Traveler Information Requirements During Nonrecurring Events

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FOREWORD

Developments in advanced traveler information systems (ATISs) have enabled the broadcast of ever-growing quantities of traveler information. This information is particularly valuable during nonrecurring events, which lead to unexpected reductions in the capacity or travel time reliability of a roadway. For the information generated by ATISs to improve safety and mobility during nonrecurring events, traveler information messaging needs to promote desired changes in traveler behavior.

This report documents a series of experiments aimed at exploring the specific traveler information messages that are most likely to result in changes in traveler behavior during nonrecurring events. The study highlights the value of information in helping drivers make informed travel decisions and reducing driver stress during nonrecurring events. The report also provides information about how specific components of travel messages are interpreted by drivers and provides recommendations regarding the type of messaging that can be used to influence travel behavior.

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

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16. Abstract
Three experiments explored the traveler information messages most likely to result in desired changes in traveler behavior during nonrecurring events. Experiment 1 focused on pretrip traveler information needs. Event type and trip importance were found to have a greater effect on intended behavior than delivery mode. Experiments 2 and 3 evaluated the effect of specific variable message sign (VMS) message components on reported and simulated driving behavior. Information disseminated on VMSs was most likely to influence behavior if it included a specific action request. Participants also preferred messages that made declarative statements about the actual state of the road to those that provided speculative information about portions of the roadway. Drivers who were provided traveler information prior to driving past a simulated nonrecurring event reported a less stressful drive than those who were not given any information. The study highlights the value of traveler information and provides recommendations regarding the type of messaging that is likely to influence traveler behavior.

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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 1000 L shall be shown in m^3		
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact degrees)		
^oF	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	^oC
		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 (2000 lb)	T
		TEMPERATURE (exact degrees)		
^oC	Celsius	1.8C+32	Fahrenheit	^oF
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

*SI is the symbol for the 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 SYMBOLS

Acronyms

ATIS	advanced traveler information system
DOT	department of transportation
GEE	generalized estimating equation
GPS	Global Positioning System
HAR	Highway Advisory Radio
LCD	liquid crystal display
MUTCD	*Manual on Uniform Traffic Control Devices*
PLA	problem-location-action
SSQ	simulator sickness questionnaire
VMS	variable message sign

Symbols

F	F-value
M	mean
p	p-value
t	t-statistic
X^2	chi-squared statistic

CHAPTER 1. INTRODUCTION

Advanced traveler information systems (ATISs) collect and distribute information about traffic and road conditions that can allow drivers to make more informed travel decisions. Advancements in communications have enabled the broadcast of ever-growing quantities of traveler information while also increasing the quality of that information. For the information generated by ATISs to have the desired effects of improving safety and mobility, that information needs to promote desired changes in traveler behavior. Meeting this goal requires an understanding of (1) how traveler information can best be disseminated, (2) when travelers use the information, and (3) what specific information and messages are most likely to influence traveler behavior.

HOW TRAVELER INFORMATION CAN BE DISSEMINATED

If the information generated by ATISs is to lead to desired changes in traveler behavior, it must first reach the traveler. Much of the previous work on ATISs has focused on how traveler information can be disseminated. Various options for obtaining traveler information are now available. The specific option a traveler chooses is likely to depend on how close, both physically and temporally, he or she is to the intended trip. The time during which a traveler can access traveler information can be divided into two broad categories: (1) pretrip (i.e., before a trip has begun) and (2) mid-trip (i.e., while the traveler is en route to his or her destination). Whether traveler information is obtained pretrip or mid-trip has important implications for both the sources of information a traveler can use and the likely changes to travel plans after that information is received.

Pretrip Dissemination Sources

Pretrip traveler information, or information obtained before one's trip has begun, can be acquired from a number of sources. The most widely used sources of pretrip information are television and radio broadcasts. (See references 1–4.) Those who utilize local television and radio as sources of pretrip traveler information report that they typically do so on a daily basis.[1] The predictive nature and widespread availability of local weather forecasts make broadcasts a particularly effective source for conveying changes in roadway conditions that result from weather events.[2]

Websites serve as another highly used source of pretrip traveler information. Robinson et al. reported that websites visited via a computer are the third most popular source of pretrip traveler information, ranking as only slightly less utilized than radio and television.[3] Websites are especially popular among those who frequently seek out traveler information.[1] State department of transportation (DOT) offices are taking heed of this trend toward online dissemination. A survey conducted in 2012 found that approximately 95 percent of surveyed agencies use computer-accessible websites to disseminate pretrip traveler information. A growing number of State DOTs are turning to social media as an additional venue for reaching travelers during trip planning.[5] Social media sites act as sources of traveler information that users can easily share, allowing traveler information disseminated via social media the potential to reach a large audience.

Travelers who use online sources of traveler information are not limited to acquiring this information on a computer. Robinson et al. found that participants were just as likely to report using mobile electronic devices as a pretrip source of traveler information as they were to use mobile devices mid-trip.[3] In other words, traffic and weather apps, mobile websites, and email and text alerts all serve as sources of pretrip traveler information. The large number of different dissemination sources available pretrip allows travelers to access multiple sources to verify information and gain a more complete picture of conditions that may affect their travel plans.[4,6]

Not only do travelers who obtain traveler information pretrip have many sources of traveler information to select from, but they also have many options for changing behavior based on that information. Adjustments can include changes in departure time, routes, and/or modes of transportation. Travelers can even choose to cancel or postpone a trip until the travel outlook becomes more favorable. Because the information is obtained during the planning stages of a trip, travelers have time to incorporate that information into their travel plans in a way that increases the information's utility relative to what is possible once the journey has begun.

Mid-trip Dissemination Sources

The most frequently used source of mid-trip traveler information is local radio.[3] In-vehicle radios are an ubiquitous, easy-to-access source of traveler information that many drivers use daily.[1] Yet despite the popularity of local radio broadcasts as a source of traveler information, very few travelers make use of the Highway Advisory Radio (HAR) System. In fact, HAR is generally considered by transportation agencies to be the least effective method for disseminating traveler information, and many travelers report having never used the system.[3] Nevertheless, HAR remains operational in most areas, primarily because of its ability to serve as a source of traveler information during emergencies.[7]

Travelers cite highway and local message signs as their second most frequently used source of mid-trip information.[3] Variable message signs (VMSs) (also referred to as changeable or dynamic message signs) allow local transportation agencies to provide drivers with updated traveler information that is specific to the road the driver is currently using.[8] Generally, drivers report having positive attitudes about the traveler information they receive via VMS. (See references 9–12.) Moreover, VMS messages that follow the guidelines put forth in the *Manual on Uniform Traffic Control Devices* (MUTCD) are able to inform drivers without distracting them from the primary driving task.[13,14] A VMS's ability to serve as a safe source of relevant, mid-trip traveler information makes it one of the most popular sources for disseminating traveler information among transportation agencies.[3]

The widespread adoption of Global Positioning System (GPS)-equipped smart phones and navigation systems has led to an increased use of electronic maps, traffic and weather apps, and mobile websites as sources of mid-trip traveler information.[5] Electronic devices offer travelers the ability to obtain information from Federal and State agencies, private sector entities, and crowd-sourcing platforms. However, travelers will only be able to benefit from these information sources if they own an electronic device and have decided to use the device during the current trip. Furthermore, because electronic devices frequently encourage drivers to look away from the roadway to obtain the desired information, the use of electronic devices as a source of mid-trip traveler information may be problematic for road safety.[15] Similar safety concerns have been cited by motorists as a reason to avoid another potential source of mid-trip information, the 511 telephone system. Use of 511 is currently on the decline as a source of traveler information.[3,16]

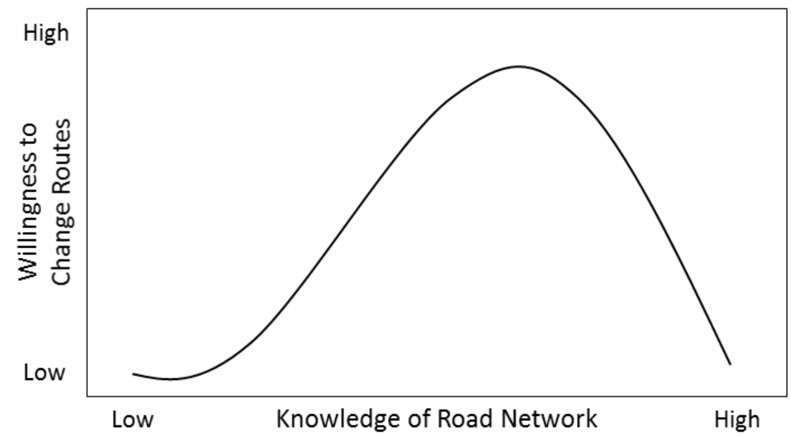
The wide variety of traveler information dissemination methods currently available gives travelers the opportunity to choose the information source that best meets their needs, be it pretrip or mid-trip. This variety also allows travelers to utilize multiple sources of information to form a broader understanding of the traffic network, which research suggests can make drivers more likely to make desirable changes in travel behavior.[6]

WHEN TRAVELER INFORMATION IS UTILIZED

Ensuring travelers have access to traveler information is only the first step in promoting its use. Multiple studies have demonstrated that simply having access to or even having positive attitudes about traveler information is not sufficient to induce behavioral change.[10,17] Consider the findings of Lerner et al., who conducted a series of focus groups in three different U.S. cities.[9] While the majority of 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. Daily driving logs confirmed the lack of influence. If travelers who have a positive attitude about the accuracy and usefulness of traveler information do not consistently change their behavior in response to that information, then what factors influence when traveler information is utilized?

Traveler information use can be influenced by one's knowledge of or familiarity with a road network. Lotan describes the potential importance of this relationship.[18] Road networks are made up of both static and dynamic features. Static features include set aspects of the road network, such as available routes and how they interconnect. Dynamic features include aspects of the roadway that fluctuate, such as traffic speed and density, and how these factors are influenced by external factors, such as weather or time of day. As a driver navigates a road network, he or she gains knowledge first of the static and then the dynamic features of the roadway. This roadway knowledge or familiarity influences driving behavior, including how likely a driver will be to utilize traveler information.

Since traveler information is frequently transmitted to encourage drivers to select an alternate route, the specific influence of road network knowledge on one's willingness to change routes is explored in greater detail. Figure 1 displays the relationship between roadway knowledge and willingness to change routes mid-trip. The relationship follows an inverted U-shape. A driver with minimal knowledge of a road network is unlikely to change routes. When knowledge of the road network is low, awareness of possible routes to a desired destination is also low. This lack of knowledge is typically accompanied by a lack of confidence in alternate routes that makes drivers hesitant to deviate from a chosen route once it has been selected. As a result, drivers whose knowledge of the road network is low are unlikely to change routes in response to traveler information. Ma et al. found novice drivers and drivers who drove infrequently reported being unlikely to divert in response to VMS messages, even when the drivers reported having a positive attitude about such messaging.[17] Fear of getting lost, particularly when driving in an unfamiliar area, is one of the most frequently cited reasons travelers give for not following alternate route suggestions obtained mid-trip.[9,10,12] Drivers with low knowledge of the road network can use pretrip traveler information to aid them in initial route selection; however, information received mid-trip is unlikely to influence route choice unless that information provides trailblazing signs or turn-by-turn instructions to guide the driver through the new route.[18]



Source: FHWA.

Figure 1. Graph. Relationship between drivers' knowledge of a road network and their willingness to change routes.

A driver with a moderate amount of knowledge of the roadway can begin to explore the potential utility of route alternatives without fear of becoming lost. An increased understanding of available routes and how they interconnect makes the driver more willing and able to use multiple routes, and willingness to change routes mid-trip goes up. Travelers with a moderate amount of knowledge of the road network also seem most willing to change routes in response to traveler information. Jeihani, Narooienezhad, and Kelarestaghi found participants with some knowledge of the simulated area in which they were driving were most likely to take a detour suggested by a VMS.[19] This was true for participants who had knowledge because they recognized the simulated area as corresponding to an actual road network they frequented, for participants who gained knowledge through the use of GPS, and for participants who accumulated knowledge by driving the scenario multiple times. A similar effect of knowledge gained by driving a simulated road network multiple times was found by Ardeshiri, Jeihani, and Peeta.[20] As the number of times a participant drove through the road network increased, the probability the driver would change routes in response to mid-trip traveler information about 10- or 15-min delays also increased. Drivers with a moderate amount of knowledge can use traveler information to increase their knowledge in a way that improves their travel decisions.

Once a driver's knowledge of the road network increases to high levels, his or her willingness to change routes mid-trip drops. This reduction in willingness to change routes results from the driver's high level of confidence in his or her initial route choice. A driver with extensive knowledge of a road network is able to use that knowledge to select an optimal route given the current conditions (e.g., time of day). Confidence in this initial route choice is high, such that a driver becomes unlikely to deviate from that choice. A driver with a high level of knowledge tends to view traveler information as less useful and is therefore less likely to be influenced by that information.[18]

When dealing only with recurring traffic, or normal variations in traffic, the view that drivers with high levels of knowledge have no need for traveler information will sometimes be justified. For example, Ben-Elia, Erev, and Shftan demonstrated that having travel time information for multiple routes can improve route choice decisions only until a participant gains knowledge of the road network.[(21)] Participants selected between two routes and received feedback about how long it took them to travel on each route. Half of participants received traveler information about the estimated travel time for each route before making their decision. The group with traveler information made better decisions initially. However, after repeated experience with each route, the group without the traveler information learned from experience, such that their choices no longer differed from the information group. Over time, experience with the road network gave participants who did not receive traveler information sufficient knowledge to choose the optimal roadway on their own.

Other times, travelers with high levels of road network knowledge will be able to obtain the information they need to select a preferred route from the levels of congestion they encounter on the roadway. In a traffic model assessing the effect of traveler information and congestion on route choice, Pan and Khattak demonstrated that electronic dissemination of traveler information about an unexpected upcoming delay led to travel time savings only when that information was distributed far enough upstream that drivers could not already see the congestion associated with the delay.[(22)] Assessments of actual diversion rates in response to congestion and traveler information draw similar conclusions.[(23,24)] Drivers use congestion levels as a source of roadway knowledge, such that additional knowledge gained by traveler information will be of limited use.

However, some traveler information cannot be gained based on experience or visible congestion. Even a driver with a high level of roadway knowledge can benefit from traveler information about nonrecurring events. Nonrecurring events are situations that lead to temporary changes in the capacity or travel time reliability of a roadway. Traffic incidents, road work, adverse weather conditions, and planned special events are all examples of nonrecurring events. Such events can lead to unexpected and often substantial travel delays. In fact, it has been estimated that nearly half of all highway delays stem from nonrecurring events.[(25)] Because nonrecurring events represent a departure from the typical travel situation that even drivers with a high level of knowledge of the road network cannot predict, travelers without traveler information will be unlikely to make appropriate changes in their travel behavior until they are within visual range of the event, at which point their options are likely to be severely limited. Traveler information can allow drivers to avoid the delays and potential safety risks associated with nonrecurring events by making appropriate changes to their travel behavior. It is during nonrecurring events that traveler information is able to provide the greatest reductions in travel time and that traveler information is most valued.[(26)]

Thus, when traveler information is most likely to be utilized depends on the traveler's knowledge of the road network. Pretrip information is especially valuable to travelers whose knowledge of the road network is low, as it allows them to plan a route through an unfamiliar area. Both pretrip and mid-trip information will be valuable to drivers with a moderate level of knowledge, as they can use the information to make beneficial adjustments to their driving behavior. A driver whose knowledge of the road network is high is less likely to seek out traveler information but still benefits from information about nonrecurring events.[(25)] Traveler information about nonrecurring events is perhaps the most valuable traveler information, as it provides information that cannot be gained from experience.

WHAT MESSAGES MOST INFLUENCE TRAVELER BEHAVIOR

The literature on traveler information has identified several mediums for information dissemination both before and during a trip. Past research has also determined when traveler information is most likely to be utilized and highlighted the high potential value of information about nonrecurring events. Which specific traveler information messages are most likely to result in desired changes in traveler behavior during those nonrecurring events is less understood.

Understanding which specific messages are most likely to promote changes in travel behavior is complicated by several factors. First, the most useful messages may vary by event type. As previously stated, nonrecurring events include traffic incidents, road work, adverse weather conditions, and planned special events. Each of these event types comes with different levels of predictability, impact, and duration. Traffic incidents, such as crashes or disabled vehicles, are caused by individual vehicles. As these events are typically not intentional, they cannot be predicted in advance. Further, variability in severity of incident events can make estimating the impact or duration of the event difficult. Roadwork, such as road maintenance or construction projects, is planned and, as such, tends to have a predictable impact on traffic; however, the duration is often longer than other nonrecurring events. Weather events, such as snow, ice, fog, heavy wind, or floods, can vary in severity. Such events often impact entire roadway systems rather than specific routes, and the duration of the events is often difficult to predict. Planned events, such as parades or street fairs, may require road or lane closures. Other planned events, such as sporting events or concerts, will simply produce an abnormal amount of traffic in a specific area. As these events are planned in advance, they tend to be predictable in impact and duration. Other nonrecurring events, such as mudslides or fallen trees, are difficult to categorize and, unsurprisingly, will have varying impacts and durations. Given the range of nonrecurring events that can impact a roadway, it is prudent to examine traveler information messages as a function of event type.

Whether information is obtained pretrip or mid-trip affects which messages are most likely to promote desired behavior. This presents another challenge in identifying the most effective messages. As discussed previously, when traveler information is obtained has implications for both the sources that can be used to disseminate that information and the types of changes a traveler can be expected to make in response to that information. As a result, past studies assessing messages' ability to influence travel behavior have distinguished between pretrip and mid-trip messages.[(5)] Following this model, the current work will first examine pretrip messages and then mid-trip messages.

Current Experiments

Past research on traveler information has produced a fairly robust understanding of both how traveler information can be distributed and when traveler information is most needed. The current group of experiments explored the final piece of the traveler information puzzle: which specific traveler information messages are most likely to result in desired changes in traveler behavior. Experiment 1 focused on pretrip information. The experiment considered how traveler needs for pretrip information vary as a function of nonrecurring event type and trip importance. The study also examined how varied amounts and types of traveler information influence traveler behavior. Experiment 2 focused on mid-trip information disseminated on VMSs. The study attempted to evaluate the specific VMS message components that are most likely to lead drivers to change routes during different types of nonrecurring events. Finally, experiment 3 expanded on the findings of experiment 2 by examining how behavior in a driving simulator is influenced by exposure to different VMS messages.

CHAPTER 2. EXPERIMENT 1: PRETRIP TRAVELER INFORMATION

INTRODUCTION

Nonrecurring events lead to temporary changes in the capacity or travel time reliability of a roadway. Traffic incidents, roadwork, severe weather, and planned special events can lead to substantial and often unexpected travel delays. Pretrip traveler information, that is, traveler information obtained before a trip has begun, has the potential to help drivers mitigate the potential effect a nonrecurring event may have on travel time and safety by allowing drivers to make changes to their intended route, departure time, or mode of transportation.

Pretrip dissemination sources offer the potential to display traveler information in several different forms. Websites can be customized with words, pictures, maps, and even audio information. Social media allows combinations of pictures and text. The potential for displaying large quantities of information using pretrip dissemination formats makes determining the specific amount and type of information that will be most useful to travelers an important research task.

Experiment 1 assessed the effect that pretrip traveler information has on travel plans. On each trial, participants were asked to imagine they intended to travel from their home to a specified destination. The purpose of each trip was manipulated to create an equal number of trips that were of high and low importance. Next, a traffic alert indicated that a nonrecurring event was restricting traffic to the intended destination. The specific nonrecurring event described in each traffic alert was manipulated such that participants could receive alerts about an incident, roadwork, weather, planned event, or miscellaneous event. Finally, the delivery mode, or type of information included in the traffic alert, varied. Traveler information could be presented in the form of a text-only alert, or the text alert could be accompanied by a traffic map, a traffic camera image, a photo of the type of event restricting traffic, or a combination of these. After receiving the traffic alert, participants indicated if and how the traveler information would affect their travel plans. They then answered a series of Likert scale questions describing the likelihood that they would make specific changes to their travel plans as a result of the pretrip traveler information they had received. This experiment assessed how pretrip traveler information impacts travel plans as well as the potential influences of event type, trip importance, and delivery mode.

METHOD

This section describes the details of the methodology used in experiment 1, including the participants who took part in the study, the equipment and stimuli used, and the experimental design and procedure.

Participants

Participants were 122 licensed drivers over the age of 18 recruited from the Washington, DC, metropolitan area. A computer error resulted in loss of data from two participants. As shown in table 1, the remaining 120 participants included approximately equal numbers of male and female participants and younger (18–45 years old) and older (46 years old and over) participants.

Table 1. Number of participants as a function of gender and age group.

Gender	Younger	Older
Female	29	30
Male	30	31

Note: Younger participants were 18–45 years old; older participants were 46 years old and over.

Apparatus and Stimuli

Stimuli were displayed on a 60-inch liquid crystal display (LCD) monitor. Participants responded using a standard QWERTY keyboard and mouse. They could also respond verbally and allow the researcher administering the experiment to enter their responses using a separate mouse and keyboard.

At the start of each trial, participants saw a travel map. The map depicted an area of roadways between Edmond and Oklahoma City, OK, that included U.S. Route 77, Interstate 35, Interstate 44, and Oklahoma State Highway 74 (see figure 2). This area was expected to be unfamiliar to all participants. A house icon presented near the top of the map was used to depict the location of the participant's home, while a star was used to indicate the location of the destination. The specific location of the star varied on each trial but was always positioned in the bottom portion of the map such that the most direct route between the home icon and the star would be to travel south on U.S. 77.

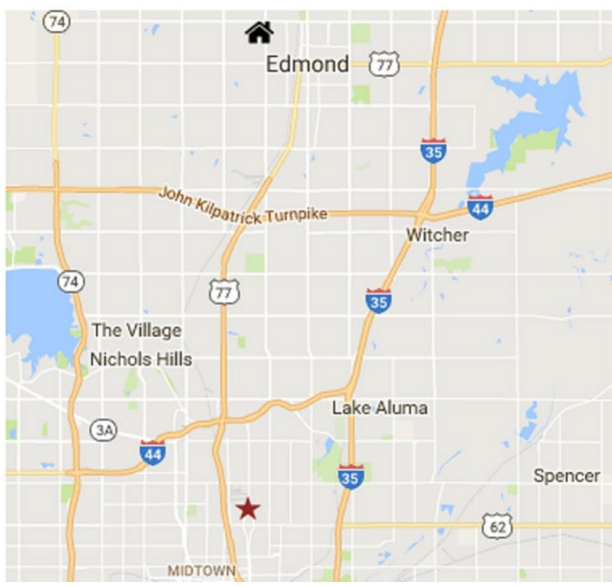


Figure 2. Map. Example of a travel map.[27]

Traffic alerts were also displayed (see figure 3). All traffic alerts included a text component. An alert title indicated that a traffic situation was occurring on U.S. 77. This was followed by text that specified the event that was causing the delay, the location of the delay, and the warning "Use caution and expect delays."

Original Map © 2017 Google (see Acknowledgments section).
Photo © 2017 Idaho Transportation Department. Screenshot compiled by FHWA.

Figure 3. Screenshot. Example of text-map-photo traffic alert displaying information about a roadwork event.(27,28)

On some trials, the traffic alert included a traffic map. Traffic map images displayed the same travel area as was depicted in the initial travel map, with the main routes colored green, yellow, and red to indicate the level of traffic on that area of the roadway. An area of red traffic always appeared on U.S. 77 with an icon indicating the specific type of event causing the delay. A white triangle with an exclamation point was used to indicate an incident event, an orange cone indicated a roadwork event, a rain cloud indicated a weather event, a red flag indicated a planned event, and a yellow triangle with an exclamation point indicated a miscellaneous event.

On some trials, the traffic alert included an image from a traffic camera. Images from traffic cameras displaying high levels of traffic were taken from State DOT websites. Each image was surrounded by a black frame that included the label "HW-77 S" in the upper right corner. The same series of traffic camera images was used in each event condition, except for the weather event, which used traffic camera images that depicted snow.

On some trials, the traffic alert included a photo that represented the specific event being reported. The majority of photos were taken from State DOT websites or Twitter feeds. The photos used to represent incident events were a picture of a crashed car and of police and emergency response vehicles on the side of the road. The photos used to represent roadwork events were an image of vehicles traveling next to a row of orange traffic barriers and images of workers making pavement repairs. The photos used to represent weather events were an image of a vehicle stuck in a snowbank and images of snowplows. The photos used to represent planned events were an image of a marching band, a stadium, a football, and a stadium parking sign. Finally, the photos used to represent miscellaneous events were an image of fallen rocks on the side of the road, an image of mud spilling across a road, and images of fallen branches on the side of a road.

Experimental Design

Experiment 1 included three independent variables: event type, trip importance, and delivery mode.

Event type was manipulated between subjects and could be either a (1) incident event (an accident, an incident, a disabled car, or a disabled truck), (2) roadwork event (roadwork or construction), (3) weather event (winter weather, snow, or ice storm), (4) planned event (stadium traffic, gameday traffic, or parade traffic), or (5) miscellaneous event (mudslide, rockslide, or fallen tree).

Trip importance was manipulated within subjects, such that the specific trip participants were asked to pretend to be planning could be a trip of (1) high importance (e.g., "You are traveling to work on a day that you have an important presentation.") or (2) low importance (e.g., "You are shopping for a new outfit."). A complete list of all trips is provided in appendix A.

Finally, delivery mode, or the type of information presented in each traffic alert, varied within subjects. Delivery modes were (1) text only, (2) text-map, (3) text-traffic camera, (4) text-photo, (5) text-map-traffic camera, and (6) text-map-photo.

Procedure

After completing informed consent paperwork, each participant's vision was assessed to ensure a minimum acuity of 20/40 (with correction). Participants then completed the pretrip information portion of the study, which included 12 trials. Each trial began with the presentation of a trip description and travel map. Participants were asked to imagine that they intended to travel from their home (depicted by the small house icon near the top of the map) to the destination indicated by the star. The most direct route to the destination was to travel south on U.S. 77. A brief description of the purpose of the trip appeared just above the map. On half of the trials, the trip described was of high importance. On the other half of trials, the trip described was of low importance. The specific trip importance and destination pairs were assigned randomly, with the qualification that each participant saw each of the destinations and trip descriptions only once. Once participants had read the trip description, they pressed the space bar, and a traffic alert appeared on the screen next to the travel map (see figure 3). The specific information included in the traffic alert varied by delivery mode. All traffic alerts included text describing the source of the delay. Traffic alerts could also include a traffic map, an image from a traffic camera, a photo depicting the source of the delay, or a combination of these features as specified by the delivery mode on that trial.

Participants were asked how (if at all) the information in the traffic alert would affect their travel plans. Participants were then asked to rate the likelihood of each of five possible outcomes: (1) they would select an alternate route, (2) they would cancel or postpone the trip, (3) they would leave earlier than originally planned, (4) they would leave later than originally planned, or (5) they would switch to public transportation. The order of the five outcome ratings was randomized for each participant. Ratings for each outcome were made on a four-point scale that included the following responses: 1 (not at all likely), 2 (somewhat unlikely), 3 (somewhat likely), and 4 (very likely).

After completing the pretrip trials (and the mid-trip portion of the study described in chapter 3), participants answered questions about their own experiences with pretrip traveler information, including how frequently they sought pretrip traveler information, the type of information they thought was most valuable, and how that information had affected their own travel plans during the past year (see appendix B for the full list of questions).

RESULTS

This section presents the findings for experiment 1, including participants' open-ended and rating responses to different types of traveler information. Participants' reported experiences using pretrip information in the previous year are also presented.

Open-ended Responses

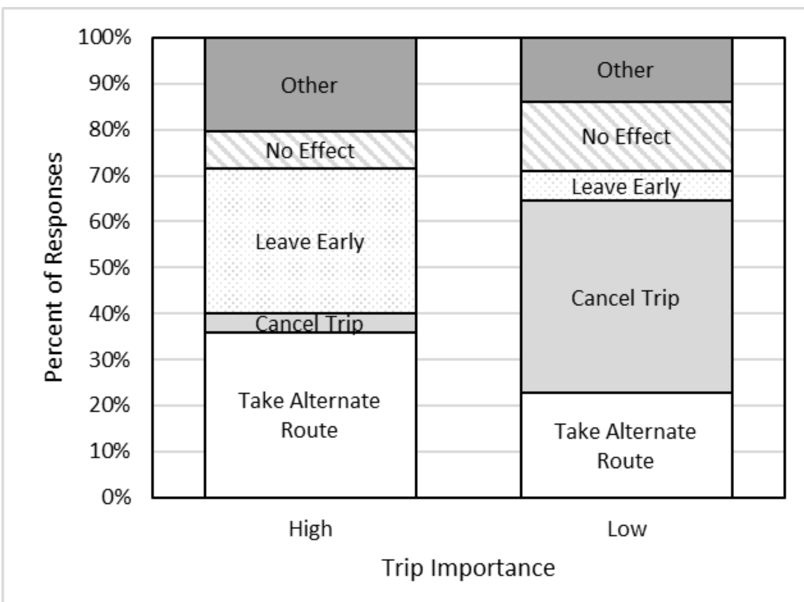
The open-ended question "How (if at all) would this information influence your travel plans?" was used to gauge participants' initial reactions to different types of traveler information. Trained coders, who were blind to condition, categorized each response. Responses that fell within multiple categories (e.g., "I would leave much earlier and probably seek an alternative route") were counted multiple times. Categories that contained less than 10 percent of responses were combined into a single "other" category. Following this procedure, four categories that represented the most frequent responses remained: "take alternate route" (35.35 percent), "cancel trip" (25.28 percent), "leave early" (23.75 percent), and "no effect" (13.33 percent).

Chi-squared (χ^2) tests assessed whether the frequency of each of the four responses varied by event type or trip importance. Response frequency varied by event type, $\chi^2(44) = 192.86$, $p < 0.001$. As displayed in table 2, the frequency of "take alternate route" was lower for weather events than for other event types, while the frequency of "cancel trip" was nearly twice as high for weather events as it was for any other event types. Additionally, planned events and roadwork events had higher frequencies of "no effect" than were found for incident, weather, or miscellaneous events.

Table 2. Frequency of open-ended responses for each event type.

Event Type	Take Alternate Route	Cancel Trip	Leave Early	No Effect	Other
Incident	122	60	68	36	73
Roadwork	99	52	70	53	61
Weather	51	123	68	21	71
Planned event	93	61	64	57	70
Miscellaneous event	144	68	72	25	66

Response frequency also varied significantly as a function of trip importance, $\chi^2(11) = 495.12$, $p < 0.001$. As shown in figure 4, when trip importance was high, "take an alternate route" and "leave early" were the most common responses. However, when trip importance was low, "cancel trip" was the most frequent response. There was also a higher frequency of "no effect" responses for low-importance trips than for high-importance trips, suggesting that traveler information is less likely to influence travel plans when trip importance is low.



Source: FHWA.

Figure 4. Graph. Frequency of each open-ended response as a function of trip importance.

Rating Responses

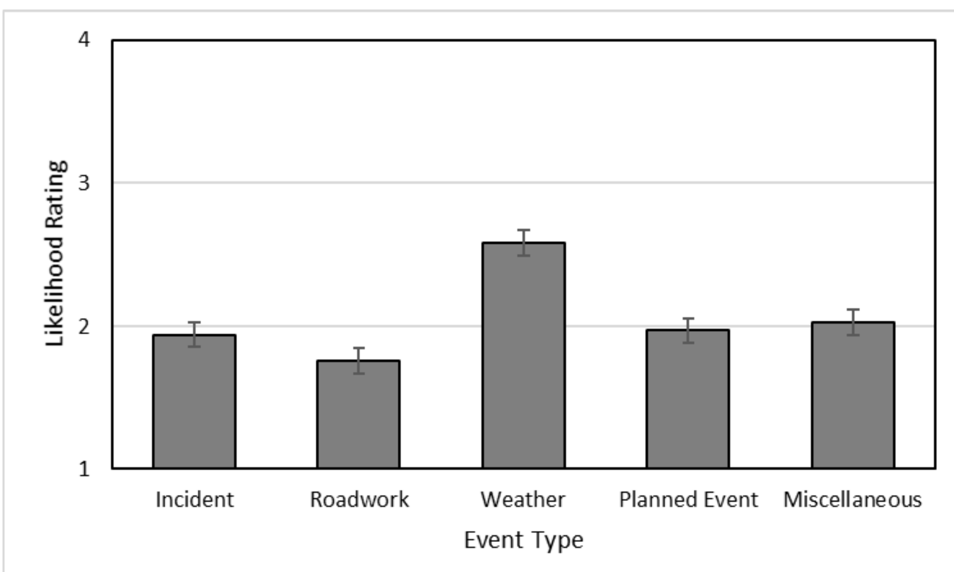
After providing their initial response, participants rated the likelihood of selecting an alternate route, canceling their trip, leaving early, leaving late, or taking public transportation using the previously described four-point scale. Responses to each rating question were analyzed using separate linear mixed models. Since the participants were nested within each of the events, participants were considered the random effect in the models; event, trip importance, and delivery mode were considered fixed effects. For significant effects, pairwise comparisons were examined. Bonferroni adjustments were applied to pairwise comparisons to correct for family-wise error.

Take Alternate Route

One method drivers can use to attempt to avoid the potential congestion associated with nonrecurring events is to select an alternate route. The likelihood of selecting an alternate route was influenced by event type, $F(4, 115) = 11.47$, $p < 0.001$. Participants were less likely to take an alternate route during a weather event (mean (M) = 2.62) than during any other event type (incident: $M = 3.45$, roadwork: $M = 3.29$, planned event: $M = 3.42$, and miscellaneous event: $M = 3.47$). Trip importance also influenced the likelihood of selecting an alternate route, $F(1, 115) = 11.47$, $p < 0.001$. Participants were more likely to select an alternate route for trips that were of high importance ($M = 3.57$) than for trips that were of low importance ($M = 2.93$). Finally, the likelihood of selecting an alternate route was influenced by delivery mode, $F(5, 575) = 2.37$, $p = 0.038$. Alternate route selection was more likely in response to text-map-photo ($M = 3.39$) than in response to text-map-traffic camera alerts ($M = 3.15$). No other differences between delivery modes were significant.

Cancel Trip

In some cases, drivers may choose to cancel or postpone their trip rather than contend with the nonrecurring event. The likelihood of canceling a trip was influenced by event type, $F(4, 115) = 12.07$, $p < 0.001$. As shown in figure 5, participants were more likely to cancel their trip in response to a weather event than in response to an incident, roadwork, or planned event. The likelihood of canceling was also influenced by trip importance, $F(1, 115) = 403.59$, $p < 0.001$. Low-importance trips ($M = 2.75$) were more likely to be canceled than high-importance trips ($M = 1.36$). No other effects were found.

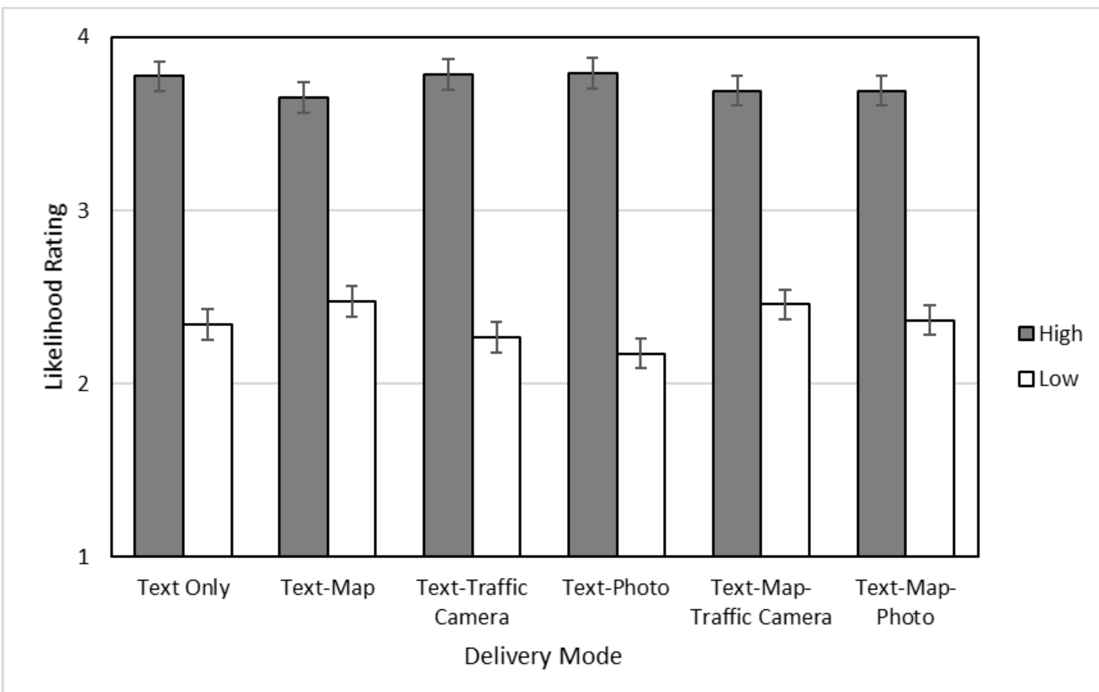


Source: FHWA.
Note: Error bars represent standard errors.

Figure 5. Graph. Likelihood ratings for canceling a trip shown as a function of event type.

Leave Early

The increased travel times typically associated with nonrecurring events can cause drivers to arrive at their destination later than intended. One option for preventing this is to leave earlier than originally planned. Reported likelihood of leaving early was influenced by event type, $F(4, 115) = 5.00$, $p < 0.001$. Participants rated the likelihood of leaving early in response to a weather event ($M = 2.68$) lower than in response to a roadwork event ($M = 3.24$). No other event types had significantly different likelihood ratings (incident: $M = 3.04$, planned event: $M = 3.05$, and miscellaneous event: $M = 3.19$). The likelihood of leaving early rating was also influenced by trip importance, $F(1, 115) = 373.34$, $p < 0.001$. Participants indicated that they were more likely to leave early when trip importance was high ($M = 3.73$) than when trip importance was low ($M = 2.35$). The interaction between trip importance and delivery mode was also significant, $F(5, 575) = 2.73$, $p = 0.02$. As displayed in figure 6, while the likelihood of leaving early was always greater when trip importance was high than when trip importance was low, the size of the difference varied by delivery mode, with the text-photo delivery mode being the most affected by trip importance. No other effects were significant.

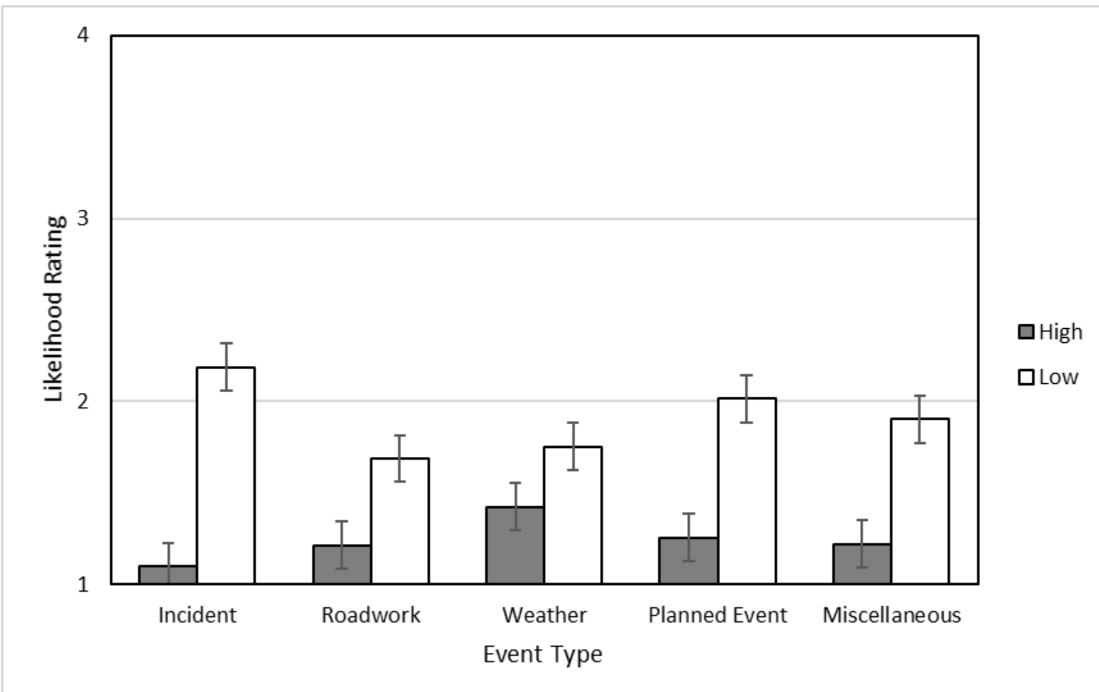


Source: FHWA.
Note: Error bars represent standard errors.

Figure 6. Graph. Likelihood ratings for leaving early as a function of trip importance and delivery mode.

Leave Late

Drivers may also attempt to avoid the congestion associated with a nonrecurring event by leaving later than they had originally planned. The rated likelihood of leaving late was influenced by trip importance, $F(1, 115) = 92.27$, $p < 0.001$. Participants rated the likelihood of leaving late higher when trip importance was low ($M = 1.90$) than when trip importance was high ($M = 1.24$). The interaction between trip importance and delivery mode was also significant, $F(4, 115) = 3.89$, $p = 0.005$. As shown in figure 7, trip importance had an influence on likelihood ratings for incident events, planned events, and miscellaneous events but did not influence roadwork or weather events. Delivery mode also had a significant effect on the likelihood of leaving late ratings, $F(5, 575) = 2.59$, $p = 0.025$, as did the trip importance by delivery mode interaction, $F(5, 575) = 4.07$, $p = 0.001$. When trip importance was high, delivery mode had no influence on the likelihood of leaving late (text only: $M = 1.24$, text-map: $M = 1.23$, text-traffic camera: $M = 1.18$, text-photo: $M = 1.29$, text-map-traffic camera: $M = 1.26$, and text-map-photo: $M = 1.25$). However, when trip importance was low, participants were more likely to report they would leave late in response to text-traffic camera ($M = 2.22$) than in response to any other type of delivery mode (text only: $M = 1.76$, text-map: $M = 1.73$, text-photo: $M = 1.95$, text-map-traffic camera: $M = 1.86$, and text-map-photo: $M = 1.88$). No other effects were significant.



Source: FHWA.
Note: Error bars represent standard errors.

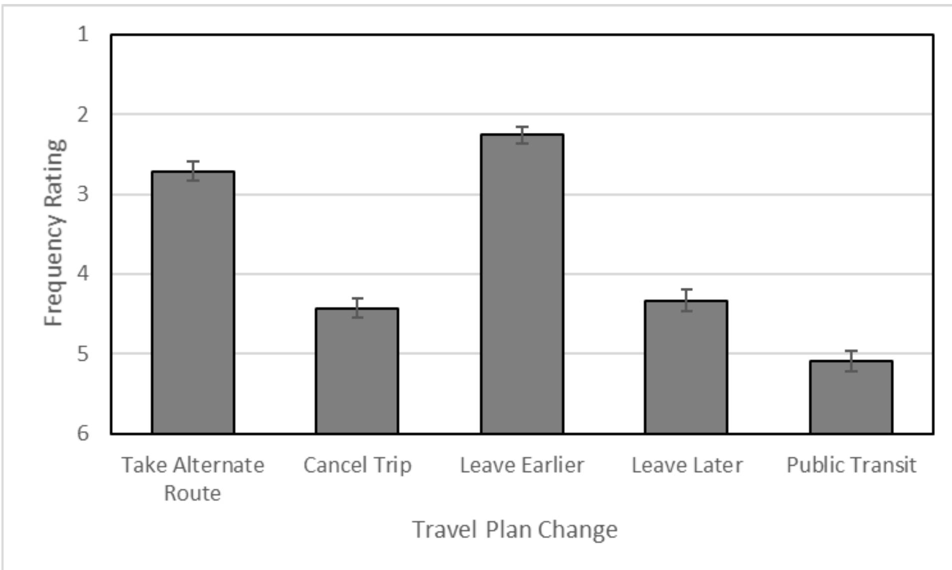
Figure 7. Graph. Likelihood ratings for leaving late as a function of trip importance and event type.

Public Transit

Travelers can avoid driving through a nonrecurring event by taking public transportation. The likelihood of switching to public transportation was very low overall ($M = 1.43$) and was only influenced by trip importance, $F(1, 115) = 27.71$, $p < 0.001$. Participants said they would be more likely to switch to public transportation when trip importance was high ($M = 1.57$) than when trip importance was low ($M = 1.30$).

Reported Experiences with Pretrip Information

Participants were asked to rate how often they seek out pretrip traffic information and how often they had made specific changes to their travel plans in the past year in response to pretrip traveler information. Ratings were made on a scale from 1 (always) to 6 (never), such that smaller numbers indicated greater frequencies. Participants indicated that they seek out pretrip traffic information more for nonroutine trips ($M = 2.28$) than for routine trips ($M = 2.90$), $t(119) = 4.64$, $p < 0.001$. Mean frequency ratings for each question on changes in travel plans are displayed in figure 8. Different changes to travel plans were made with different frequencies, $F(4, 476) = 116.59$, $p < 0.001$. Participants reported leaving early more often than taking an alternate route, both of which were more common than leaving later or canceling the trip. Switching to public transportation was reported to occur least often.

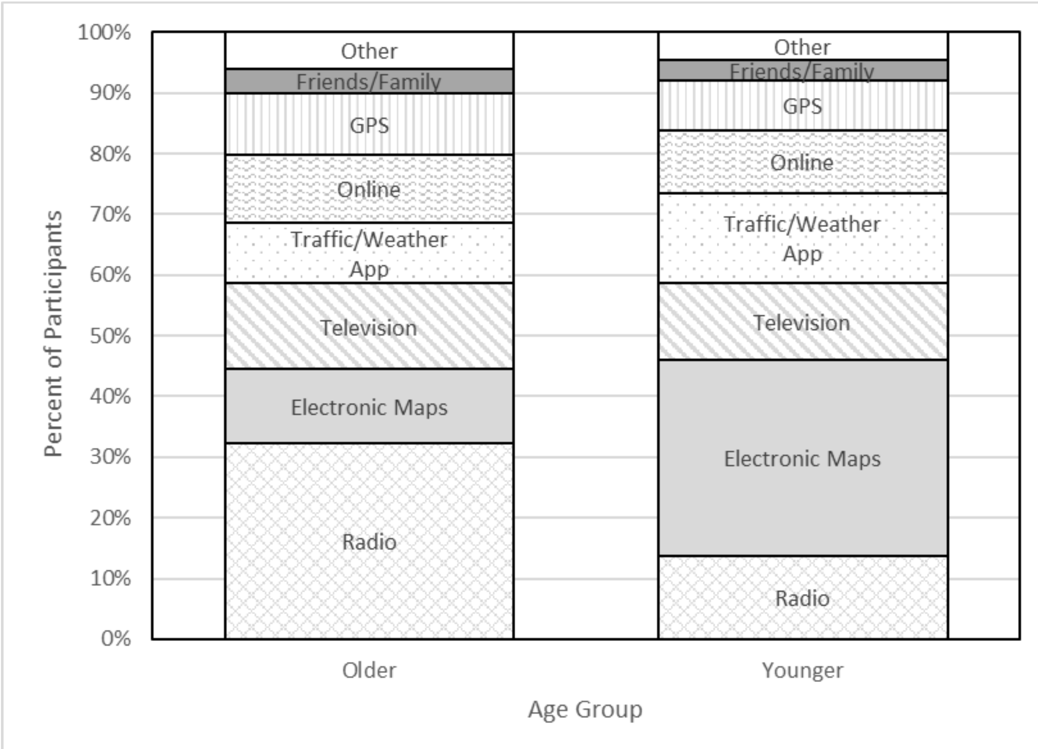


Source: FHWA.

Note: Error bars represent standard errors.

Figure 8. Graph. How frequently participants rated making specific changes to their travel plans in the past year based on pretrip traveler information.

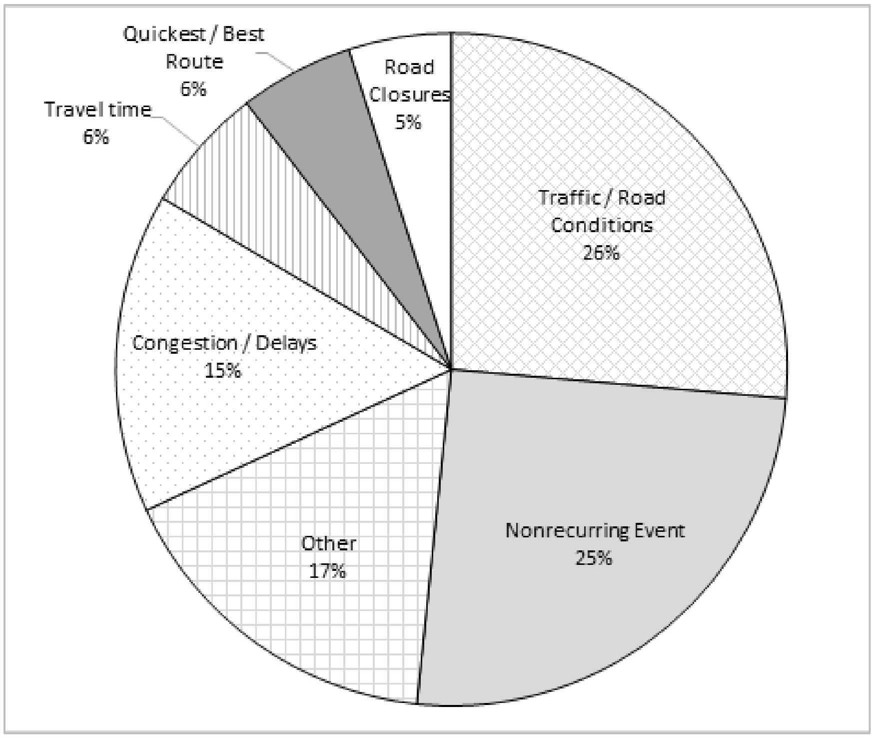
Participants were also asked to indicate their primary source for pretrip traveler information. As shown in figure 9, participants' primary source of pretrip traveler information was influenced by participant age group, $\chi^2(7) = 16.81$, $p = 0.02$. Radio was the most frequently reported source of traveler information among older participants, whereas younger participants reported using electronic maps most often.



Source: FHWA.

Figure 9. Graph. Primary source of pretrip traveler information among older and younger participants.

Finally, participants were asked what specific traveler information they most often sought or felt was most valuable to obtain before beginning a trip. As shown in figure 10, just over a quarter of responses indicated seeking general information on traffic or road conditions. Another quarter of responses indicated a desire to learn about nonrecurring events such as crashes, roadwork, or weather.



Source: FHWA.

Figure 10. Pie Chart. Pretrip traffic information most sought or most valuable.

DISCUSSION

Experiment 1 assessed the effect that pretrip traveler information has on travel plans. Participants were told to imagine planning a specific trip that was either of high or low importance. They were then exposed to traveler information in the form of a traffic alert. The specific delivery mode of each traffic alert was manipulated such that it could include written text, a traffic map, an image from a traffic camera, a photo representing the source of the delay, or a combination of up to three of these. Event type was also manipulated such that each participant was exposed to one of five different nonrecurring events: incident, roadwork, weather, planned events, or miscellaneous events. A combination of open-ended and Likert scale questions assessed the effect of each variable on travel plans.

When drivers gained pretrip traveler information, the most important determinant of how they reacted to that information seemed to be the importance of the trip they were planning. Trip importance significantly influenced participants' initial responses to the open-ended question regarding how the presented traveler information would affect their travel plans. When trip importance was high, participants reported an intention to take an alternate route or leave early with high frequency. In contrast, when trip importance was low, the most frequent reaction to traveler information was to cancel the trip. The high value of trip importance in determining how drivers will react to pretrip traveler information was confirmed by the effect that this variable had on participants' responses to each of the likelihood questions. When trip importance was high, participants reported that they would be more likely to leave early, select an alternate route, or switch to public transit. When trip importance was low, participants reported that they would be more likely to leave late or cancel their trip. While most participants indicated an intention to use pretrip traveler information to change their travel plans, the specific change they were likely to make was dependent on the importance of the intended trip.

This study also examined whether the specific type of nonrecurring event drivers encounter influences how they react to pretrip traveler information. Five event types were included in the study: incident, roadwork, weather, planned events, and miscellaneous events. However, the only type of event that significantly impacted participants' travel plans was weather events. After receiving pretrip traveler information about a weather event, participants were less likely to take an alternate route or leave early and more likely to simply cancel their trip. Not surprisingly, drivers are less willing to travel during weather events and instead prefer to cancel or postpone their plans until the weather event has ended.

Delivery mode did not have a consistent effect on how participants reacted to pretrip traveler information. Delivery mode only had an impact on the likelihood that participants would leave late or take an alternate route. In those cases, it seems that including a traffic camera image in the traffic alert influenced participants' responses to the alert. However, the effects are difficult to interpret since they were not found for all alerts that included traffic camera images. The lack of effect of delivery mode was somewhat unexpected since State DOTs have reported that pretrip information disseminated on social media tends to receive more attention if that information contains a photo in addition to text. Photos within traveler information messages might encourage travelers to share the information with others, but those increased dissemination rates may not always translate into similar levels of behavioral change. More research is needed to help define the relationship between traveler information delivery mode, message dissemination, and changes in traveler behavior.

This experiment included two portions: (1) stated preference questions that asked drivers to imagine how they would react to specific pretrip traveler information, and (2) reported instances questions that asked drivers to report how their own travel had been affected by pretrip traveler information in the past year. A comparison of stated preferences and reported instances reveals areas of agreement and disagreement. In both portions of the study, participants reported a high likelihood of taking an alternate route and leaving early in response to traveler information reporting a nonrecurring event. In the stated preference portion, participants also reported a high likelihood of canceling their trip. However, the frequency with which participants actually reported having canceled a trip in the past year in response to pretrip traveler information was quite low. It may be that drivers are more willing to cancel an imagined trip than they are to cancel a real trip. Previous reports have noted that participants often overreport the rate that they would perform actions during stated preference research.[29] The difference in trip canceling frequency may also be a product of the influence that event type and trip importance have on the likelihood of canceling a trip. Canceling a trip was only a frequent response to weather events. So, if participants did not experience many severe weather events in the past year, then their reported instances of trip canceling would be expected to be low. Additionally, in the stated preference portion of the study, canceling a trip was most frequently a response to low-importance trips. In real life, drivers may be less likely to seek out traveler information for trips of low importance and thus would have few occasions on which they sought information and then chose to cancel the trip.

CHAPTER 3. EXPERIMENT 2: MID-TRIP TRAVELER INFORMATION

INTRODUCTION

The majority of the research on specific traveler information messages used mid-trip has focused on VMS messaging. VMSs offer several advantages as a traveler information dissemination source. First, information presented on VMSs is typically limited to events occurring either on the current roadway or a road that directly intersects with the current roadway. Thus, information obtained from a VMS will almost always be relevant to the current driving situation. Another advantage is that the messages are accessible to all drivers, even those who do not have a personal electronic device or radio. Additionally, traveler information can be obtained from VMSs with minimal distraction from the primary driving task.(13) Thus, VMSs serve as a safe, accessible source of relevant traveler information.

MUTCD provides general guidelines for VMS content as well as specifications on message length, acceptable abbreviations, and use of color and animation.(14) However, the specific messages displayed on a VMS during any given nonrecurring event tend to be left up to the traffic management center operator who is managing the VMS at the time of the event.(30,31) One popular message development technique is to follow the problem-location-action (PLA) method.(8,32) Two examples of a VMS message generated using the PLA method are shown in figure 11. The PLA method advises that a VMS message should contain three basic elements: the problem, the location, and the suggested action. The first line of the message should specify the problem or situation the driver will encounter. The second line of the message should indicate the location of the problem, or the distance between the VMS and the problem. The third line of the message should indicate the suggested action or recommendation to the driver. Each of these message components is explored in greater detail in the following subsections.

Source: FHWA.

Figure 11. Illustration. Examples of VMS messages generated using the PLA method.

Problem

The PLA method dictates that the first piece of information that should appear on a VMS is the problem or situation the driver can expect to encounter. Selecting the appropriate problem to display during a nonrecurring event will often be straightforward. However, there are some situations in which the problem that should be included in a PLA message may be unclear. For example, consider a situation in which flooding causes a road to be closed. In this situation, what problem should be displayed on the first line of the VMS, flooding or road closed? Similarly, if a disabled vehicle is blocking the right lane of the roadway, should information about the disabled vehicle or the blocked lane be prioritized?

Whether it is best to include the nonrecurring event, the effect that event is having on the roadway, or both in a VMS message is not always clear. Research by Wardman, Bonsall, and

Shires indicates that including a nonrecurring event, such as ACCIDENT, in a VMS message leads to increased changes in driver behavior.[33] However, including nonrecurring events as the problem in a VMS message does not negate the need to also include effect of event information in the message. In fact, Dudek and Ullman advise that the effect of event ROAD CLOSED is the most informative piece of information that can be included in a VMS message and, as such, should always have priority.[8] Other effects of an event, such as the length of a potential delay, are less critical but have still been found to help drivers understand the severity of the event and promote changes in driver behavior.[9,24,33] As a result, VMS guidelines acknowledge that it will sometimes be helpful to include the effect of event in a VMS message, even when this information does not fit naturally into the message that would be created using the PLA method.[8,32]

Location

Location information is frequently included in VMS messages. This information allows drivers to understand where an event is occurring and to gauge the opportunity for making changes to their behavior before reaching the event. Further, when cross streets or exits are used to specify location, drivers often use this information as an indication of which streets or exits can be used to avoid the event.[11] When surveyed about the type of information they wish to see on VMSs, drivers report valuing location information.[34,35] However, Peeta, Ramos, and Pasupathy did not find that adding location information to a VMS message about a nonrecurring event changed ratings of how drivers would react to the message.[35] These mixed results suggest that the instances in which location information will lead to changes in traveler behavior warrants additional research.

Action

Providing drivers with a direct action suggestion is an effective way of influencing travel behavior.[24,29,30] Schroeder and Demetsky demonstrated that increases in the specificity of a suggested action displayed via VMS led to increases in the proportion of vehicles that complied with the suggested action.[30] Specifically, messages indicating an incident or delay without suggesting an alternate route were associated with low diversion rates. Messages suggesting taking an alternate route without identifying the specific route to be used led to moderate diversion rates, while messaging that suggested drivers use a specific alternate route were associated with the highest rates of diversion. Instructing drivers to take a specific alternate route leads to the highest levels of compliance; however, Dudek and Ullman caution that VMS operators suggesting a specific alternate route will need to ensure the suggested route is able to accommodate diverting drivers, since encouraging drivers to take the alternate route will only benefit the roadway system so long as the capacity of the alternate route is not exceeded.[8,36] Concern that diverted traffic may exceed the capacity of a specific alternate route prevents many transportation agencies from suggesting specific roadways on VMSs.[4,30,31]

Suggested actions delivered on VMSs can influence driver behavior. Nevertheless, the number of actions available to travelers mid-trip is somewhat limited. Drivers can be advised to take an alternate route or to take precautionary measures, such as adjusting their speed or preparing to stop. When none of these actions are applicable, the phrase USE CAUTION has sometimes been displayed on the action line. However, the acceptability of this practice is unclear. Signal words, such as USE CAUTION or WARNING, may help convey the severity of a nonrecurring event and thus increase the amount of attention directed toward the message.[37] However, Proffitt and Wade argue that signal words should be avoided, as they increase the length of the message without providing a verified benefit to travelers.[37] Lichty, Richard, Campbell, and Bacon also advise against the use of signal words such as CAUTION and WARNING at the start of a message but indicate that the phrase USE CAUTION at the end of a message is acceptable.[32] The actual effect of signal words on traveler behavior has not, to the best of the research team's knowledge, been empirically tested.

Since the amount of time and effort required to read VMS messages increases with increased content, Dudek and Ullman advise that VMS operators should attempt to avoid including more information in a VMS message than is necessary.[8] But how much information do drivers need? Peeta et al. conducted a survey to assess the content of VMSs that would make someone most likely to select an alternate route.[35] The survey asked drivers how willing they would be to divert after viewing a sign that indicated that an accident had occurred, the expected delay, the best alternate route, or some combination of these messages. Participants who were exposed to at least two of the three components indicated greater willingness to change routes than those who viewed messages with only one piece of information, suggesting that having more information may be advantageous. However, further research is required to determine the limits to the amount and type of information that is necessary to inform drivers and promote desired changes in behavior during different types of nonrecurring events.

Experiment 2 used stated preferences to assess which components of VMS messages are most effective in leading to desired changes in traveler behavior during nonrecurring events. Participants were presented with VMS messages that could include phrases referring to different nonrecurring events, event locations, effects of events, suggested actions, and signal words. Participants were asked to indicate the meaning of each message and what they would do in response to each. Then they rated the likelihood that they would switch to an alternate route and the likelihood of continuing on their current route after encountering each VMS message. Self-reported data regarding preferences for different VMS messages and past use of mid-trip traveler information were also collected. The study examined how VMS messages influence traveler behavior as well as the specific phrases that are most likely to increase diversion rates during different nonrecurring events.

METHOD

The same 122 participants who participated in the pretrip traveler information experiment also completed experiment 2. As in experiment 1, stimuli were displayed on a 60-inch LCD monitor, and participants responded either using a standard QWERTY keyboard and mouse or by allowing the researcher administering the experiment to enter their verbal response using a separate mouse and keyboard.

Experimental Design

The experiment included five variables, each of which corresponded to a specific type of information that can be included on a VMS: event, event location, effect of event, suggested action, and signal word. The event was manipulated within subjects and included

11 levels: INCIDENT, DISABLED VEHICLE, ROAD WORK, CONSTRUCTION, BLACK ICE, DENSE FOG, WATER ON ROAD, RACE TRAFFIC, MUDSLIDE, BLOWING DUST, and no event. The event location was manipulated between subjects and included two levels: 5 MILES and no location. The effect of event was also manipulated between subjects and included four levels: ROAD CLOSED, RIGHT LANE CLOSED, MAJOR DELAY, and no effect. The suggested action was manipulated within subjects and included three levels: USE OTHER ROUTES, SLOW DOWN, and no action. Finally, the signal word was manipulated between subjects and included three levels: WARNING, USE CAUTION, and no signal.

The factorial design included all combinations of these variables with the following exceptions. Signal words were not displayed in isolation or with location information alone, since this type of sign (e.g., WARNING/5 MILES) would be highly uninformative. In addition, the events DENSE FOG and BLOWING DUST were not combined with the effect of event RIGHT LANE CLOSED, as it is unlikely that fog or dust would lead to one lane being closed.

Procedure

The main portion of the study assessed participants' responses to traveler information messages displayed on VMSs. On each trial, an image of a VMS displayed a different travel message (see figure 12). One unit of information (corresponding to one of the five variables) was displayed on each line of the VMS. The order of display was event, event location, effect of event, and suggested action. If the signal word was WARNING, it was displayed on the first line of the VMS. If the signal word was USE CAUTION, this phrase was displayed last. If the message included more than three units of information, a two-phase sign was displayed. Two-phase signs displayed the first phase of the message for 1 s and the second phase for 1.5 s and then alternated between the two phases every 1.5 s until the participant made his or her response.

Source: FHWA.

Figure 12. Photo. Example of a VMS.

On each trial, one VMS was presented, and participants were asked to imagine they had encountered the presented VMS while driving in a familiar area. They were asked to describe the meaning of the sign and what they would do in response to the sign. Open-ended responses were recorded. Participants then rated their likelihood of continuing on the current route, followed by their likelihood of taking an alternate route. Ratings were made on the same four-point scale used in experiment 1: 1 (not at all likely), 2 (somewhat unlikely), 3 (somewhat likely), and 4 (very likely). Each participant completed 33 trials.

The second portion of the experiment gauged participants' preferences for specific VMS messages. Participants were presented with a series of messages that have been used by different VMS operators to convey the same information and were asked to rank the messages from most effective to least effective at conveying the desired information. Each participant completed 10 rankings.

Finally, during the last portion of the study, participants answered questions about their own use of mid-trip traveler information, including their preferred source of information, the information they felt was most useful, and the effect that mid-trip traveler information had on their travel in the past year (see appendix B for the list of questions). Participants were then debriefed and paid.

RESULTS

This section presents the findings for experiment 2, including participants' open-ended and rating responses to different types of VMS messages. Participants' reported experiences using mid-trip information in the previous year are also presented.

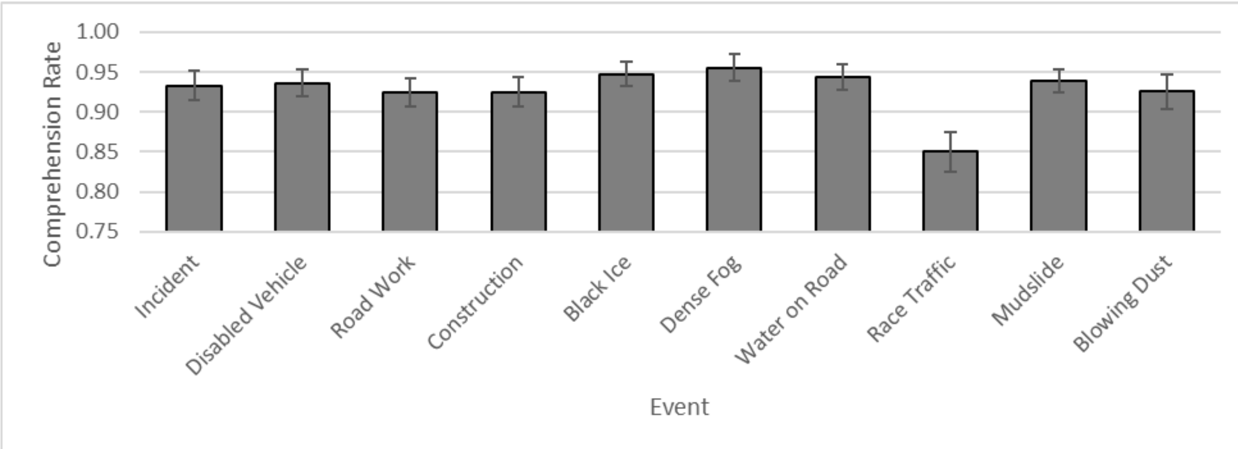
Open-ended Responses

Participants were asked to answer two open-ended questions in response to each presented VMS: "What does this sign mean?" and "What would you do in response to this sign?" A summary of the responses to each question is provided in the following subsections.

What Does This Sign Mean?

The open-ended question "What does this sign mean?" evaluated participants' comprehension of each message. Following data collection, trained coders read each response and marked those that indicated that the participant had misinterpreted the sign's meaning or found any portion of the sign confusing. A second coder independently reassessed all marked responses to verify accurate coding. The majority of messages (92.50 percent) were understood correctly. A generalized estimating equation (GEE) model with a binomial response distribution was used to assess differences in message comprehension for each variable.

Message comprehension was influenced by event, $\chi^2(10) = 48.46$, $p < 0.001$. As shown in figure 13, messages that included the phrase RACE TRAFFIC were understood less often than messages with any other event phrase. Examination of the specific responses provided by participants indicated that participants did not have much experience with this message. Further, some participants mistakenly interpreted RACE TRAFFIC to indicate that traffic ahead would be traveling at a high speed (i.e., racing).



Source: FHWA.
Note: Error bars represent standard errors.

Figure 13. Graph. Message comprehension rate as a function of event.

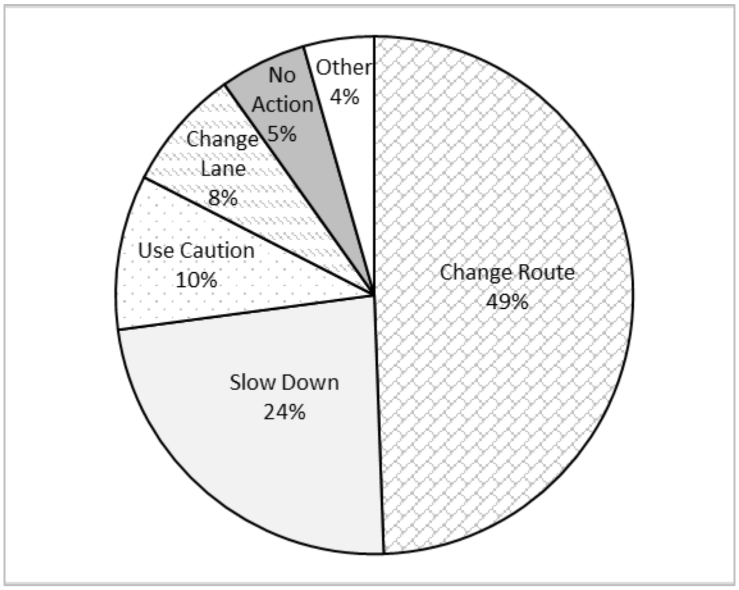
Event location also had a significant effect on message comprehension, $\chi^2(1) = 6.66$, $p < 0.001$. Messages with the phrase 5 MILES were understood somewhat less frequently (91.98 percent) than messages without the location phrase (96.45 percent). The most common source of confusion appeared to be a misinterpretation of the phrase 5 MILES as an indication of the length of the nonrecurring event (e.g., "right lane closed due to road work spanning 5 mi.") rather than the distance to the nonrecurring event.

The effect of event also influenced message comprehension, $\chi^2(3) = 14.32$, $p = 0.003$. Messages with the phrase MAJOR DELAY were understood slightly less frequently (88.63 percent) than messages with other effect of event phrases (ROAD CLOSED: 96.31 percent, RIGHT LANE CLOSED: 97.03 percent, and no effect of event: 93.57 percent). Some participants found the message MAJOR DELAY too vague to interpret.

Finally, signal word influenced message comprehension, $\chi^2(2) = 6.47$, $p = 0.04$. Messages with the phrase USE CAUTION were comprehended slightly more frequently (96.85 percent) than WARNING messages (93.15 percent) or messages without a signal word (92.93 percent).

What Would You Do in Response To This Sign?

The open-ended question "What would you do in response to this sign?" was used to gauge participants' initial reactions to different VMS messages. Trained coders, who were blind to condition, categorized each response. Responses that fell within multiple categories were counted multiple times. Categories that contained less than 5 percent of responses were combined into a single "other" category. Figure 14 displays the percentage of responses that fell within each category. Approximately half of the responses indicated an intention to change routes. Another quarter of the responses indicated an intention to slow down.



Source: FHWA.

Figure 14. Pie Chart. Frequency of responses to the open-ended question "What would you do in response to this sign?"

To determine which specific messages resulted in change route responses, the number of participants who indicated an intent to change routes was calculated for each condition. Table 3 displays a heat map of the results, with darker areas (higher numbers) indicating greater numbers of participants. In general, the number of participants who indicated an intention to change routes was high for messages that included the phrase USE OTHER ROUTES. Messages that included the phrase ROAD CLOSED or MAJOR DELAY also produced a relatively high number of change route responses. Messages that only included the event type and SLOW DOWN led to very few change route responses.

Table 3. The number of spontaneous change route responses in each condition.

Location	Signal Word	Effect of Event	Use Other Routes											Slow Down											No Action										
			Disabled Vehicle	Dense Fog	Blowing Dust	Construction	Road Work	Incident	Water on Road	Black Ice	Race Traffic	Mudslide	No Event	Disabled Vehicle	Dense Fog	Blowing Dust	Construction	Road Work	Incident	Water on Road	Black Ice	Race Traffic	Mudslide	No Event	Disabled Vehicle	Dense Fog	Blowing Dust	Construction	Road Work	Incident	Water on Road	Black Ice	Race Traffic	Mudslide	No Event
5 MILES	Use Caution	Road Cl	4	4	5	4	5	5	5	5	5	4	5	2	4	4	3	1	2	5	3	3	5	2	2	5	5	4	4	4	3	3	3	5	3
		Major delay	3	3	4	4	3	4	5	4	3	4	4	2	1	2	2	1	3	3	2	3	2	2	1	1	1	2	2	2	3	2	3	3	1
		Right lane Cl	3	—	—	3	3	4	4	3	4	5	5	2	—	—	1	1	1	1	2	2	2	1	1	—	—	1	2	2	1	2	2	2	1
		No effect	3	3	1	2	3	3	3	4	4	5	3	0	1	1	0	3	0	2	2	4	4	0	0	2	1	2	0	0	2	4	3	4	—
	Warning	Road Cl	5	4	4	4	4	3	4	3	4	5	4	3	4	5	3	3	3	4	2	5	4	3	3	3	4	3	3	3	5	5	3	4	5
		Major delay	4	3	3	3	5	5	4	4	5	5	5	1	1	0	3	2	2	2	0	4	1	0	0	1	2	3	1	1	2	4	2	3	2
		Right lane Cl	4	—	—	3	4	4	3	4	4	3	4	2	—	—	3	3	2	4	4	3	4	3	1	—	—	2	4	3	3	4	5	2	2
		No effect	5	4	5	4	4	5	5	5	5	5	4	0	1	2	2	1	1	2	2	1	1	1	1	1	1	2	1	1	2	3	1	3	—
	No Signal	Road Cl	5	5	4	5	5	4	5	4	5	5	5	3	3	2	2	3	4	3	3	3	4	4	3	5	4	4	5	4	4	4	5	5	5
		Major delay	5	5	5	5	5	5	4	4	5	5	5	5	5	4	5	4	5	5	3	5	3	4	5	4	5	5	5	5	4	5	5	5	5
		Right lane Cl	4	—	—	4	5	5	5	5	5	3	5	1	—	—	0	0	2	2	3	4	2	1	1	—	—	1	1	1	1	2	4	3	1
		No effect	5	5	5	5	5	5	5	5	5	5	0	4	2	2	3	3	4	2	3	4	3	1	3	2	4	4	3	3	3	2	5	4	—
No Location	Use Caution	Road Cl	5	5	4	5	5	5	4	5	5	5	5	4	4	3	5	4	5	5	4	5	5	5	4	5	4	4	5	5	5	3	4	5	5
		Major delay	3	4	5	5	4	5	4	3	4	5	5	2	1	2	3	3	3	4	1	2	3	2	3	2	3	3	2	3	2	1	3	3	2
		Right lane Cl	5	—	—	5	5	3	5	3	4	5	4	0	—	—	0	1	1	2	1	2	1	0	1	—	—	0	1	0	2	1	1	3	0
		No effect	4	4	5	4	4	4	4	3	4	4	4	2	0	1	0	0	2	0	0	1	1	1	0	0	0	1	1	2	0	0	3	2	—
	Warning	Road Cl	5	5	5	5	4	5	5	3	4	5	5	4	4	5	4	4	4	4	5	3	4	3	4	3	5	4	5	5	5	5	5	5	4
		Major delay	5	3	4	4	4	4	3	4	4	4	5	5	3	3	4	4	4	5	4	2	4	4	5	4	2	3	4	3	2	5	2	3	4
		Right lane Cl	3	—	—	4	5	4	3	3	3	4	4	0	—	—	0	1	2	3	1	2	3	0	1	—	—	1	2	2	2	1	1	1	0
		No effect	5	4	4	5	4	4	4	5	4	5	4	1	0	2	1	0	0	0	0	1	2	0	1	0	1	1	0	2	0	0	1	3	—
	No Signal	Road Cl	4	5	5	5	5	5	4	5	4	5	5	4	4	3	4	5	4	4	3	4	4	3	5	3	3	5	5	5	4	4	5	5	4
		Major delay	5	5	5	4	3	4	4	5	3	5	5	3	2	3	2	2	3	3	4	3	3	2	3	2	4	4	3	5	4	2	3	5	3
		Right lane Cl	4	—	—	4	5	5	4	5	5	5	5	1	—	—	2	0	1	1	0	2	1	1	1	—	—	2	2	0	2	1	4	3	1
		No effect	5	4	4	3	3	2	3	4	3	4	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	1	1	1	1	2	2	—

—No data.
Cl = closed.

Likelihood Ratings

On each trial, participants used the previously described four-point scale to rate both the likelihood of selecting an alternate route and the likelihood of continuing on their current route in response to the displayed VMS. Although small variations were found between ratings of the likelihood of switching to the alternate route and the likelihood of continuing on the current route, the general pattern of findings (referred to hereafter as diversion ratings) tended to be consistent across measures.

Responses to each likelihood rating were analyzed using a linear mixed model. The mixed model considered participant a nested variable and all other characteristics fixed. The model included all two-, three-, and four-way interactions for event location, effect of event, suggested action, and signal word but only two-way interactions for event because of the large number of events that were tested. In the full model, many of the interactions with signal word were not significant, so they were removed, and the model was re-run. To explore which aspects of the message were significant for different events and potential interactions between variables, data were divided into subsets for each event to explore how event location, effect of event, suggested action, and signal word influenced responses. Pairwise comparisons with a Bonferroni adjustment to correct for family-wise error were examined for significant effects.

Event

The event significantly affected the likelihood ratings both of switching to an alternate route, $F(10, 3{,}547) = 21.99$, $p < 0.001$, and of continuing on the current route, $F(10, 3{,}552) = 22.95$, $p < 0.001$. Table 4 displays mean likelihood ratings as a function of event type, as well as the results of the pairwise comparisons for each event type. Diversion ratings were greater in response to a MUDSLIDE event than to any other event. The events RACE TRAFFIC and BLACK ICE also had higher diversion ratings compared to messages without event information.

Table 4. Mean likelihood ratings and pairwise comparisons of switching to an alternate route and continuing on the current route as a function of event.

Event	Switch to Alternate Route	Continue on Current Route	Disabled Vehicle	Dense Fog	Blowing Dust	Construction	Road Work	Incident	Water on Road	Black Ice	Race Traffic	Mudslide
Disabled vehicle	2.94	2.35	—	—	—	—	—	—	—	—	—	—
Dense fog	2.94	2.29	ns	—	—	—	—	—	—	—	—	—
Blowing dust	3.03	2.21	ns	ns	—	—	—	—	—	—	—	—
Construction	3.11	2.24	*	ns	ns	—	—	—	—	—	—	—
Road work	3.13	2.19	*	ns	ns	ns	—	—	—	—	—	—
Incident	3.19	2.16	**	*	ns	ns	ns	—	—	—	—	—
Water on road	3.24	2.04	**	**	*	+	ns	ns	—	—	—	—
Black ice	3.30	1.93	**	**	**	**	+	+	ns	—	—	—
Race traffic	3.33	1.97	**	**	**	**	**	ns	ns	ns	—	—
Mudslide	3.54	1.68	**	**	**	**	**	**	**	**	**	—
No event	3.06	2.21	ns	ns	ns	ns	ns	ns	ns	**	**	**

*$p < 0.05$ for switching to an alternate route.
+$p < 0.05$ for continuing on the current route.
**$p < 0.05$ for both switch to alternate route and continue on current route.
—No data.
ns = no significant difference.

Event Location

Event location did not have a significant effect on ratings of the likelihood of switching to the alternate route but did influence ratings of the likelihood of continuing on the current route. As shown in table 5, participants who were given event location information rated their likelihood of continuing on the current route as less than participants who were not. This effect was observed for four events: WATER ON ROAD, BLACK ICE, RACE TRAFFIC, and MUDSLIDE.

Table 5. Mean likelihood ratings as a function of event location across all events and for events where event location had a significant effect.

Event	5 MILES		No Location		*F*-Value	
	Alt. Rte.	Cur. Rte.	Alt. Rte.	Cur. Rte.	Alt. Rte.	Cur. Rte.
All	ns	2.02	ns	2.21	ns	4.91*
Water on road	3.34	1.85	3.09	2.23	5.34*	11.18**
Black ice	ns	1.71	ns	2.14	ns	9.55**
Race traffic	ns	1.83	ns	2.11	ns	4.35*
Mudslide	ns	1.56	ns	1.80	ns	4.41*

*$p < 0.05$.
**$p < 0.001$.
ns = not significant.
Alt. Rte. = switching to an alternate route.
Cur. Rte. = continuing on the current route.

Effect of Event

The effect of event significantly influenced ratings of both the likelihood of switching to the alternate route and continuing on the current route (see table 6). As may be expected, diversion ratings were higher in response to ROAD CLOSED than in response to any other effect of event. When individual event types were considered, the effect of event significantly affected both the likelihood of switching to an alternate route and continuing on the current route for each event. For each event, diversion ratings were highest when the road was closed. Additionally, the effect of event MAJOR DELAY increased diversion ratings above those found for the remaining effects of the event (i.e., RIGHT LANE CLOSED and no effect of event) for the events CONSTRUCTION, INCIDENT, and WATER ON ROAD.

Table 6. Mean likelihood ratings as a function of the effect of event for all events.

Event	Road Closed		Major Delay		Right Lane Closed		No Effect		*F*-Value	
	Alt. Rte.	Cur. Rte.	Alt. Rte.	Cur. Rte.	Alt. Rte.	Cur. Rte.	Alt. Rte.	Cur. Rte.	Alt. Rte.	Cur. Rte.
All	3.79	1.28	3.13	2.13	3.05	2.47	2.68	2.59	25.40**	47.31**
Disabled vehicle	3.71	1.34	2.89	2.41	2.80	2.76	2.34	2.90	17.13**	30.63**
Dense fog	3.72	1.31	2.80	2.42	—	—	2.42	2.79	23.99**	37.52**
Blowing dust	3.68	1.34	2.99	2.23	—	—	2.53	2.70	21.12**	33.40**
Construction	3.80	1.39	3.17	2.09	2.97	2.73	2.52	2.76	18.54**	28.75**
Road work	3.86	1.19	3.10	2.56	2.94	2.58	2.63	2.74	20.00**	38.25**
Incident	3.73	1.37	3.21	2.04	3.10	2.53	2.70	2.69	12.33**	22.03**
Water on road	3.82	1.21	3.33	1.98	3.09	2.41	2.70	2.57	14.68**	28.04**
Black ice	3.80	1.29	3.08	2.18	3.34	1.99	2.98	2.26	7.17**	9.86**
Race traffic	3.83	1.38	3.19	1.98	3.34	2.28	2.96	2.26	7.75**	9.91**
Mudslide	3.92	1.07	3.51	1.67	3.46	2.00	3.27	1.98	8.13**	13.96**

*$p < 0.05$.
**$p < 0.001$.
— No data.
Alt. Rte. = switching to an alternate route.
Cur. Rte. = continuing on the current route.

Suggested Action

Suggested action influenced ratings of the likelihood of switching to an alternate route and continuing on the current route (see table 7). Diversion ratings were greater for USE OTHER ROUTES than for no action, whereas diversion ratings were lower for SLOW DOWN than for no action. The influence of suggested action was seen for every event. In each case, diversion ratings were greater for USE OTHER ROUTES than for SLOW DOWN. This action difference (defined as the absolute value of the likelihood of changing routes in response to USE OTHER ROUTES minus the likelihood of changing routes in response to SLOW DOWN) contributed to all of the significant interactions found in the data. To foreshadow, the size of the action difference, or the extent to which the phrase USE OTHER ROUTES increased diversion rates over that found when the phrase SLOW DOWN was present, tended to be larger when the VMS message included fewer phrases or when the VMS message suggested a less severe event.

Table 7. Mean likelihood ratings as a function of the suggested action for all events.

Event	Use Other Route		Slow Down		No Action		*F*-Value	
	Alt. Rte.	Cur. Rte.	Alt. Rte.	Cur. Rte.	Alt. Rte.	Cur. Rte.	Alt. Rte.	Cur. Rte.
All	3.60	1.64	2.90	2.39	2.99	2.31	354.94**	359.92**
Disabled vehicle	3.43	1.91	2.65	2.60	2.73	2.55	55.76**	34.20**
Dense fog	3.46	1.70	2.67	2.44	2.82	2.38	29.64**	23.36**
Blowing dust	3.52	1.61	2.79	2.33	2.89	2.33	25.99**	27.67**
Construction	3.59	1.68	2.85	2.53	2.90	2.52	44.45**	52.83**
Road work	3.58	1.68	2.90	2.50	2.92	2.40	48.76**	53.96**
Incident	3.61	1.66	2.96	2.46	2.99	2.36	37.68**	49.21**
Water on road	3.65	1.61	3.02	2.29	3.04	2.23	38.85**	41.58**
Black ice	3.60	1.65	3.11	2.13	3.19	2.01	23.00**	15.42**
Race traffic	3.67	1.61	3.13	2.20	3.20	2.11	31.30**	23.20**
Mudslide	3.88	1.29	3.32	1.91	3.43	1.83	32.32**	36.90**

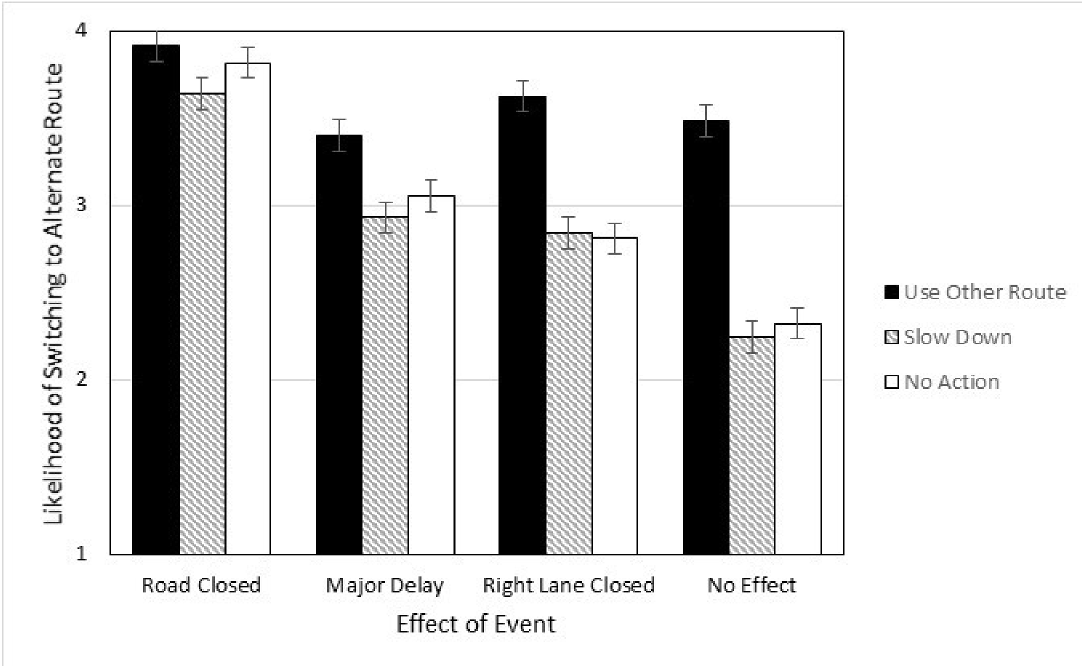
*$p < 0.05$.
**$p < 0.001$.
Alt. Rte. = switching to an alternate route.
Cur. Rte. = continuing on the current route.

Interaction of Event Location and Suggested Action

An interaction between event location and suggested action was found both for ratings of the likelihood of switching to an alternate route, $F(2, 3{,}547) = 4.10$, $p = 0.017$, and the likelihood of continuing on the current route, $F(2, 3{,}552) = 5.57$, $p = 0.003$. While the likelihood of changing routes was consistently greater for the suggested action USE OTHER ROUTES than SLOW DOWN, the size of the action difference was slightly greater for no location (switch to alternate route: $M = 0.78$; continue on current route: $M = 0.79$) than for 5 MILES (switch to alternate route: $M = 0.61$; continue on current route: $M = 0.69$). The interaction between event location and suggested action was not significant for any individual events.

Interaction of Effect of Event and Suggested Action

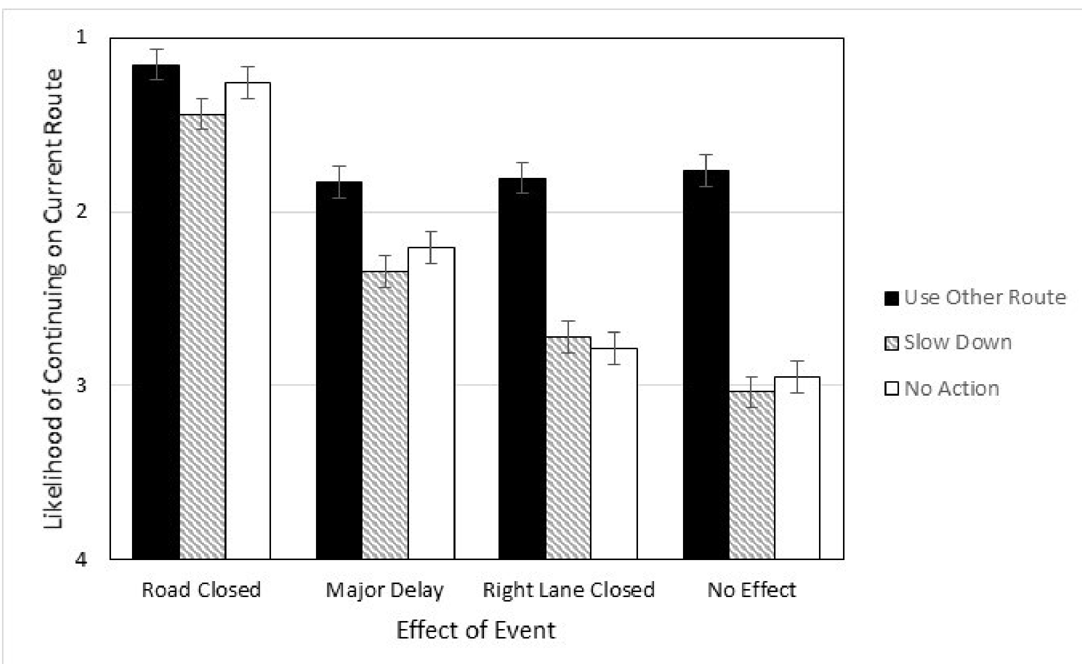
The interaction between effect of event and suggested action was significant both for ratings of the likelihood of switching to an alternate route, $F(6, 3{,}547) = 44.73$, $p < 0.001$, and for ratings of the likelihood of continuing on the current route $F(6, 3{,}524) = 44.81$, $p < 0.001$. As shown in figure 15 and figure 16, when the effect of event was ROAD CLOSED or MAJOR DELAY, suggested action did not influence diversion ratings. In contrast, when the effect of event was RIGHT LANE CLOSED or no effect, an action difference was found such that diversion ratings were greater for the suggested action USE OTHER ROUTES than for any other suggested actions.



Source: FHWA.

Note: Error bars represent standard errors.

Figure 15. Graph. Mean ratings of the likelihood of switching to an alternate route as a function of the effect of event and suggested action.



Source: FHWA.

Note: Error bars represent standard errors. The y-axis is reversed such that higher bars represent higher diversion ratings/lower likelihood of continuing on the current route.

Figure 16. Graph. Mean ratings of the likelihood of continuing on the current route as a function of the effect of event and suggested action.

The interaction between effect of event and suggested action was significant for all events (see table 8). The severity of the effect of event appeared to influence the number of events for which a significant action difference was found. Specifically, as the severity of the effect of event decreased, the number of specific events for which a significant action difference was found increased. As displayed in table 8, no significant action differences were found when the effect of event was ROAD CLOSED. However, when MAJOR DELAY was displayed, an action difference was found for half of the events. When the effect of event was RIGHT LANE CLOSED, a significant action difference was found for all events except BLACK ICE. A significant action difference was found for all events when no effect of event was displayed.

Table 8. Mean action differences and *F*-values as a function of the effect of event and event type.

Event	Road Closed		Major Delay		Right Lane Closed		No Effect		*F*-Value	
	Alt. Rte.	Cur. Rte.	Alt. Rte.	Cur. Rte.	Alt. Rte.	Cur. Rte.	Alt. Rte.	Cur. Rte.	Alt. Rte.	Cur. Rte.
Disabled vehicle	0.33	0.30	0.57*	0.47	0.80*	0.97*	1.40*	1.03*	6.29**	2.82*
Dense fog	0.30	0.17	0.70*	0.63	—	—	1.37*	1.43*	6.98**	6.65**
Blowing dust	0.30	0.57	0.60	0.50	—	—	1.30*	1.10*	5.68**	3.50**
Construction	0.33	0.37	0.47	0.70*	0.90*	1.10*	1.27*	1.20*	44.45**	52.83**
Road work	0.33	0.37	0.33	0.40	1.07*	1.13*	1.00*	1.40*	4.64**	3.77**
Incident	0.10	0.23	0.33	0.63*	0.87*	1.07*	1.30*	1.27*	6.22**	5.77**
Water on road	0.30	0.20	0.13	0.13	0.73*	0.83*	1.37*	1.57*	10.61**	11.53**
Black ice	0.13	0.17	0.40	0.47	0.47	0.37	0.97*	0.90*	4.39**	4.68**
Race traffic	0.30	0.17	0.40	0.33	0.57*	0.80*	0.90*	1.07*	2.45*	2.72*
Mudslide	0.17	0.10	0.50	0.57*	0.67*	0.63*	0.90*	1.17*	3.59**	6.03**

*p < 0.05.
**p < 0.001.
—No data.
Alt. Rte. = switching to an alternate route.
Cur. Rte. = continuing on the current route.

Interaction of Event Location, Effect of Event, and Suggested Action

A significant three-way interaction between event location, effect of event, and suggested action was found for the likelihood of switching to an alternate route, $F(9, 3{,}547) = 2.88$, $p = 0.002$.

For the effects of event ROAD CLOSED and MAJOR DELAY, no action differences were found. For the effect of event RIGHT LANE CLOSED, an action difference was present, and the absolute size of the action difference was similar for both location conditions. An action difference was also found when no effect of event was displayed, and the size of that action difference was smaller when location information was present than when no location information was provided (see table 9).

The three-way interaction between event location, effect of event, and suggested action influenced likelihood ratings of switching to an alternate route for CONSTRUCTION, $F(6, 204) = 3.06$, $p = 0.007$, and likelihood ratings of continuing on the current route for INCIDENT, $F(6, 204) = 2.25$, $p = 0.040$, and WATER ON ROAD, $F(6, 204) = 3.41$, $p = 0.003$. For the effects of event RIGHT LANE CLOSED and no effect of event, the size of the action difference was reduced when location information was displayed (see table 9).

Table 9. Mean action differences as a function of event location and the effect of event across all events and for each event for which the interaction was significant.

	Road Closed		Major Delay		Right Lane Closed		No Effect	
Event by Location	**Alt. Rte.**	**Cur. Rte.**	**Alt. Rte.**	**Cur. Rte.**	**Alt. Rte.**	**Cur. Rte.**	**Alt. Rte.**	**Cur. Rte.**
All—5 MILES	0.33	ns	0.48	ns	0.67	ns	0.98	ns
All—no location	0.22	ns	0.46	ns	0.46	ns	1.50	ns
Construction—5 MILES	0.47	ns	0.47	ns	1.13	ns	0.60	ns
Construction—no location	0.20	ns	0.47	ns	0.67	ns	1.93	ns
Incident—5 MILES	ns	0.13	ns	0.47	ns	1.07	ns	0.93
Incident—no location	ns	0.33	ns	0.80	ns	1.07	ns	1.60
Water on road—5 MILES	ns	0.27	ns	0.53	ns	0.67	ns	1.13
Water on road—no location	ns	0.13	ns	0.27	ns	1.00	ns	2.00

Alt. Rte. = switching to an alternate route.
Cur. Rte. = continuing on the current route.
ns = not significant.

Interaction of Effect of Event, Suggested Action, and Signal Word

A significant three-way interaction was found for effect of event, suggested action, and signal word both for ratings of the likelihood of switching to an alternate route, $F(22, 3{,}519) = 3.80$, $p < 0.001$, and continuing on the current route, $F(18, 3{,}524) = 2.94$, $p < 0.001$. As shown in table 10, no action differences were found when the effect of event was ROAD CLOSED. For the effect of event MAJOR DELAY, the presence of a signal word significantly increased the size of the action difference. Signal word did not have a consistent effect on action differences for RIGHT LANE CLOSED or no effect of event.

The three-way interaction between effect of event, suggested action, and signal word was significant for two events: WATER ON ROAD and BLACK ICE (see table 10). For the event WATER ON ROAD, the interaction influenced ratings of the likelihood of continuing on the current route, $F(12, 204) = 1.91$, $p = 0.035$. For the event BLACK ICE, the interaction influenced ratings of the likelihood of switching to an alternate route, $F(12, 204) = 2.41$, $p = 0.006$. The pattern of action differences when no signal words were presented for both events was consistent with that reported previously. An action difference was present only when the effect of event was less severe (i.e., RIGHT LANE CLOSED or no effect). Overall, the presence of signal words was associated with an inconsistent pattern of results and, importantly, did not increase diversion rates for any of the events or the effects of the event.

Table 10. Mean action differences as a function of the effect of event and the signal word across all events and for each event for which the interaction was significant.

Event by Signal Word	Road Closed		Major Delay		Right Lane Closed		No Effect	
	Alt. Rte.	Cur. Rte.	Alt. Rte.	Cur. Rte.	Alt. Rte.	Cur. Rte.	Alt. Rte.	Cur. Rte.
All—Warning	0.23	0.21	0.52	0.57	0.43	0.59	1.45	1.35
All—Use caution	0.29	0.32	0.70	0.67	0.71	0.88	0.87	0.94
All—No signal word	0.31	0.33	0.19	0.30	1.21	1.27	1.39	1.54
Water on road—Warning	0.60	ns	0.70	ns	0.20	ns	1.70	ns
Water on road—Use caution	0.10	ns	0.20	ns	0.70	ns	1.10	ns
Water on road—No signal word	0.10	ns	0.10	ns	1.60	ns	1.90	ns
Black ice—Warning	ns	0.10	ns	0.50	ns	0.10	ns	1.00
Black ice—Use caution	ns	0.50	ns	0.70	ns	0.20	ns	0.60
Black ice—No signal word	ns	0.00	ns	0.00	ns	1.10	ns	1.00

Alt. Rte. = switching to an alternate route.
Cur. Rte. = continuing on the current route.
ns = not significant.

Interaction of Event Location, Effect of Event, Suggested Action, and Signal Word

Finally, the four-way interaction between event location, the effect of event, suggested action, and signal word was significant both for likelihood ratings of switching to an alternate route, $F(24, 3{,}547) = 2.11$, $p = 0.001$, and continuing on the current route, $F(24, 3{,}552) = 2.19$, $p < 0.001$ (see table 11). Action differences were minimal for the effects of event ROAD CLOSED, MAJOR DELAY, and RIGHT LANE CLOSED. Instead, the source of the interaction appeared to be the size of the action difference when no effect of event information was present. Specifically, the action difference was reduced when location information was provided relative to when it was not, and the size of this reduction was larger when no signal word was presented than when either USE CAUTION or WARNING were displayed. This interaction was not significant for any individual event.

Table 11. Mean action differences as a function of event location, the effect of event, and signal word.

Location by Signal Word	Road Closed		Major Delay		Right Lane Closed		No Effect	
	Alt. Rte.	Cur. Rte.	Alt. Rte.	Cur. Rte.	Alt. Rte.	Cur. Rte.	Alt. Rte.	Cur. Rte.
5 MILES—Warning	0.07	0.02	0.73	0.84	0.24	0.36	1.33	1.18
No location—Warning	0.38	0.44	0.31	0.31	0.62	0.82	1.56	1.51
5 MILES— Use caution	0.53	0.58	0.65	0.69	0.49	0.67	0.62	0.73
No location—Use caution	0.05	0.05	0.75	0.65	0.9	1.09	1.13	1.15
5 MILES— No signal word	0.38	0.35	0.05	0.02	1.29	1.22	0.98	1.13
No location—No signal word	0.24	0.31	0.33	0.58	1.13	1.31	1.82	1.95

Alt. Rte. = switching to an alternate route.
Cur. Rte. = continuing on the current route.

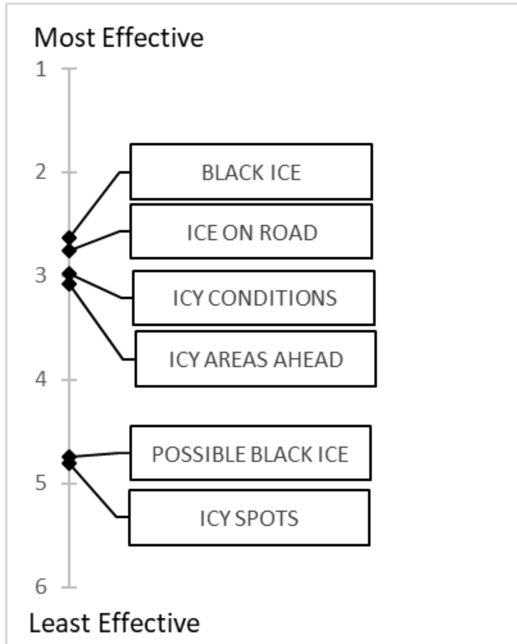
VMS Message Rankings

To assess the specific message preferred for conveying different types of traveler information on VMSs, participants were given possible VMS messages and were asked to rank the messages from most to least effective at conveying the intended information. Mean values were calculated to compare rankings. Since messages were ranked from first to last, lower mean values indicate that the message was more effective. To determine if the rankings were significantly different among the signs of interest, Friedman rank tests (nonparametric analysis of variance) were calculated.

Events

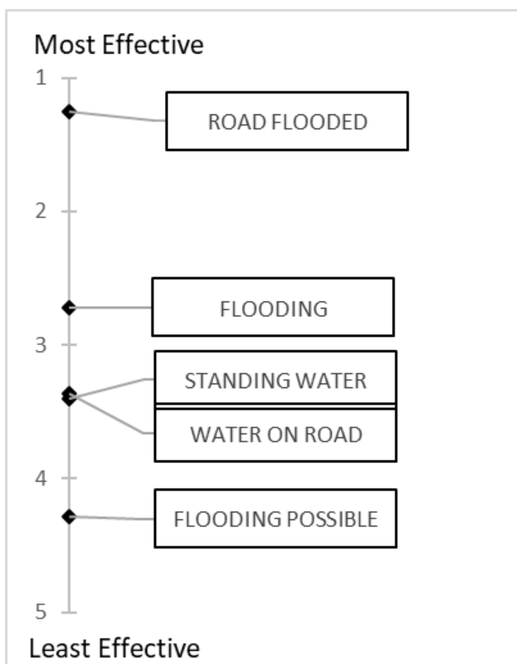
The messages CRASH, MAJOR CRASH, and TRUCK CRASH are all designed to indicate that a crash that is affecting traffic has occurred on the road ahead. MAJOR CRASH ($M = 1.24$) was ranked as more effective than CRASH ($M = 2.42$) or TRUCK CRASH ($M = 2.34$), $\chi^2(4) = 183.75$, $p < 0.001$, at conveying the intended meaning. A comparison of CRASH and INCIDENT indicated that CRASH ($M = 1.11$) was more effective than INCIDENT ($M = 1.89$) when a crash is affecting traffic, $\chi^2(1) = 144.15$, $p < 0.001$.

The most effective messages for the weather events ice, fog, and flooding were assessed. When the ice messages displayed in figure 17 were ranked, a significant difference between messages was found, $\chi^2(25) = 304.80$, $p < 0.001$, such that BLACK ICE, ICE ON ROAD, ICY CONDITIONS, and ICY AREAS AHEAD were all ranked as more effective than POSSIBLE BLACK ICE or ICY SPOTS. Rankings of the messages DENSE FOG, FOG AHEAD, and AREAS OF DENSE FOG found that the messages DENSE FOG ($M = 1.75$) and FOG AHEAD ($M = 1.86$) were ranked as more effective than AREAS OF DENSE FOG ($M = 2.39$), $\chi^2(4) = 42.55$, $p < 0.001$. A comparison of flooding messages revealed a clear preference for the message ROAD FLOODED ($M = 1.25$), $\chi^2(4) = 119.68$, $p < 0.001$, as displayed in figure 18.



Source: FHWA.

Figure 17. Chart. Mean values for ice message rankings.

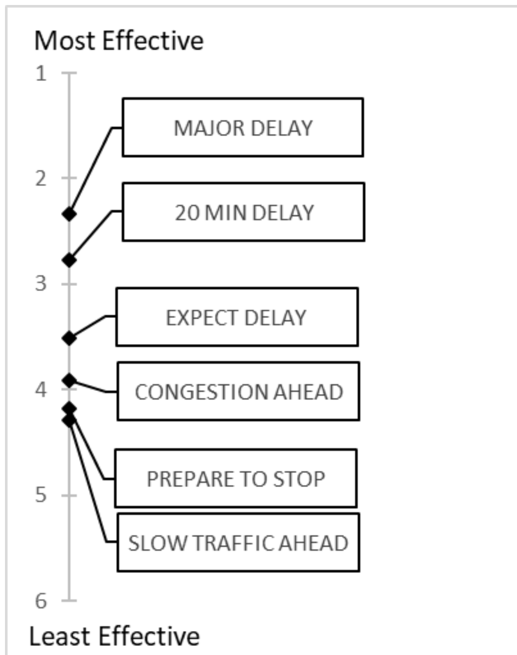


Source: FHWA.

Figure 18. Chart. Mean values for flood message rankings.

Effects of the Event

Messages designed to convey a road closure or delay in travel time were ranked. The messages ROAD CLOSED, ALL LANES CLOSED, and ALL LANES BLOCKED can be used to indicate that the road ahead is closed and cannot be driven on. When compared, the message ALL LANES CLOSED ($M = 1.62$) was ranked as more effective than ROAD CLOSED ($M = 1.90$), which was ranked as more effective than ALL LANES BLOCKED ($M = 2.48$), $\chi^2(4) = 114.4$, $p < 0.001$. Rankings of messages designed to indicate a delay in travel time are displayed in figure 19. The messages MAJOR DELAY and 20 MIN DELAY were ranked as more effective than any of the other messages, $\chi^2(25) = 224.4$, $p < 0.001$.

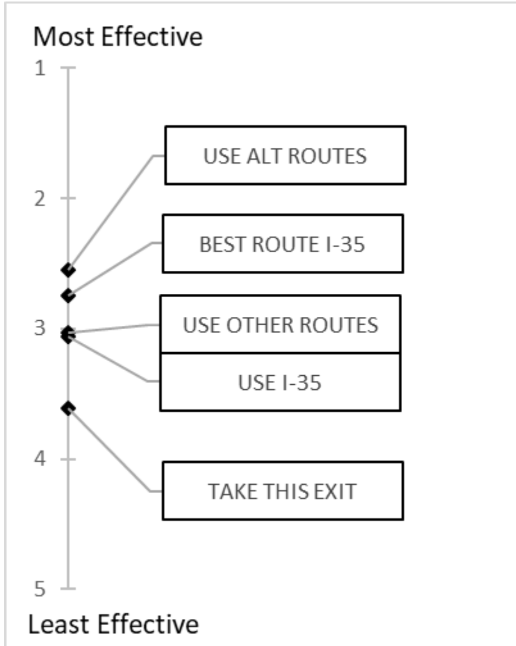


Source: FHWA.

Figure 19. Chart. Mean values for delay message rankings.

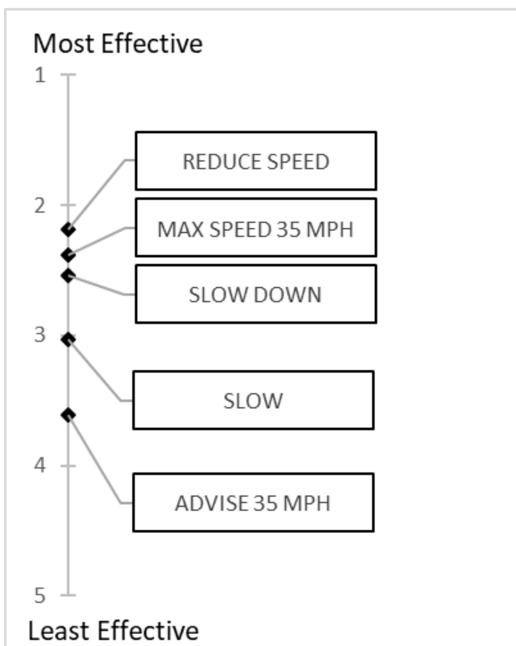
Suggested Actions

Messages suggesting that drivers reroute or reduce their speed were ranked. Figure 20 displays the rankings of messages designed to advise vehicles to take an alternate route. Significant differences were found between all messages except USE OTHER ROUTES and USE I–35, $\chi^2(16) = 113.08$, $p < 0.001$. Significant differences were found between the effectiveness of messages designed to advise drivers to reduce their speed, $\chi^2(16) = 293.75$, $p < 0.001$. As shown in figure 21, SLOW DOWN, REDUCED SPEED, and MAX SPEED 35 MPH were all ranked as more effective than SLOW, which was ranked as more effective than ADVISE 35 MPH.



Source: FHWA.

Figure 20. Chart. Mean values for reroute message rankings.



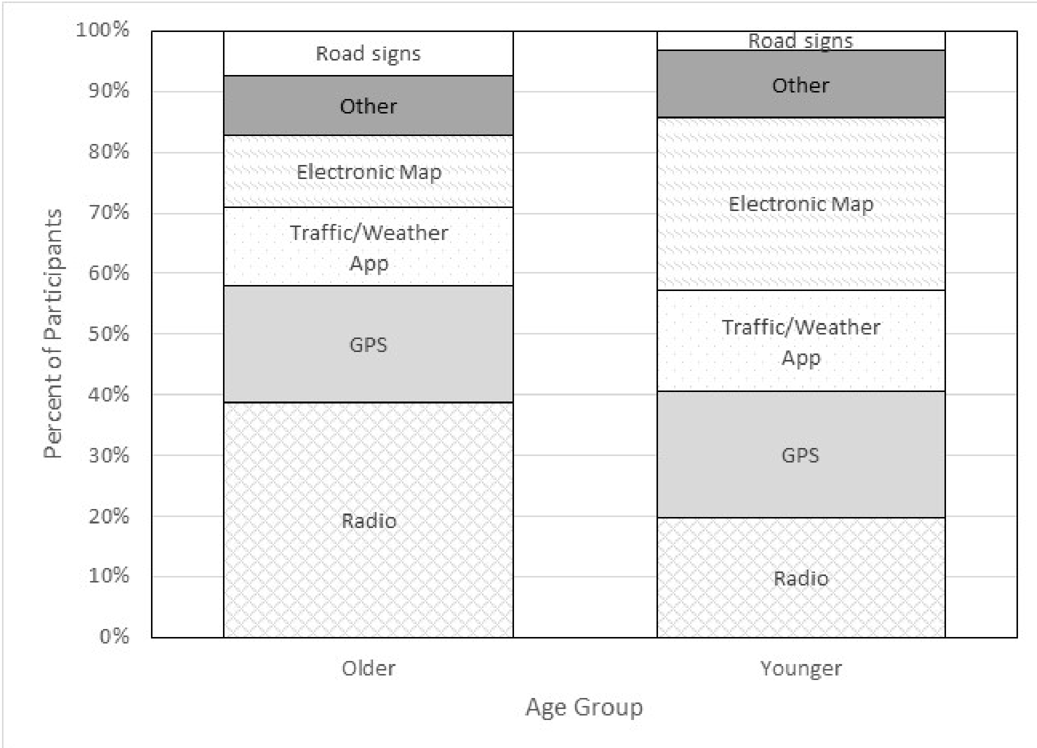
Source: FHWA.

Figure 21. Chart. Mean values for reduce speed message rankings.

Reported Experiences With Mid-trip Information

Participants ended the experiment by responding to questions about their personal use of mid-trip traveler information. Participants were asked to rate how often they seek mid-trip traffic information and how often they make specific changes to their travel plans in response to that information. Ratings were made on a scale from 1 (always) to 6 (never), such that smaller numbers indicated greater frequencies. Results showed that, on average, participants sought mid-trip traffic information more often when traveling on unfamiliar roads ($M = 2.35$) than on familiar roads ($M = 3.03$), $t(119) = 5.19$, $p < 0.001$. When asked how often mid-trip traveler information had caused them to switch to an alternate route of their own choosing, switch to an alternate route suggested by a VMS, or cancel their trip, participants reported that they switched to an alternate route of their own choosing ($M = 2.48$) more frequently than thy switched to a route suggested by a VMS ($M = 3.23$). Reports of canceling a trip in response to mid-trip traveler information were rare ($M = 5.08$), $F(1, 119) = 1{,}796.37$, $p < 0.001$. Participants who were 46 years old and over ($M = 2.97$) reported having switched to a route suggested by a VMS more frequently than 18–45 year old participants ($M = 3.49$), $F(1, 118) = 4.04$, $p = 0.047$.

Participants' primary source of mid-trip traveler information influenced how frequently they sought out that information when traveling in unfamiliar areas, $\chi^2(5) = 12.11$, $p = 0.033$. Participants who reported using electronic maps reported seeking mid-trip information most frequently ($M = 1.78$), whereas participants who reported using road signs reported seeking mid-trip traveler information least frequently ($M = 3.40$). Participants' primary source for mid-trip traveler information was also influenced by participant age group, $\chi^2(5) = 16.32$, $p = 0.006$. As shown in figure 22, radio was the most frequently reported source of traveler information among older participants, whereas younger participants reported using electronic maps most often.

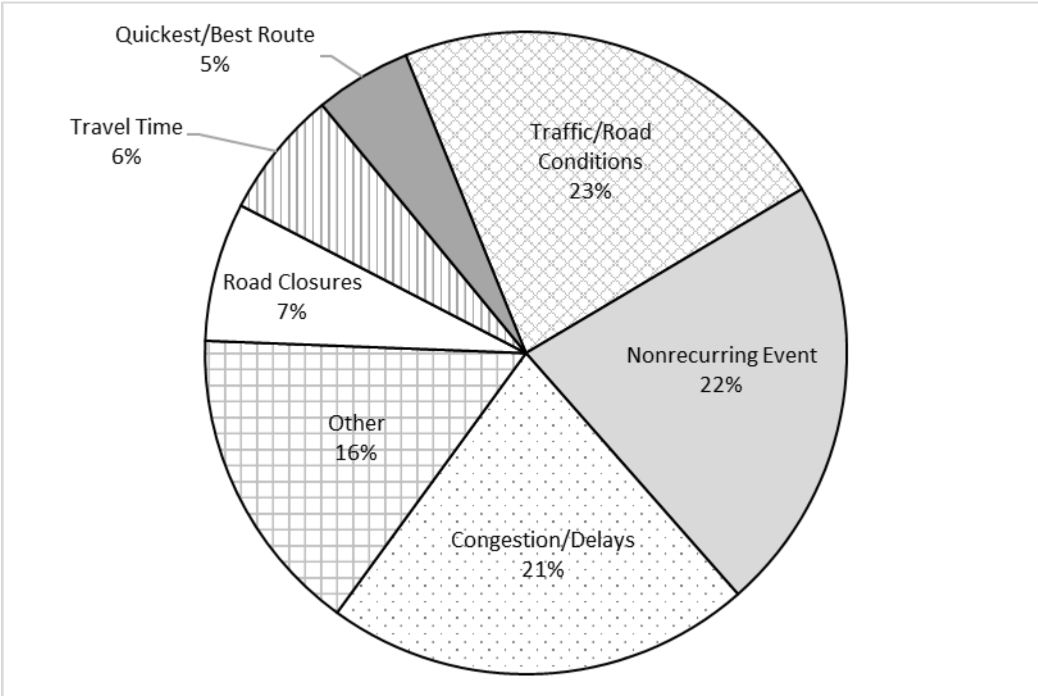


Source: FHWA.

Note: Younger participants were 18–45 years old; older participants were 46 years old and over.

Figure 22. Graph. Primary source of mid-trip traveler information among older and younger participants.

The open-ended question "What specific information do you try to obtain/think is most valuable to obtain while you are traveling?" assessed the type of information participants find most valuable mid-trip. Trained coders, who were blind to condition, categorized each response. Responses that fell within multiple categories were counted multiple times. Categories that contained less than 5 percent of responses were combined into a single "other" category. Figure 23 displays the percentage of responses that fell within each category. As with pretrip information, approximately half of the responses indicated a desire to obtain general information on traffic or road conditions and nonrecurring events such as crashes, construction, or weather. Travelers seeking traveler information mid-trip were also highly interested in congestion or delays along their route.



Source: FHWA.

Figure 23. Pie Chart. Mid-trip traffic information most sought or most valuable.

DISCUSSION

This experiment examined participants' responses to traveler information received mid-trip. Participants were shown a VMS that displayed various traveler information messages and were asked to report on the meaning of the sign and what they would do in response to the sign. Participants then rated the likelihood that they would switch to an alternate route and that they would continue on the current route in response to the VMS. Various components of the message were manipulated to assess the impact that each component had on message comprehension and route diversion ratings.

Overall comprehension of VMS messages was high, with over 90 percent of messages interpreted correctly. Nevertheless, some messages were more prone to misinterpretation than others. Specifically, the phrase RACE TRAFFIC was understood less often than other event phrases. Participants indicated that they were unfamiliar with this phrase, possibly because of the lack of race courses in the local area. Some participants suggested that a more neutral phrase, such as "event traffic," would be easier to interpret.

Another phrase that was misinterpreted by drivers was the location of event phrase 5 MILES. Some participants mistakenly believed that this phrase specified the length of the nonrecurring event rather than specifying the distance to the event. Adding the preposition IN to the beginning of the phrase (i.e., IN 5 MILES) or AHEAD to the end of the phrase could eliminate this confusion.

Of primary interest in experiment 2 was the way that participants would respond to specific traveler information messages encountered while driving. When asked to imagine encountering a sign while driving on a familiar road, the most common stated reaction was to change routes. Followup questions explored which components of the message were most likely to result in a decision to change routes. Several components of the message had an influence.

Diversion ratings were influenced by the specific nonrecurring event that was included in the VMS message. Messages with the events MUDSLIDE, RACE TRAFFIC, and BLACK ICE increased diversion ratings above those found when no event information was provided. Messages with location information also increased diversion ratings, but only for events that were already likely to lead to a change in route. This suggests that knowing the location of the event made participants who were considering changing routes based on the perceived severity of the nonrecurring event rate their likelihood of diverting even higher.

When the road ahead was closed, such that participants would be unable to continue on the current route, diversion ratings were near ceiling. The message MAJOR DELAY also resulted in a high likelihood of route diversion for events that were of medium severity (e.g., incident or water on road). The phrase MAJOR DELAY may increase the perceived impact of an event of medium severity, such that changes in driving behavior are perceived as more necessary.

The suggested action USE OTHER ROUTES led to large increases in diversion ratings across all event types. This finding is consistent with past research indicating that direct action requests are most likely to influence drivers.(24,30) The specific extent that USE OTHER ROUTES was found to increase diversion ratings was dependent on the amount of information contained in the message. Generally, the more ambiguous the message, that is, the fewer the number of phrases included in the message, the greater the impact of including USE OTHER ROUTES. In situations of uncertainty, drivers may be more reliant on suggested action phrases to determine whether they should change routes.

Messages that included the suggested action SLOW DOWN led to reduced diversion ratings. It is likely that drivers are only able to perform one action at a time, such that action requests that do not instruct a driver to change routes are likely to prevent route diversion. This may be especially true for the phrase SLOW DOWN, since the actions implied by this phrase are not compatible with route diversion. Specifically, SLOW DOWN implies that a driver should reduce speed and pay close attention to potentially hazardous conditions on the current roadway. If drivers comply with this request and pay close attention to the current roadway, then they are less likely to devote attention toward other potential routes, and diversion would be less likely.

Signal words had small and inconsistent impacts on the likelihood of changing routes. Previous guidelines have advised against adding signal words such as WARNING to the beginning of messages, as they were judged to increase the time required to read the sign without influencing behavior.(37) The current findings expand on these guidelines by demonstrating that if the purpose of the message is to encourage drivers to seek alternate routes, then both WARNING and USE CAUTION are likely to be counterproductive.

When participants were asked to rank the effectiveness of different VMS message phrases, some general trends were seen. For both crashes and delays, including the word “major” in the phrase (i.e., MAJOR DELAY/MAJOR CRASH) was seen as increasing the effectiveness of the message. For weather events, messages that indicated that a weather condition was possible rather than definite (i.e., FLOODING POSSIBLE/POSSIBLE BLACK ICE) or that the event may only be occurring in some areas (i.e., ICY SPOTS/AREAS OF DENSE FOG) were seen as less effective. It seems that drivers prefer messages that declare information about the actual state of the current roadway over messages that provide speculative information about portions of the road network.

When asked about how they used mid-trip traveler information, participants reported seeking information about road conditions, nonrecurring events, and delays with approximately equal frequencies. Older participants indicated that the radio was their most frequent source of mid-trip traveler information, whereas younger participants used electronic maps most frequently. Participants who used electronic maps as their primary source of mid-trip traveler information reported utilizing the information most often. The increased availability and use of electronic maps is likely to increase the rates at which travelers obtain traffic information mid-trip.

CHAPTER 4. EXPERIMENT 3: RESPONSES TO VMS MESSAGES IN A DRIVING SIMULATOR

INTRODUCTION

Experiment 2, described in chapter 3, examined the effect that different types of traveler information received mid-trip, have on participants' stated preference for taking an alternate route. Experiment 3, discussed in this chapter, used a driving simulator to expand on these findings by examining changes in driving behavior that occur in response to different traveler information messages presented on an overhead VMS.

MUTCD puts forth standards regarding the amount of information that can be conveyed on VMSs.[14] To ensure readability, a sign may display no more than three units of information at one time. This limit helps to ensure drivers can read and process the message without undue distraction from the primary driving task. The amount of information that can be displayed on a VMS can be increased with a two-phase message—a sign that alternates between two different groups of messages. Two-phase signs provide drivers with more information, which may help them make appropriate travel decisions during a nonrecurring event. However, increasing the number of phases also increases the probability that a driver may miss some of the information. Therefore, it is unclear if the extra information presented in a two-phase message will produce a net benefit in traveler behavior when drivers are required to process information from both phases while driving. The current experiment sought to address this question by comparing responses to a one- and two-phase sign as participants drove on a simulated roadway.

Another question of interest is how well drivers comply with explicit action requests on VMSs. In experiment 2, the suggested action USE OTHER ROUTES was one of the messages most effective at increasing the likelihood that participants would switch to an alternate route. That result suggested that drivers are willing to comply with suggested actions displayed on VMSs. However, additional research is needed to verify this result. First, experiment 2 assessed how participants indicated they would respond to different VMS messages. However, actual compliance rates tend to be less than those found in stated preference surveys.[29] Assessing actual changes in route choice within a driving simulator provides a more stringent assessment of compliance. Additionally, experiment 2 was only able to assess the likelihood that participants switched to an alternate route. It is unclear whether this same level of compliance would be found for other suggested actions, such as SLOW DOWN. Experiment 3 addressed these questions by examining changes in driving behavior after exposure to VMSs that display the suggested actions SLOW DOWN and USE OTHER ROUTES.

Finally, experiment 3 assessed the effect of VMS messages on driving speed. One concern regarding VMS messaging is that drivers may slow down when approaching a VMS to read its contents, particularly if the sign contains a large amount of information or multiple phases.[38] Drivers who slow down while approaching a VMS could create a traffic bottleneck and become a safety hazard.[39] Experiment 3 measured changes in driving speed that occurred as the VMS message became legible for both one- and two-phase messages.

METHOD

This section describes the details of the methodology used in experiment 3, including the participants who took part in the study, the equipment used, and the experimental design and procedure.

Participants

Participants were 120 licensed drivers from the greater Washington, DC, metropolitan area. All drivers were over the age of 18, and none had participated in the previous experiment. Half of the participants were 46 years old or over, and half were 18–45 years old. Each age group had an equal number of male and female participants.

Apparatus

The study was conducted using the FHWA Highway Driving Simulator. The simulator consists of a compact sedan mounted on a 6-degree-of-freedom motion base surrounded by a 200-degree portion of a cylinder with a radius of 8.7 ft. Directly in front of the driver, the design eye point of the simulator is 8.5 ft from the screen. Three projectors, with resolutions of 4,096 × 2,400 pixels each, project stimuli onto the screen.

Experimental Design

Experiment 3 assessed drivers' responses to messages on an overhead permanent VMS. Drivers encountered one of the five following messages:

1. RACE TRAFFIC / LEFT LANE CLOSED / USE OTHER ROUTES.
2. RACE TRAFFIC / 5 MILES / LEFT LANE CLOSED / USE OTHER ROUTES.
3. WATER ON ROAD / 5 MILES / SLOW DOWN.
4. WATER ON ROAD / 5 MILES.
5. No message (control condition).

Message 1 was a one-phase message. Message 2 was a two-phase message that displayed each phase for 4 s. A comparison of responses to messages 1 and 2 was used to assess the effects of two-phase messages on drivers' behavior. A comparison of messages 3 and 4 assessed drivers' compliance with requests to reduce speed. The final sign, which displayed no information, served as a baseline to which the other messages could be compared.

Traffic density was also manipulated such that half of the participants experienced light traffic (175 vehicles per lane per hour), and half of the participants experienced heavy traffic (268 vehicles per lane per hour). Traffic traveled in both lanes, and traffic behavior did not vary as a function of message type.

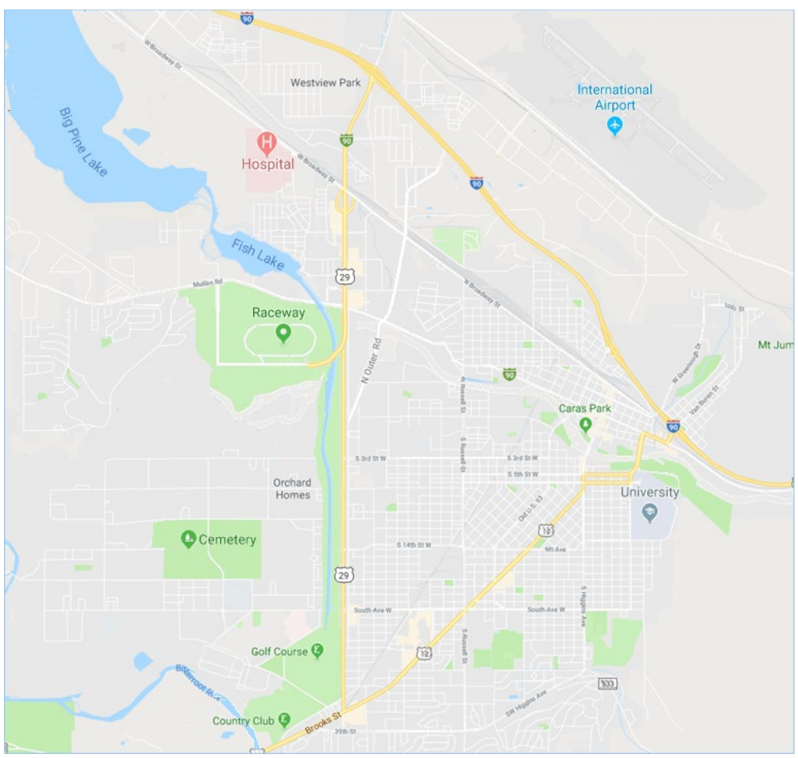
Dependent variables were the proportion of participants who took the exit to the alternate route, driving speed, and the location of lane changes.

Procedure

Participants first provided informed consent and displayed a valid driver's license. A Bailey-Lovie eye chart was used to verify a minimum of 6/12 (20/40) visual acuity, with correction if necessary. Participants then completed the simulator sickness questionnaire (SSQ) to provide a symptoms baseline.

Next, participants completed a brief practice drive to become familiar with the simulator. During the practice drive, participants were asked to accelerate, brake, change lanes, and exit the highway to become comfortable with the speed and steering dynamics of the simulated vehicle. After completing the practice drive, participants exited the vehicle and completed the SSQ a second time.

Participants were then shown a map of a fictional city that contained the simulated roadway (see figure 24). Participants were asked to identify the university and the country club on the map and trace a route between them. Then, to emphasize that locations can be reached using multiple routes, participants were asked to trace an alternate path between the locations. Next, participants were told that in the current experiment they would be driving from the golf course to the hospital and were given a moment to study the map. As shown on the map, the most direct route between the two points is to travel north on Route 29 until W Broadway. However, as an alternate route, participants would also be able to reach their destination by exiting the highway and driving on North Outer Road. Participants were asked to drive as they typically would and obey all traffic laws.



Original Photo: © 2018 Google® (see Acknowledgments section).

Figure 24. Map. Fictional city containing the simulated roadway.[40]

Next, participants completed the experimental scenario. Participants began the simulation in the left lane of a four-lane divided highway with a speed limit of 65 mi/h. Other roadways were visible from the main route to make the route appear as though it was part of a larger roadway system that could provide multiple routes to the destination. Within the vehicle's center console, a simple GPS displayed the roadway system and tracked the vehicle location along the roadway. After traveling on the roadway for 4 mi, participants encountered an overhead VMS. The specific message displayed on the VMS was manipulated such that an equal number of participants viewed each of the five VMS messages: (1) RACE TRAFFIC / LEFT LANE CLOSED / USE OTHER ROUTES, (2) RACE TRAFFIC / 5 MILES / LEFT LANE CLOSED / USE OTHER ROUTES, (3) WATER ON ROAD / 5 MILES / SLOW DOWN, (4) WATER ON ROAD / 5 MILES, or (5) no message.

An exit was located 2 mi downstream from the VMS, and standard exit signs preceded the exit. The exit led to a two-lane, undivided arterial road that traveled perpendicular to the highway. Between 10 and 15 percent of the other vehicles traveling on the roadway took the exit. For participants that chose to take the alternate route, the simulation ended once they reached the end of the exit. Participants that chose to continue down the highway encountered a lane reduction and the specific nonrecurring event mentioned on the permanent VMS (race traffic or water on road). Participants who viewed a blank sign (the control condition) encountered water on the road. Once participants passed the nonrecurring event, the simulation ended.

After completing the scenario, participants completed a brief questionnaire about the drive. Specifically, participants were asked to rate their stress level during the drive on a scale from 1 to 6, where 1 indicated low stress and 6 indicated high stress. Each participant's memory of the VMS message was also tested. Participants then rated how frequently they encountered VMSs and how accurate the information on VMSs is on a scale from 1 to 6, where 1 indicated lower frequency of viewing VMSs and lower sign accuracy, and 6 indicated greater frequency and greater sign accuracy.

After completing the questionnaire, participants completed a legibility drive to determine a maximum legibility distance for each participant. The scenario used for this drive was the same as that used during the larger experiment except that a novel VMS message was displayed for the majority of participants. In this modified method of limits, participants were asked to drive slowly toward the VMS and stop as soon as they could read the VMS message, with the goal of trying to read the message from as far away as possible. When participants reached their maximum legibility distance, they were asked to place the vehicle in park, and the distance was recorded. Owing to a technical error, 11 participants viewed message 3 during both the experimental and legibility drives. A comparison of maximum legibility distances found no significant difference between those participants who viewed the same sign ($M = 0.23$ mi) and those who viewed a novel sign ($M = 0.21$ mi), $t(12) = 1.07$, $p = 0.30$.

Analysis

GEE models were used to test the associations between variables. All independent variables were included in the initial model. Insignificant effects were removed, and the models were rerun until the remaining effects were all significant.

RESULTS

This section presents the findings for experiment 3, including use of the alternate route, lane changes, and driving speed during the experimental drive. Participants' responses to the post-drive questionnaire are also presented.

Alternate Route Usage

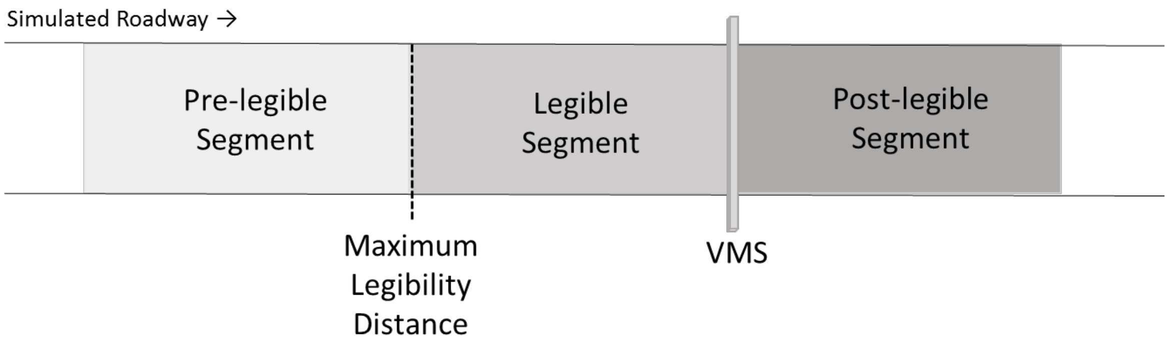
The first question of interest in experiment 3 was what effect VMS messaging would have on the frequency with which participants took the alternate route. None of the participants took the alternate route. The absence of alternate route taking across all 120 participants suggests this behavior was a product of the experimental procedure itself rather than any specific VMS messages. Possible reasons for the result are expanded on in the discussion section of this chapter.

Lane Changes

In addition to the suggested action USE OTHER ROUTES, both VMS messages 1 and 2 displayed the message LEFT LANE CLOSED. Since participants began the simulation in the left lane, moving to the right lane could also be considered an action that complied with the VMS message. To assess this, the proportion of drivers who switched from the left lane to the right lane was assessed as a function of VMS message during the 2 mi following the VMS sign. However, no significant effects were found.

Driving Speed

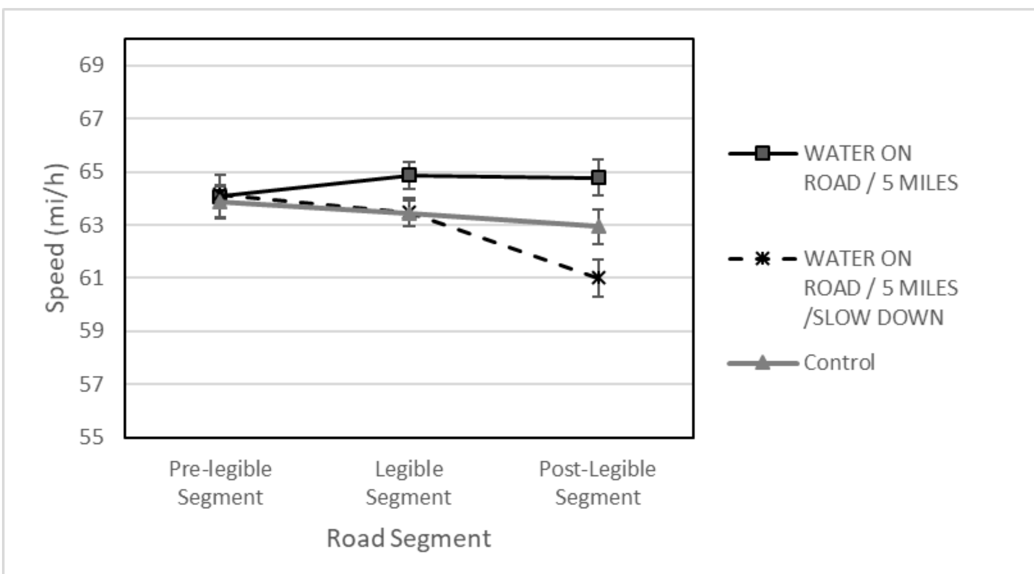
To assess the effect of VMS messages on driving speed, the roadway was sectioned into three equal segments (see figure 25). This was done individually for each participant, so that each segment was equal to the maximum legibility distance found during that participant's legibility drive. The pre-legible segment was defined as the portion of roadway just prior to the point at which the VMS message became legible. Driving behavior during this section of the roadway served as a baseline to which the other two segments could be compared. The legible segment was defined as the area of roadway between the maximum distance at which that participant could read the VMS message and the VMS itself. This segment represented the portion of roadway during which participants could read the VMS message. Changes in driving behavior during this roadway section would be suggestive of distraction by the VMS. Finally, the post-legible segment was defined as the portion of roadway just following the VMS sign. Changes in driving behavior during this roadway section would suggest a driver is responding to the VMS message.



Source: FHWA.

Figure 25. Illustration. Roadway segments.

To assess compliance with the VMS message SLOW DOWN, speed was assessed as a function of road segment for messages 3, 4, and 5. Both an effect of road segment, $\chi^2(2) = 12.39$, $p = 0.002$ and a marginally significant effect of VMS message were found, $\chi^2(2) = 5.75$, $p = 0.056$. As displayed in figure 26, these effects were qualified by a significant VMS message by road segment interaction, $\chi^2(4) = 15.11$, $p = 0.005$. Post hoc tests indicate a significant reduction in speed from the pre-legible segment to the post-legible segment in response to the message that included the phrase SLOW DOWN. This reduction in speed was not found in response to the WATER ON ROAD message that did not instruct participants to slow down or when the VMS was blank.



Source: FHWA.

Figure 26. Graph. Mean participant speed as a function of road segment and VMS message condition.

The extent that participants reduced speed while reading the VMS was assessed by comparing driving speed during the legible segment for messages 1, 2, and 5. No significant differences in speed were found, $\chi^2(2) = 0.13$, $p = 0.939$. Speeds for message 2, which included two phases

(M = 63.31 mi/h), were nearly identical to those found for message 1, which included only one phase (M = 63.06 mi/h), and message 5, which did not include any message (M = 63.32).

Across all road segments and VMS message conditions, older (46 years old and over) participants (M = 62.94 mi/h) tended to drive more slowly than younger (18–45 years old) participants (M = 64.30 mi/h), $\chi^2(1) = 6.19$, $p = 0.013$. Traffic level also influenced travel speed, $\chi^2(1) = 4.33$, $p = 0.037$. Participants in the heavy traffic condition (M = 63.06 mi/h) drove more slowly than participants in the light traffic condition (M = 64.19 mi/h).

Post-drive Questionnaire

Post-drive stress levels were assessed on a scale of 1 to 6, where lower numbers represented lower stress, and higher numbers represented greater stress. Overall stress levels were low (M = 1.58). Stress did vary significantly as a function of VMS messages, $\chi^2(4) = 12.13$, $p = 0.016$. As displayed in table 12, stress ratings were highest for participants in the control condition who did not see a VMS message.

Table 12. Mean stress ratings as a function of VMS message.

Message Number	VMS Message	Mean Stress Rating
1	RACE TRAFFIC LEFT LANE CLOSED USE OTHER ROUTES	1.48
2	RACE TRAFFIC 5 MILES LEFT LANE CLOSED USE OTHER ROUTES	1.29
3	WATER ON ROAD 5 MILES SLOW DOWN	1.75
4	WATER ON ROAD 5 MILES	1.42
5	No message	2.00

An assessment of participants' post-drive memory of the VMS message required participants to type out the message that had been displayed on the VMS sign during their drive. Response were coded on a three-point scale as either completely correct, partially correct, or incorrect. Recall was higher for participants in the light traffic condition (M = 1.75) than for participants in the heavy traffic condition (M = 1.46), $\chi^2(1) = 4.46$, $p = 0.035$.

Participants were also asked to rate how frequently they encounter VMSs while driving and how accurate they feel the information on those signs is on a scale from 1 to 6, where 1 indicated lower frequency of viewing VMSs and lower sign accuracy, and 6 indicated greater frequency and greater sign accuracy. Mean frequency of encountering VMSs was 3.35 (midway between low and high frequency), and the accuracy of the signs was rated as 4.56 (moderately high feelings of accuracy). Ratings did not vary as a function of gender or age.

DISCUSSION

This experiment examined participants' responses to traveler information presented on a VMS while driving on a simulated highway. Participants traveling in either a heavy or light traffic environment passed beneath a VMS that presented information about a nonrecurring event on the road ahead. The specific message presented was manipulated to examine the effect of VMS messaging on driving behavior.

Participants complied with the VMS message SLOW DOWN by reducing speed after passing a VMS that displayed this message. That this reduction in speed was found only for the message WATER ON ROAD / 5 MILES / SLOW DOWN and not for the message WATER ON ROAD / 5 MILES indicates participants reduced speed because the VMS instructed them to do so and not because of the potential safety implications of the message WATER ON ROAD. The result highlights the value of including specific action suggestions within VMS messages, particularly as drivers may have limited time and resources for drawing safety inferences while driving.

Past research has been split regarding the potential for VMS messages to lead to reductions in driving speed. Harder found reductions in speed at the point at which a VMS message becomes legible.(41) Similar reductions in speed were found by Erke, Sagberg, and Hagman and by Jamson, Tate, and Jamson but only for VMS messages that included four lines of text, which is a length of message not endorsed by MUTCD.(38,39) Experiment 3 compared driving speed for both a one- and two-phase message and found no reduction in driving speed. The results are consistent with the findings of Inman, Bertola, and Phillips, who found no reduction in driving speed for VMS messages that follow MUTCD recommendations.(13) Data from the post-drive questionnaire provide further input into this finding. Participants in the heavy traffic condition had reduced memory for VMS messages relative to participants in the light traffic condition. One explanation for these results is that participants who were faced with the need to attend to both high levels of traffic and the VMS message may choose to prioritize attending to traffic rather than allowing attention to the VMS message to change their driving performance. However, this interpretation should be taken with caution, as the reduced memory of this group could also be a result of differences in memory decay as a result of the increased time required to complete the drive in the heavy traffic condition.

Post-drive questionnaire data found an effect of VMS message on ratings of the stressfulness of the drive. Specifically, participants who saw a blank VMS reported higher stress. This finding is consistent with past research indicating drivers value VMS information even when they do not make any direct changes to their driving behavior as a result of the information.(9,10,17) For example, participants in a focus group on VMS messaging conducted by Lerner et al. indicated that seeing information on VMSs reduced frustration by removing uncertainty, such that even when the information displayed was not positive (e.g., indicated a long delay), it was considered useful.(9) Experiment 3 expanded on this finding by providing a quantitative measure of the effect of VMS messaging on stress levels.

In experiment 2, participants indicated a strong intent to comply with VMS messages with the suggested action USE OTHER ROUTES. Of interest in experiment 3 was the effect this messaging would have on driver behavior in a driving simulator environment and, specifically, whether compliance with the suggested action would vary depending on whether that request was part of a one- or two-phase VMS message. To make this assessment, a comparison of the proportion of drivers who took the exit in each VMS message condition was intended. However, none of the 120 participants who completed the experiment took the exit. The complete lack of compliance across all conditions suggests that participants' reluctance to exit was a product of the experimental procedure itself rather than a result of any one specific VMS message.

Attempts to encourage participants to view the exit as a viable option were made, first by having participants take an exit as part of the practice drive, second by having them trace two routes to a location on the map of the simulated driving area, and third by having 10–15 percent of the other vehicles traveling on the roadway take the exit. However, these procedures did not seem to have been sufficient. The reason for this reluctance could stem from several sources. First, it is known that the actual rate at which drivers take an alternate route as suggested by a VMS in the absence of a complete road closure is often quite small.[10] In fact, when similar signage was used on a Virginia highway, Schroeder and Demetsky found diversion rates of only 8.7–9.5 percent.[30] Reluctance to take an alternate route is particularly low among drivers who are driving in an unfamiliar area.[17–19] Although participants in experiment 3 were given a chance to study a map prior to their drive to help familiarize them with the area, participants only actually drove through the route one time. Future studies of this nature should consider having the participant drive the simulation route a few times under normal traffic conditions prior to completing the critical drive that includes the nonrecurring event and accompanying VMS message.

CHAPTER 5. CONCLUSIONS AND RECOMMENDATIONS

Nonrecurring events represent a departure from the typical travel situation that temporarily changes the capacity or travel time reliability of a roadway. Nonrecurring events, such as traffic incidents, roadwork, severe weather, and planned special events, can lead to unexpected and often substantial delays. Providing travelers with information can enable them to make appropriate changes to their travel behavior to avoid the delays and potential safety risks associated with the nonrecurring event. The literature on traveler information has identified several mediums for information dissemination both before and during a trip; however, the specific messages most likely to result in desired traveler behavior change are less well understood.

The following three experiments examined the effect traveler information messages have on travel decisions and behaviors during nonrecurring events:

- Experiment 1 examined participants' stated responses to traveler information messages received pretrip.
- Experiment 2 assessed reported reactions to messages received mid-trip on a VMS.
- Experiment 3 evaluated changes in simulated driving behavior after receiving traveler information on an overhead VMS within a driving simulator.

The findings from these experiments offer insight into the messaging that is likely to be effective in changing drivers' behavior and allow for recommendations on constructing messaging for nonrecurring events.

First, the current study highlights the value of traveler information during nonrecurring events. Dissemination of traveler information is intended to allow the public to make better driving decisions.[3] Use of traveler information can lead to reductions in travel times, particularly during nonrecurring events, when travelers most value the information.[3,26] However, even drivers who do not change their behavior in response to traveler information still report that they like receiving the information and consider it useful.[9,10,17] The current set of experiments provides a possible explanation for this finding. In experiment 3, participants who received any traveler information prior to encountering a nonrecurring event reported less stress during their drive than those drivers who did not receive information. Traveler information seems to reduce the potential frustration associated with driving during nonrecurring events. As a result, even drivers who are unable or unwilling to make changes in their driving behavior still benefit from receiving the information.[9]

The study also demonstrated evidence of a possible change in the way drivers are obtaining traveler information. Previous research has long noted radio as the primary sources of traveler information. (See references 1–4.) In the current study, radio was cited as the primary information source by older participants (46 years old and over). However, among younger participants (18–45 years old), electronic maps were cited as the primary source of both pretrip and mid-trip information. Further, participants who reported utilizing electronic maps as their primary source of information also reported higher rates of seeking out traveler information than those who relied on other information sources. This shift in how drivers are choosing to gather travel information has implications both for travel information dissemination and driver safety.

Traveler information provided on a VMS was able to be received without any reduction in driving performance. Harder found that under some circumstances drivers reduce speed in order to read VMSs, a behavior that could be a potential safety hazard to other drivers.(41) However, in experiment 3, no reductions in speed were found during the time when the VMS message was legible, even when traffic levels were high and participants encountered a two-phase message. This result is consistent with previous work indicating that VMS messages that comply with MUCTD regulations for information content do not impair driver performance.(13) When conveyed appropriately, traveler information provides its benefits with minimal risk.

One of the main goals of this set of experiments was to determine the specific traveler information messages most likely to encourage drivers to make appropriate changes to their travel behavior. Examination of participants' responses to different pieces of traveler information suggests that whether drivers will change their behavior in response to traveler information depends at least in part on the perceived severity of the nonrecurring event's impact on their travel plans.

ROAD CLOSED

Nonrecurring events that have the most severe impact on travel plans are those that result in a road closure. When a road is closed, it is necessary for all travelers who intend to use the road to change their travel plans. The findings from experiment 2 suggest that seeing the message ROAD CLOSED on a VMS is sufficient to encourage changes in driving behavior. Higher diversion ratings were found in response to this message than in response to any other single unit of information tested. In fact, diversion ratings were near ceiling, such that additional information about event type or suggested actions provided little additional impact on reported responses. When participants were asked to rate different road closure messages based on their effectiveness, messages that used the term "closed" (i.e., ROAD CLOSED or ALL LANES CLOSED) were rated as more effective than those that used the term "blocked" (i.e., ALL LANES BLOCKED). When a nonrecurring event results in a road closure, it is recommended this information be prioritized at the top of the message, and, to prevent ambiguity, the message should include the word "closed."(8)

SUGGESTED ACTION

Providing travelers with a suggested action is an effective way of encouraging that action.(24,29,30) This finding, prominent in both pretrip and mid-trip traveler information research, was confirmed in this study. In experiment 2, including the phrase USE OTHER ROUTES significantly increased the reported likelihood of selecting an alternate route. This effect was found for all event types, but the increase in alternate route selection was particularly large when the amount of other information provided on the VMS was low, such as when the message did not contain information about the effect of event. When the potential implications of a nonrecurring event are ambiguous or the amount of traveler information able to be provided is limited, including a suggested action within a traveler information message can help fill the information gap by providing drivers with a specific action plan.

The effectiveness of suggested actions was also seen in experiment 3. When the traveler information message WATER ON ROAD was also accompanied by the suggested action SLOW DOWN, participants significantly reduced their speed after viewing the message. Changes in speed were not seen when the suggested action was not included in the message. The results indicate that the speed reduction was in response to the suggested action and not to the potential impact of the nonrecurring event on the roadway. When faced with information about a nonrecurring event, drivers must first decide on and then execute an appropriate action. However, when information is received mid-trip, this decision making process must compete with the cognitive demands associated with driving. By specifying the change in behavior that is most appropriate for the current nonrecurring event, suggested actions allow drivers to bypass the decision making process, thus making action execution more likely.

EVENT TYPE

Drivers perceive some nonrecurring events as more severe than others. Event type is likely to impact traveler behavior if that event is perceived as likely to have a severe impact on the roadway. In experiment 1, the most frequently reported responses to pretrip information for four of the five tested event types were to leave early or take an alternate route. However, when exposed to information about severe weather, the most commonly reported response was to cancel the trip. Participants seemed to have one set of behavioral changes they would use in responses to information about most nonrecurring events. However, severe weather events prompted an additional, more substantial change in travel plans.

In experiment 2, only 3 of the 12 tested events increased participants' likelihood of selecting an alternate route beyond the ratings made when the nonrecurring event was not specified. Specifically, receiving information about a mudslide, race traffic, or black ice increased diversion ratings. In contrast, receiving event type information about less severe weather events (i.e., blowing dust or fog), roadwork (i.e., construction or roadwork), or incidents (i.e., incident or disabled vehicle) did not provide any event-specific increase in diversion ratings. The results suggest that event information affects travel plans only if the event itself is seen as severe.

The specific phrases used to relay event information can influence drivers' perception of event severity. For example, Ullman found that focus group participants perceived the phrase ROAD FLOODED as referring to a severe event in which the road was impassible because of flooding, whereas the phrase WATER ON ROAD indicated a less severe flooding event in which the road was still functional.[11] A similar result was found in experiment 2. The phrase ROAD FLOODED was rated as more effective in conveying an event that is impacting traffic than other phrases like FLOODING, STANDING WATER, or WATER ON ROAD. In addition, phrases that indicated an event was possible rather than definite (i.e., FLOODING POSSIBLE and POSSIBLE BLACK ICE) or that the event was only occurring in some areas (i.e., ICY SPOTS and AREAS OF DENSE FOG) were seen as less effective than similar phrases that did not include qualifiers. Using qualifying words when describing a nonrecurring event may reduce the perceived severity of that event and thus reduce the likelihood of behavioral change.

When attempting to decide whether to include event information in a traveler information message, one should assess whether the specific event being reported would either be perceived as having a severe impact on travel plans or whether the event alone would help inform drivers about the specific action that would be appropriate. In the case of weather events, the answer to both questions is likely to be yes. Event phrases 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 wind may not increase route deviation rates but does suggest a valid reason for making other changes to one's travel behavior, such as reducing 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.

Specifying event type is likely to be less crucial for events that are perceived as less severe or that do not provide information about the specific change in behavior that is required. 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 should react similarly to a lane closed for pavement repair and a lane closed because of a disabled vehicle. In this situation, knowing that the lane is closed is more critical than knowing the source of the lane closure. In such instances, it is recommended that the effect of event information be prioritized over the event type.

MAJOR

If drivers do not inherently perceive a nonrecurring event as severe, adding adjectives to describe the severity of the impact of the event may increase the likelihood that drivers make changes in their behavior. In experiment 2, participants reported an increased likelihood of changing routes after viewing VMS messages that included the phrase MAJOR DELAY compared to messages that did not include this phrase. The impact of adding MAJOR DELAY to a message was particularly effective for nonrecurring events perceived as somewhat severe (i.e., construction, incident, and water on road). Further, the benefit of including the suggested action phrase USE OTHER ROUTES was reduced for VMS messages that already included the phrase MAJOR DELAY, suggesting that MAJOR DELAY may be a useful alternative to providing a suggested action in cases where advising a specific action is not desirable.

The potential effectiveness of the adjective MAJOR is also suggested by the portion of experiment 2 in which participants were asked to rate the effectiveness of different VMS phrases. MAJOR CRASH was rated as more effective than CRASH or TRUCK CRASH. Similarly, MAJOR DELAY was rated as more effective than any of the other messages meant to indicate the presence of a delay and was rated as similarly effective as 20 MIN DELAY. Dudek and Ullman maintain that the inclusion of the word MAJOR in a VMS phrase (i.e., MAJOR ACCIDENT or MAJOR DELAY) implies the associated delay will be 45 min or more.(8) While the current study cannot verify how the adjective is quantified by drivers, the findings do suggest that adding MAJOR to a VMS phrase can increase the perceived severity of a nonrecurring event and thus increase the likelihood of behavioral change.

SIGNAL WORDS

In contrast to the adjective MAJOR, including signal words such as WARNING or CAUTION in a VMS message did not increase the perceived severity of the message in a way that consistently influenced driver behavior. In experiment 2, including WARNING or USE CAUTION in a VMS message had an inconsistent effect and did not increase diversion ratings. It is recommended that signal words not be included in VMS messages, as they increase the time required to read a message but do not lead to increases in behavioral change.

LOCATION

Location information allows drivers to understand where an event is occurring and gauge their opportunity for making behavior changes before reaching the event. While this information does not always influence driver behavior, drivers tend to report valuing location information.[34,35] In experiment 2, location information increased diversion ratings for severe events. Nevertheless, some participants misinterpreted the location phrase 5 MILES to indicate the length or span of the nonrecurring event rather than specifying the distance to the event. When a location phrase is used to indicate the distance to a nonrecurring event, adding the preposition IN to the beginning of the phrase (e.g., IN 5 MILES) could eliminate this potential confusion.

CONCLUSION

Past research on traveler information has produced a fairly robust understanding of both how traveler information can be distributed and when traveler information is most needed. The current group of experiments found that the specific phrases used to convey traveler information can impact how likely travelers are to make appropriate changes in their travel behavior. Providing suggested actions and using phrases that convey a sense of the severity of the impact the nonrecurring event is having on the roadway can help encourage behavioral change.

APPENDIX A. TRIP PURPOSES FROM EXPERIMENT 1

In experiment 1, participants were asked to imagine they were traveling for a purpose that was of either high or low importance. This section lists the specific high- and low-importance trip purposes used in the experiment.

High-importance trips included the following:

- You are traveling to work on a day that you have an important presentation.
- You are traveling to meet with an important client to discuss a profitable business deal.
- You are going to see the farewell performance of your favorite band.
- After weeks of trying, you were able to get an appointment with a very exclusive medical specialist. You are going to see the specialist.
- You are going to a dentist appointment. You will be charged an expensive fee if you miss the appointment.
- You are going to a job interview for a position you really hope to get.

Low-importance trips included the following:

- You are shopping for a new outfit.
- You are traveling to picking up your dry cleaning.
- You are picking up dinner for your family.
- You are traveling to a friend's house to have coffee and visit.
- You are going to the mall to shop for a birthday gift for a family member.
- You need to pick up supplies for an upcoming trip that you have planned next month.

APPENDIX B. QUESTIONNAIRE ON TRAVELER INFORMATION USE

After completing the mid-trip portion of the study described in chapter 3, participants from experiments 1 and 2 answered questions about their own experiences with pretrip and mid-trip traveler information during the year prior to their participation in the experiments. This section provides a full list of the questions participants answered.

MID-TRIP QUESTIONS

Likert response: scale from 1 (always) to 6 (never):

- How often do you seek out information about traffic or road conditions after you have begun a trip when you are traveling on roads that are familiar to you?
- How often do you seek out information about traffic or road conditions after you have begun a trip when you are traveling on roads that you are not familiar with?

Open-ended response:

- What is/are your primary source(s) of traffic and road condition information while traveling?
- What specific information do you try to obtain/think is most valuable to obtain while you are traveling?

Likert response: scale from 1 (always) to 6 (never):

- Thinking back over the past year, how often did you switch to an alternate route of your choosing based on information that you obtained while traveling?
- Thinking back over the past year, how often did you switch to a route suggested by a variable message sign?
- Thinking back over the past year, how often did you cancel your trip and return to your point of origin based on information that you obtained while traveling?

PRETRIP QUESTIONS

Likert response: scale from 1 (always) to 6 (never):

- How often do you seek out information about traffic or road conditions before taking a routine trip?
- How often do you seek out information about traffic or road conditions before taking a nonroutine trip?

Open-ended response:

- What is/are your primary source(s) of traffic and road condition information while traveling?
- What specific information do you try to obtain/think is most valuable to obtain while you are traveling?

Likert response: scale from 1 (always) to 6 (never):

- Thinking back over the past year, how often did you leave earlier than initially planned?
- Thinking back over the past year, how often did you leave later than initially planned?
- Thinking back over the past year, how often did you take an alternate route?
- Thinking back over the past year, how often did you cancel or postpone your trip?
- Thinking back over the past year, how often did you switch to public transportation?

DEMOGRAPHIC QUESTIONS

- How many trips do you typically make in a week?
- How many miles do you travel on average per trip?

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The maps in figure 2, figure 3, and figure 24 were modified by the authors of this report. The original maps are the copyright property of Google® Earth™ and can be accessed from https://www.google.com/earth.[27,40] Figure 2 was modified to include a house and a star icon representing the starting and ending points of the trip. In figure 3, main routes were colored green, yellow, and red to indicate the level of traffic on that area of the roadway and a traffic cone, was added to indicate the location of roadwork. Figure 24 was modified to remove identifying information, add landmarks, and modify the road network, such that it was consistent with the roadway participants drove on in the simulator.

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