead, when a nonrecurring event results in a road closure, information about the event may be most effective when placed on the first line of the CMS message.

Lane Closed

When a nonrecurring event results in a lane reduction, the specific CMS message depends on the goal of that message. A message that indicates the direction of the lane closure tends to lead to earlier merging into the open lane but reduces levels of route diversion.(19) When the goal is to encourage an early merge, a message can indicate the direction of the lane closure by using the terms “right” or “left.” Since those terms can sometimes be confusing, the team discourages variations in directional words—especially within the same sign (e.g., RIGHT LANE CLOSED / MERGE LEFT).(45) Previous research on whether CMS messages indicating a lane closure should refer to the lane that is closed (e.g., RIGHT LANE CLOSED) or to the lane that is open (e.g., MERGE LEFT) has been difficult to interpret.(19) Experiment 2’s findings were similarly inconclusive. RIGHT LANE CLOSED elicited slightly prompter lane changes; however, the findings of high diversion rates in response to the incident drive were based on only a small number of drivers and lacked statistical significance. While more direct, command message MERGE LEFT is likely to be slightly less familiar to participants than RIGHT LANE CLOSED, since that phrase, along with either the distance in feet or miles at which the closure will occur or the word AHEAD, appears in signs approved by MUTCD prior to a lane closure.(2) Since consistency in messaging typically leads to reduced processing times and more consistent driving behavior, the use of RIGHT LANE CLOSED on CMSs may be advisable.

Delay

One common effect of nonrecurring events is that the events cause delays in travel time. Drivers who receive information about the presence of a delay are more likely to select an alternate route.(12,26,40) Delay messages that specify the magnitude of the delay are especially helpful in enabling drivers to understand the severity of the event and then make appropriate changes in their driving behaviors.(10,34,46) A CMS can specify the magnitude or length of a delay by using either a quantitative message with numbers to convey delay length (e.g., 30 MIN DELAY) or a qualitative message with descriptors to convey delay magnitude (e.g., MAJOR DELAY). Experiment 2’s findings suggest that drivers interpreted quantitative messages in a straightforward manner, such that they saw larger numbers as leading to larger delays. However, drivers tended to assume that quantitative messages underestimated the actual time that would be associated with the delay.

If CMS operators cannot accurately estimate the precise timing associated with a delay, they may prefer to display a qualitative delay message, which uses adjectives rather than numbers to describe the magnitude of a delay. Research suggests that drivers are sensitive to qualitative delay descriptions. Drivers are more likely to divert in response to a message about a long delay than in response to a message about a short delay, and they rate MAJOR DELAY as more effective in indicating that a nonrecurring event is affecting traffic than DELAY.[14,26]

Some research has attempted to assess whether drivers associate different qualitative messages with specific quantitative values. Experiment 1 expanded that effort by having participants directly estimate the length of delay they would expect after seeing various types of delay messages. The delays participants expected in the current study tended to be longer than those seen in previous work. For example, Wardman, Bonsall, and Shires used a traffic simulation model to conclude that LONG DELAY was estimated to be 35–47 min, while in experiment 1, EXPECT LONG DELAY had a mean estimated delay time of more than 80 min.[34] Likewise, Dudek and Ullman indicated that drivers interpret HEAVY DELAY as referring to delays of 25–45 min and MAJOR DELAY as referring to a delay of 45 min, while the current study found that CMS operators estimated MAJOR DELAY and HEAVY DELAY to refer to delays of 55 and 60 min, respectively.[11] Those differences in delay time estimates for different messages may be results of the differences in delay times that drivers are typically exposed to in different areas. Wardman, Bonsall, and Shires based their work on drivers in Toronto, and Dudek and Ullman meant their estimates to reflect the times estimated by drivers in New Jersey, whereas the current experiment questioned drivers in the Greater Washington, DC, metro area—an area known to have particularly heavy traffic and long delay times. It seems that estimates about the qualitative messages have different values among drivers in different areas.

The perceived value of quantitative messages appears to vary not only across different areas of the country but also across different types of events. Some research had hypothesized that drivers associate descriptor words (e.g., HEAVY or MAJOR) with quantitative delay values that remain constant regardless of whether the descriptor describes a delay (e.g., MAJOR DELAY) or an event (e.g., MAJOR CRASH).[11] However, the results of experiment 1 suggest that when estimating the length of a delay caused by a nonrecurring event, drivers consider both the event itself and the descriptor that describes the event. When participants were asked to estimate the time associated with the messages MAJOR DELAY, MAJOR CRASH, and MAJOR STORM, they associated the addition of the descriptor MAJOR to the event STORM with a much larger increase in estimated delay time than when that descriptor was added to CRASH or DELAY. Participants also exhibited greater variability in their responses to the phrase MAJOR STORM than to the other phrases. That variability across different events and across subjects for the same event suggests that descriptor words, while able to increase the perceived severity of an event, do not carry similar weights across different events or different drivers.

The ways drivers perceive specific times associated with different qualitative messages appear to vary as functions of the events the messages are describing and the drivers' own past experiences. Nevertheless, the use of descriptors does appear effective in altering drivers' perceived severity of a delay both in the amount of time they estimate a delay will take and how likely they are to change their behaviors in response to it. Thus, qualitative messages may be especially helpful when CMS operators cannot accurately estimate the precise timing associated with a delay or when they expect the timing of a delay to be more than 30 min. In experiment 1, qualitative messages that included descriptors such as "long," "major," or "heavy" tended to elicit a desire to change routes at rates similar to those seen for the 40 MIN DELAY message. Further, there seemed to be a ceiling on the extent to which a delay message caused participants to say they would change routes, such that after a delay reached, say, 40 min, additional increases in estimated delay times were unlikely to yield additional changes in behaviors. Participants perceived all quantitative messages except those that did not use descriptors (i.e., EXPECT DELAYS) or that used a nonsevere descriptor (i.e., MINOR DELAY) as exceeding that threshold. Thus, when presenting information about a delay, CMS operators may find that presenting consistent and accurate information may be more important than the specific words they use to convey the information.

SUGGESTED ACTION

Providing drivers with a direct action suggestion is an effective way of influencing travel behavior.[19,46,50] Two of the most frequently studied action suggestions are a change in route and a change in driving speed.

Change Route

Increasing the rates of route change is a frequent goal and a reported effect of CMS messaging. As noted in the preceding section, route change results in response to a number of different types of messages, including messages that indicate road closure,[16,17], delay,[10,40,51], high congestion level,[48,10] and increased travel time.[29] Past research has found that the highest rates of diversion result from CMS messages that directly suggest drivers change routes—especially if the specified alternate route drivers change to is included in the CMS message. (See references 14, 15, 22, and 39.) Experiment 2 examined two aspects of route change in response to CMS messages. First, it compared the potential influence of the command message USE OTHER ROUTE with the message MAJOR DELAY on diversion rates when event-related congestion was present on the roadway. In the current study, both messages were equally successful in eliciting route diversion, thereby suggesting that when a tenable alternate route is available, both command message and messages that warn about increased delay time can be successful in eliciting changes in route.

The experiment also assessed differences in rates of diversion in response to one- and two-phase messages. CMS messages are limited in the amount of information they can convey to drivers. Specifically, MUTCD stipulates that only three units of information are permitted to display on a sign at one time. CMS operators can increase the amount of information they provide drivers by creating a two-phase message—a message that alternates between two different groups of messages. Creating a two-phase message enables CMS operators to convey more information to drivers. Experiment 2 assessed the potential value of using a two-phase message to convey a fourth unit of information to drivers that explicitly instructed them to change routes. The addition of the two-phase message did not affect diversion rates. Drives that included the two-phase message did produce a small but significant increase in stress ratings. The result is consistent with previous work demonstrating that drivers consider one-phase messages easier to understand than two-phase messages.[7]

Change Speed

During a nonrecurring event, reductions in speed can help drivers better negotiate dangerous conditions, help prevent end-of-queue collisions, and help alleviate traffic congestion. A number of different phrases can encourage drivers to reduce their speeds during nonrecurring events.[21,38] The current study assessed both the effectiveness of different CMS messages in encouraging drivers to reduce speed and whether drivers perceive different speed messages as requiring different changes in speed. Previous work has noted that a command message (e.g., SLOW DOWN) can be an effective method of eliciting a change in speed and that it is more effective than relying on drivers to infer that a speed reduction is required based on the description of a potentially hazardous weather event.[14] Consistent with that finding, experiment 1 demonstrated that participants rated messages with a direct command (i.e., SLOW DOWN, REDUCE SPEED) as most likely to result in a change of speed. However, when asked how much they should slow down in response to each message, participants perceived those same command messages as requiring the smallest reductions in speed. In contrast, participants associated messages that referenced slow traffic or stopped traffic (e.g., SLOW TRAFFIC AHEAD) with lower frequencies of expected speed reduction but also perceived them as requiring greater reduction in driving speed. The reason for the contrast between the frequency with which a message results in a speed reduction and the magnitude of that speed reduction is likely a result of the extent to which a message elicits a change in route.

Previous work has found that CMS messages that included the suggested action SLOW DOWN led to reduced diversion ratings.[14] The authors speculated that drivers typically perform only one action in response to a CMS message, such that when encountering a message about a nonrecurring event, drivers may choose to slow down or may choose to change routes but are unlikely to do both. Consistent with that hypothesis, in experiment 1, messages that participants perceived as referring to severer events—and also as requiring greater reductions in speed—were less likely to result in a slowing and more likely to result in a route change.

Experiment 2 directly assessed changes in driving behavior in response to a message that included the phrase SLOW DOWN and in response to a message that included the phrase SLOW TRAFFIC AHEAD. That situation, in which drivers were unable to divert in response to the messages, found slightly lower speeds and slightly lower stress ratings for SLOW TRAFFIC AHEAD compared with SLOW DOWN. However, due to high diversion rates during this drive, the study lacked power to produce a significant result. Nevertheless, the findings are somewhat consistent with those found in experiment 1 and suggest that when slow traffic or stopped traffic is occupying a roadway, messages that describe that traffic could result in greater speed reductions than a command message might.

INTENDED AUDIENCE

Dudek and Ullman suggest that when a message applies to a specific audience (e.g., METRO TRAFFIC), the audience be specified in the CMS message.[11] Experiment 1 found some support for such practice. Participants were slightly better at identifying the intended audience of a message that directly contained intended-audience information than they were for messages that did not. The finding suggests that intended-audience information is appropriate in situations in which the potential target audience of the message is unclear.

APPENDIX. SCENARIO TABLE

Scenario No.	Scenario Name	Event Location or Lane Start	First CMS Message	Second CMS Message	Event Type	Travel Time (≅ min)
1	Default	None/ right Lane	Blank sign	Blank sign	*no event*	4
2	East–Road Closed–No Flood	East Rd/ right Lane	ROAD CLOSED TAKE HWY 45 WEST	Blank sign	Barrels block road entrance	4
3	East–Road Closed–Flood	East Rd/ right lane	FLOODING ROAD CLOSED TAKE HWY 45 WEST	Blank sign	Barrels block road entrance	4
4	East–Lane Closed–one phase–right lane	East Rd/ right lane	TRAFFIC INCIDENT HWY 45 EAST ONE LANE CLOSED	TRAFFIC INCIDENT RIGHT LANE CLOSED	Lane closure	5
5	East–Lane Closed–one phase–merge left	East Rd/ right lane	TRAFFIC INCIDENT HWY 45 EAST ONE LANE CLOSED	TRAFFIC INCIDENT MERGE LEFT	Lane closure	5
6	East–Lane Closed–two phase–right lane	East Rd/ right lane	TRAFFIC INCIDENT HWY 45 EAST / ONE LANE CLOSED USE OTHER ROUTES	TRAFFIC INCIDENT RIGHT LANE CLOSED	Lane closure	5
7	East–Lane Closed–two phase–merge left	East Rd/ right lane	TRAFFIC INCIDENT HWY 45 EAST / ONE LANE CLOSED USE OTHER ROUTES	TRAFFIC INCIDENT MERGE LEFT	Lane closure	5

Scenario No.	Scenario Name	Event Location or Lane Start	First CMS Message	Second CMS Message	Event Type	Travel Time (≅ min)
8	East–Congestion–other routes–slow down	East Rd/ right lane	GAME DAY TRAFFIC HWY 45 EAST USE OTHER ROUTES	GAME DAY SLOW DOWN	Congestion	5
9	East–Congestion–other routes–slow traffic	East Rd/ right lane	GAME DAY TRAFFIC HWY 45 EAST MAJOR DELAY	GAME DAY SLOW TRAFFIC AHEAD	Congestion	5
10	East–Congestion–delay–slow down	East Rd/ right lane	GAME DAY TRAFFIC HWY 45 EAST MAJOR DELAY	GAME DAY SLOW DOWN	Congestion	5
11	East–Congestion–delay–slow traffic	East Rd/ right lane	GAME DAY TRAFFIC HWY 45 EAST MAJOR DELAY	GAME DAY SLOW TRAFFIC AHEAD	Congestion	5
12	West–Road Closed–No Flood	West Rd/ left lane	ROAD CLOSED TAKE HWY 45 WEST	Blank sign	Barrels block road entrance	4
13	West–Road Closed–Flood	West Rd/ left lane	FLOODING ROAD CLOSED TAKE HWY 45 WEST	Blank sign	Barrels block road entrance	4
14	West–Lane Closed–one phase–right lane	West Rd/ left lane	TRAFFIC INCIDENT HWY 45 WEST ONE LANE CLOSED	TRAFFIC INCIDENT RIGHT LANE CLOSED	Lane closure	5
15	West–Lane Closed–one phase–merge left	West Rd/ left lane	TRAFFIC INCIDENT HWY 45 WEST ONE LANE CLOSED	TRAFFIC INCIDENT MERGE LEFT	Lane closure	5

Scenario No.	Scenario Name	Event Location or Lane Start	First CMS Message	Second CMS Message	Event Type	Travel Time (≅ min)
16	West–Lane Closed–two phase–right lane	West Rd/ left lane	TRAFFIC INCIDENT HWY 45 WEST / ONE LANE CLOSED USE OTHER ROUTES	TRAFFIC INCIDENT RIGHT LANE CLOSED	Lane closure	5
17	West–Lane Closed–two phase–merge left	West Rd/ left lane	TRAFFIC INCIDENT HWY 45 WEST / ONE LANE CLOSED USE OTHER ROUTES	TRAFFIC INCIDENT MERGE LEFT	Lane closure	5
18	West–Congestion–other routes–slow down	West Rd/ left lane	GAME DAY TRAFFIC HWY 45 WEST USE OTHER ROUTES	GAME DAY SLOW DOWN	Congestion	5
19	West–Congestion–other routes–slow traffic	West Rd/ left lane	GAME DAY TRAFFIC HWY 45 WEST MAJOR DELAY	GAME DAY SLOW TRAFFIC AHEAD	Congestion	5
20	West–Congestion–delay–slow down	West Rd/ left lane	GAME DAY TRAFFIC HWY 45 WEST MAJOR DELAY	GAME DAY SLOW DOWN	Congestion	5
21	West–Congestion–delay–slow traffic	West Rd/ left lane	GAME DAY TRAFFIC HWY 45 WEST MAJOR DELAY	GAME DAY SLOW TRAFFIC AHEAD	Congestion	5

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