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MARYLAND DEPARTMENT OF TRANSPORTATION
STATE HIGHWAY ADMINISTRATION

RESEARCH REPORT

Potential Effects of Composition and Structure of Dynamic Message Sign Messages on Driver Behavior and Their Decision to Use Freeway Incident Traffic Management (FITM) Routes

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16. Abstract

In this study the research team reviewed the literature and best practices and then completed a comprehensive comparison of content, type, length of the message, and standards of dynamic message signs (DMSs) and their effect on driver behavior. The research team also investigated the potential effect(s) of various formats and content of DMS displays on driver's route choice and compliance behavior using a driving simulator and survey questionnaires. The diversion rate, a measure of the ability of the message(s) displayed to divert traffic in a given direction, of different message types was also investigated. A 155-square-mile (400-km^2) road network in Maryland was simulated, and different scenarios were considered. A total of 390 simulation runs were conducted by 65 participants from diverse socioeconomic backgrounds. Single-phase messages were always preferable to two-phase messages, as motorists could comprehend single-phase messages faster. Two-three units of information on a DMS led to an increase in overall speed while six-seven units of information led to a decrease in overall speed when approaching and passing a DMS. A route diversion analysis, a route choice analysis and a compliance analysis identified the different DMS that have a high likelihood of influencing these behaviors. Lane closure and delay information with advisory messages were found to be the most influential DMS regarding diversion. Color-coded DMS and *avoid route* advice were the top contributors to route choice decisions and DMS compliance. The pre/post simulation surveys and driving simulation results confirm the findings of the effectiveness of the color blind-friendly, color-coded DMS over the others. Interestingly, people who stated that they would choose their navigation system over a conflicting DMS message were the ones who complied with most of the advisory DMS in the absence of a navigation system in this study.

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Table of Contents

List of Figures

List of Tables

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Executive Summary

This study reviewed the literature and best practices and then completed a comprehensive comparison of content, type, length of the message, and standards of dynamic message signs (DMS) and their effect on driver behavior. The potential effect(s) of various formats and content of DMS displays on driver's route choice and compliance behavior using a driving simulator and survey questionnaires was also investigated. The diversion rate, a measure of the ability of the message(s) displayed to divert traffic in a given direction, of different message types was also investigated. A 155-square-mile (400-km^2) road network in Maryland was simulated, and different scenarios were considered. A total of 390 simulation runs were conducted by 65 participants from diverse socioeconomic backgrounds. Single-phase messages were always preferable to two-phase messages, as motorists could comprehend single-phase messages faster. Two-three of information on a DMS led to an increase in overall speed while six-seven units of information led to a decrease in overall speed when approaching and passing a DMS. A route diversion analysis, a route choice analysis and a compliance analysis identified the different DMSs that have a high likelihood of influencing these behaviors. Lane closure and delay information with advisory messages were found to be the most influential DMS regarding diversion. Color-coded DMS and *avoid route* advice were the top contributors to route choice decisions and DMS compliance. The pre/post simulation surveys and driving simulation results confirm the effectiveness of the color blind-friendly, color-coded DMS over the others. Interestingly, people who stated that they would choose their navigation system over a conflicting DMS message were the ones who complied with most of the advisory DMS in the absence of a navigation system in this study.

Introduction

Dynamic message signs (DMS), a component of Advanced Traveler Information Systems (ATIS), are electronic devices positioned either above or beside a roadway (Edwards & Young, 2009), to facilitate the efficient and timely transmission of information to road users. They are used for traffic control, traffic regulation, routing, warning and management. The goal is to influence driver behavior by providing traffic-related information in real time (Conrad L Dudek, 2008) and increase the efficiency of the transportation network (Balakrishna, Ben-Akiva, Bottom, & Gao, 2013). Figure 1 provides an example of DMS displaying information.

Figure 1. Picture of Dynamic Message Signs (Source: Anya, 2017)

A large variety of messages -- incident-management, advisory, diversion, special events, adverse road weather condition, speed control, construction, maintenance messages and safety campaign messages -- can be displayed (Conrad L Dudek, 1997). The messages are carefully worded and strategically positioned to elicit driving behavior that enhances the safety and efficiency of the transportation network.

Pictograms (e.g. a picture or symbol that represents a word or phrase) are increasingly being used on DMS. Richard & Jaisung (2009) found that even though most pictograms were easily understood, in cases of incident occurrence, less than 50% of study participants accurately comprehended the information displayed.

The use of DMS in the United States is widespread and 29 Departments of Transportation (DOT) of 29 states have written guidelines or policies on DMS design and operation (Conrad L Dudek, 2008). Despite their widespread use, the impact of DMS on driver behavior and safety has been questioned and researched by many (Jeihani & Ardeshiri, 2013; Richard & De Barros, 2010). Several studies (C. Dudek & Ullman, 2002; B. Ullman, Ullman, Dudek, & Williams, 2007; Wang & Cao, 2005) indicate that the type, form, length and phrasing of information presented directly affects drivers' level of comprehension. The level of comprehension influences various aspects of driver behavior, especially route choice and compliance. Since diversion compliance and route choice behavior, especially during inclement weather conditions or incident occurrence, are targeted uses of DMS, there is a need to study the impact of different message displays.

Few researchers have used driving simulators to perform DMS-related studies due to the lack of route choice capability; drivers are restricted to fixed predetermined routes. However, a comprehensive approach for the study of drivers' route choice behavior is feasible using suitably equipped driving simulators. Such simulators allow drivers to choose their routes and subsequently see information about alternate routes as trips are made between a given pair of

origin and destination. In addition, a driving simulator provides a controlled environment with realistic traffic and environmental scenarios, which is not possible in other research methods.

Literature Review

The impact of different DMS message types on driver behavior has been studied by researchers. The length of DMS displays as well as the presence of abbreviated and complex words in messages have been shown to cause traffic to slow down (Wang, Keceli, & Maier-Speredelozzi, 2009). However, another study by Haghani et al. (Haghani, Hamedi, Fish, & Nouruzi, 2013), showed a negligible speed reduction of about 3.1 mph (5 km/hr) in the presence of active DMS. The study results suggest that even though DMS can potentially cause speed reduction, the magnitude of the reduction is so small that its contribution to overall traffic congestion is negligible. Similarly, Jeihani et al (Ardeshiri & Jeihani, 2014) showed that drivers' speed reduction as they attempt to read quantitative DMS displays was insignificant even though an average speed reduction of 2.6 mph (4.3 km/hr) was observed in the study.

Other studies have investigated the diversion rate of DMS as well as the effect of DMS location and message displays on driver's route choice and compliance behavior. Peeta and Ramos (Peeta & Ramos, 2006) suggested that route diversion was strongly correlated with the DMS message content and the quantity of information provided. Horowitz et. al (Horowitz, Weisser, & Notbohm, 2003) reported that even though the majority of drivers in their study responded to traffic delay warnings and diverted to the suggested route, a subset of drivers ignored such warning messages and refused to divert. The result was consistent with that obtained by Xuan et. al (Xuan & Kanafani, 2014); some drivers stick to their pre-planned route choice regardless of the message displayed on DMS. Jeihani and Ardeshiri (Jeihani & Ardeshiri, 2013) concluded that compliance with DMS-based travel time guidance was not fully consistent with drivers' stated choices. This was consistent with the findings of another field-based study (Chatterjee, Hounsell, Firmin, & Bonsall, 2002). The authors did not find a comprehensive study of the potential effects of the content, structure, length, and type of message posted on the DMS.

Usage of DMS

The most common use of DMS are travel time, traffic incidents, road/ramp/tunnel closures, moveable bridge operations, construction and maintenance activities, emergency messages, missing persons, and law enforcement officer (LEO) alerts (VDOT, 2016). DMS may also be used to provide real-time traffic conditions, safety, and guidance information (NYSDOT.GOV, 2011).

Standard and portable dynamic message signs (PDMS) may be used to give motorists real-time traffic safety and guidance information about planned and unplanned events that significantly impact traffic on the state highway system (Lawrence Wooster, 2013). DMS usage for planned events includes DMS displays that notify the travelling public in advance of upcoming road maintenance operations or, inform drivers of work zones well before the work zone location.

The Virginia Department of Transportation (VDOT) has provided a list of acceptable DMS message displays for consistency and to help motorists understand and respond to messages. The guidelines also recommend that if any non-lane impacting message appears to be causing congestion immediately upstream of the sign, the sign should be blanked until the congestion clears.

In Virginia, improper/unconventional uses of DMS include generic congestion messages[1], advertising, public service announcements, contact information, date/time, and static signing. VDOT's changeable message sign guidelines (VDOT, 2016), hereafter referred to as VA-guideline, emphasize that before display on DMS, any questionable message or unusual circumstance should be directed to the appropriate Regional Operations Director (ROD) or Regional Traffic Operations Manager (RTOM) for consideration and forwarding to the State Operations Engineer for final approval.

According to Dudek (Conrad L Dudek, 1997) (NJDOT hereafter), the most effective messages are those that elicit some type of response from the motorist. Desired responses include but are not limited to: speed reduction, lane diversion, and route diversion.

Location of DMS

Installation and Placement

The NY-guideline and the CA-guideline assumes that the Department of Transportation's Operations Division, Maintenance, and Design shall work closely to determine the proper location of each permanent and PDMS before it is designed and installed. The guidelines state that the most appropriate locations for installing or placing a DMS are in advance of major decision points, such as interchanges or intersections, where motorists can respond to specific information displayed. Ease of access for maintenance personnel is another consideration when deciding on the placement of DMS.

The State of Missouri DMS guideline (MO-guideline hereafter) clarifies that the following factors should be considered when installing permanent DMS:

- The DMS should be located sufficiently upstream of known bottlenecks and high crash locations to enable road users to select an alternate route or take other appropriate action in response to a recurring condition.
- The DMS should be located sufficiently upstream of major diversion decision points, such as interchanges, to provide adequate distance for travelers to change lanes to reach an exit for an alternate route.
- The DMS should not be located within an interchange except for toll plazas or managed lanes.
- The DMS should not be positioned at locations where the information load on drivers is already high because of guide signs and other types of information.
- The DMS should not be in areas where drivers frequently perform lane-changing maneuvers in response to static guide sign information, or because of merging or weaving conditions.

Visibility and Safety

The NY-guideline and the CA-guideline define visibility as the distance at which a motorist can first detect a sign on the roadway. The following are components of DMS sign visibility:

- The ease in which a sign can be detected and how well it attracts the driver's attention (Target Value)

[1] Because "travel time" messages are the main way of communicating traffic delays, messages such as "expect delays" should not be used unless no travel time information is available.

- The ease in which the message can be seen (Brightness)
- The ease in which the message can be read (Legibility)
- The ease in which it can be read from the side (Cone of Visibility)

Also, the safety of staff and the motorist shall also be considered when proposing DMS locations, along with considering the traffic management and visibility aspects of a DMS (Lawrence Wooster, 2013; NYSDOT.GOV, 2011).

DMS Messages

The NY-guideline states that DMS messages that inform motorists of real-time roadway conditions, traffic conditions and, in some cases, a suggested course of action, should encourage motorists to make appropriate driving decisions. These messages should eliminate confusion on the roadway, improve traffic flow, and enhance safety (Lawrence Wooster, 2013). A large amount of traffic information is difficult to perceive, process, and remember at one time. Studies have shown that motorists better comprehend messages that are made up of words and phrases that they recognize, rather than ones with which they are unfamiliar. This is because, over time, motorists associate certain phrases with specific meanings. Deviating can cause confusion and, potentially, congestion as motorists slow down to read the sign and compehend the message. Therefore, it is important to use common and consistent words and phrases on DMS not only within a region but also throughout the state (NYSDOT.GOV, 2011). The CA-guideline highlights that since motorists have difficulty perceiving, processing, and remembering a large amount of traffic information at one time, the DMS and Transportation Management Center (TMC) operators are responsible for deciding which piece of information is most important and how best to present that information to motorists.

According to NJDOT, an effective DMS message display has all or a combination of some of the following elements:

- The type of problem (incident or road work descriptor);
- Location of the problem;
- The lanes that are affected (closure description);
- Location of the lane closure;
- The effect on travel;
- The audience for the message;
- Proper response or driving action by motorists; and
- A reason to follow the recommended driving action.

Message Factors

Both the NY-guideline and the CA-guideline require DMS messages to be divided into information components that when read separately or collectively convey a complete thought or message to motorists. The following are factors that enhance motorists' understanding of DMS messages:

Display Time

The minimum display time is three seconds per phase (a phase is a single message on one screen). However, two phases (the screen changes to display a different message) with a three-second display time for each is not adequate for traffic moving at 60 mph. Therefore, a single-

phase three-line message is preferred (NYSDOT.GOV, 2011). Motorists would need to be in a queue for 12 seconds to read the full message twice when reading a two-phase message with three-second display times. On the other hand, the VA-guideline elaborates on the phase timing and asserts that the display time for each phase should never be less than two seconds and the total display time for both phases should be no more than eight seconds. Moreover, the duration between the displays of two phases should not exceed 0.3 seconds.

The VA-guideline defines "message load" as the units of information in the total message, a measure of the amount of total information contained in a message. A single unit of information can be described as an answer to a question a motorist might ask. For example, anticipated questions may be: "What happened, where, and what should I expect?" Each unit of information should typically be four words or less, given that the average motorist can comprehend no more than one unit of information each second.

Message Length

Messages should provide motorists with enough information to make a timely decision. Message length refers to either the number of words or the number of characters and spaces in a DMS. State guidelines generally refer to the length of messages by the term "units of information", that according to the CA-guideline, is defined as "one to three words of text [that] usually occupies one line on a changeable message sign (CMS) phase." Operators should resist the urge to lengthen a message simply because space is available on the sign. Empty spaces on a DMS may be used for visual clarity (Lawrence Wooster, 2013; NYSDOT.GOV, 2011). The VA-guideline highlights that messages should be limited to no more than 20 characters per line.

The NY-guideline and the CA-guideline clarify that when creating or editing a DMS message, abbreviations may be used. It is important to use a list of standard abbreviations. Certain words or abbreviations are evident to the driver. For instance, the use of "Street," "Avenue," or "Boulevard" following a familiar arterial name is not required and could be omitted. When used in conjunction with a prompt word, the motorist understands most commonly used words and abbreviations. Also, all DMS operators should follow the same message format, content, and abbreviations (standardized messages). Message familiarity reduces motorist reading time, thereby enhancing delivery. In general, motorists need more time to read unfamiliar messages (Lawrence Wooster, 2013; NYSDOT.GOV, 2011). A study by Wang et al. (Wang et al., 2009) states that lengthy messages, abbreviated messages, and complex wording on DMSs are principal reasons for traffic slowdowns.

Brooke and Conrad (B. R. Durkop & Dudek, 2000) offered recommendations for abbreviations that can be used when the required DMS message surpasses the space available on a sign. Abbreviations are particularly useful in portable DMSs which have a space restriction of eight characters per line. The recommendations are made based on the outcomes of human factors studies that were conducted in Austin, Dallas, EI Paso, Fort Worth, Houston and San Antonio. Table 1 covers the abbreviations that 85% or more of the study subjects understood.

Table 1. Abbreviations Examined by Brooke and Conrad (2000)

Original word/phrase	Abbreviation	Percentage of participants understanding the abbreviation (n=300)
2 miles	[number] MI	94
15-minute delay	[number] MIN DELAY	95
Access road	ACCES RD	95
Emergency vehicle	EMER VEH	92
Fog ahead	FOG AHD	90
Hempstead Highway	[name] HWY	94
Interstate 35	I-35	91
Interstate highway 20	IH-20	85
Lane closed	LN CLSD	93
Major accident	MAJ ACCDT	94
On shoulder	ON SHLDR	93
Oversize load	OVSZ LOAD	90
Parking lot	PRK LOT	96
Prepare to stop	PREP TO STOP	97
Service road	SERV RD	93
To downtown	TO DWNTN	92
Weight limit	WT LIMIT	89
Wet pavement	WET PVMT	95

Message Type

The NY-guideline and the CA-guideline classify different types of messages as follows:

- ***Early warning messages*** give motorists advance notice of unexpected, slow, or stopped traffic and queuing due to a planned or unplanned event. Such early warning messages are effective in reducing secondary crashes.
- ***Advisory messages*** provide motorists with real-time information about a specific problem along their route. The message should use days of the week and not dates (i.e., Mon to Wed not 12/15 to 12/17). Additional use of advisory messages such as traffic congestion (travel time) or AMBER Alert information is displayed on permanent DMSs. The traffic congestion messages may give expected travel times or expected delays from one location to another. Travel time displays shall be in accordance with the travel time system's interim policy. AMBER Alert messages are typically a one-phase, three-line message that provides information to motorists about child abduction.
- ***Alternative Route/Detour messages*** are used when an incident blocks or closes an exit or freeway interchange. This event requires motorists to use or take a route other than that originally intended. Motorists should not be detoured to arbitrary routes. The suggested detour route should be one that contains adequate road signs so that motorists can travel without getting lost. Before a recommended detour route is displayed on a DMS, the operator should know the traffic conditions and constraints on the new route (Lawrence Wooster, 2013; NYSDOT.GOV, 2011). The VA-guideline highlights that during some

major incidents, alternate routes may exist that can accommodate a portion of the affected traffic, simultaneously reducing delay for diverted vehicles, and reducing the queue at the incident scene. If a reasonable alternate route exists, but the original road is not closed to traffic, DMS may be used in such a way as to encourage a greater percentage of motorists to divert to the alternate route. Alternative route messages are divided into two categories: Soft Detours and Hard Detours. A Soft Detour is an optional, suggested detour, for example, USE OTHER ROUTES. A Hard Detour is a required detour, for example, USE NEXT EXIT / USE I-295. If a detour route is not available, a message should be posted with an estimated travel time (VDOT, 2016).

Brooke Durkop and Kevin N. Balke (B. Durkop & Balke, 2000) investigated the use of the Texas Department of Transportation's (TxDOT) DMS to inform motorists about the status of the different responders during incident conditions. In their study, the types of status information that were examined included messages such as "Police EnRoute," "Police on Scene," and "Police Notified." These status messages were used in place of the typical "Expect Delays" message currently used by TxDOT in any location in Texas. Also, limited surveys of both TxDOT traffic management center (TMC) operators and motorists were used to examine user acceptability and response to the messages.

The TxDOT districts surveyed specified that they would not favor dropping "Expect Delays" messages for status information about the incident response, citing concerns about increases in operator workload, legal issues, and message formatting problems. The survey of motorists found that only 28% of the motorists thought status information about responders was useful. Therefore, it was recommended that TxDOT continue to use "Expect Delays" messages on its DMS and not display information about the status of the incident response.

Message Content

The VA-guideline defines message content as specific information displayed on a DMS. The specific structure and content of DMS messages should be carefully designed to relay accurate, easily understandable and comprehensible information. Peeta et al. (Peeta, Ramos, & Pasupathy, 2000) concentrated on the efficiency of DMS content on the route diversion problem. The researchers made behavioral models to forecast the likelihood of individual route diversion under various message types based on a stated preference (SP) survey questionnaire. Drivers' inclination to divert to a viable alternate route was measured, while the DMS offered various information such as expected delay, weather and night-time condition, incident clearance time, and their combinations. The results revealed that the probability of drivers to divert increases with the amount of information provided on the DMS.

Ullman et al. (B. R. Ullman, Trout, & Dudek, 2009) investigated the effectiveness of using graphic displays and symbols to facilitate communication with motorists. Through three human factor assessments of alternative designs, researchers recognized precise design elements that should be incorporated in graphic displays and those that should be avoided. Some of the key benefits of using graphic displays as opposed to text messages are:

- A graphic show appears to advance the skill of drivers to recognize existing lanes in a problem area.
- The distribution of incident descriptor information (e.g., accidents or work zones) using graphic symbols improves understanding levels of non-native-language drivers.

- Graphics and symbols may reduce the time needed for a non-native speaker to comprehend the message.
- The use of graphics efficiently demonstrates unusual operational scenarios, such as high-occupancy vehicle lanes or adjacent toll lanes, through a graphic representation of roadway geometry, logos, shields, etc.

Rodier et al. (Rodier, Finson, & Shaheen, 2010) investigated the following questions about displaying safety campaign messages on DMSs:

1. How attentive is the public to messages displayed on DMS?
2. Is there a public safety benefit for displaying safety campaign messages on DMS?
3. Do travelers slow down to read DMS messages and, thus, interrupt traffic flow?

To answer these questions, the researchers employed a variety of approaches:

- An extensive review of the relevant published literature on DMS was made.
- Interviews were conducted with experts and stakeholders.
- Focus groups were created with California drivers.
- Telephone and intercept surveys were effected/distributed statewide.
- Speed data from California highway loop detectors were analyzed.

Based on the results obtained, the following conclusions were made:

- Driver inattentiveness to DMS messages does not seem to be a substantial problem among California drivers.
- Positive safety effects may be derived from public safety campaign messages on DMS when the public is familiar with and understands the messages displayed.
- A small percentage of drivers may slow in the presence of safety campaign messages displayed on DMS, but this does not appear to cause disruptions in the overall flow of traffic.

According to NJDOT, a basic DMS message is composed of: incident/ roadwork descriptor (situation description), incident location, lanes closed/blocked, closure descriptor, closure location, effect on travel (e.g., major delay), audience for action, action, and good reason for following the action.

Message Format

Message formatting refers to the order and arrangement of the units of information on a DMS. The DMS message must contain the proper information, in the expected order, to allow motorists to read, interpret and make rational decisions based on the displayed information. Placement of message elements on the wrong line or in the wrong sequence will result in driver confusion and increase the time needed to read a message. Conversely, consistent formatting of information enhances motorist expectations and reduces the time required to read and understand messages (Conrad L. Dudek, 2001).

The VA-guideline defines message format as “the order and arrangement of the units of information on a DMS.” Most messages should convey some of the following five units of information, listed below in the order of importance and according to motorist expectations.

- Problem – what happened? (e.g., crash, roadwork, closure descriptor)
- Location – where? (e.g., 5 miles ahead, at exit 180, at Gaskins Rd)
- Effect – what is the effect on traffic? (road closed, left lane blocked)
- Audience/Attention – if necessary, for whom is the message intended? (e.g., DC traffic, all trucks)
- Recommended Action – if necessary, what is advised? (e.g., exit, prepare to stop, take alternate route)

The guideline also emphasizes that all messages, when applicable, should include a problem statement, location, and either effect or action. Messages may also include effect, audience/attention statement, and recommended action. If the message can be displayed in one phase and the DMS can display three lines of text, then the top line should present the problem, the center line should present the location or distance ahead, and the bottom line should present the recommended action. While this is the preferred message format, it may not always be possible to provide information for each of these elements due to information availability. In some instances, audience/attention and recommended action may not be necessary (VDOT, 2016).

Also, Wang et al. (Wang & Cao, 2005) investigated the consequence of using graphics-aided DMS. They employed a survey questionnaire and video-based simulation techniques to assess drivers' response to a graphical message. Outcomes specified that graphics-aided messages significantly improved preference, response time, and accuracy compared to text-only messages, particularly for elderly drivers. Adding graphics on a DMS also highly reduced the time needed for comprehension by drivers for whom English is a second language.

Ullman et al. (G. L. Ullman, Ullman, Dudek, Williams, & Pesti, 2005) identified the consequences of a laptop-based human factor study of alternative formats of presenting advance notice work zone information on Portable Dynamic Message Signs (PDMS). They also examined the ability of motorists to capture and process information on two PDMS used in sequence to carry information about upcoming traffic situations, using a driving simulator available at Texas Transportation Institute (TTI).

Based on these studies, the researchers suggested that messages that display calendar dates for future roadwork and other traffic control activities should utilize a message format containing the three-character abbreviation of the month (e.g., APR for April) in concert with the date. When future work activities span several days all in the same month, the month needs be noted only once in the message (i.e., APR 21-23) rather than repeating the month (i.e., APR 21-APR 23). The CA-guideline also emphasizes that days of the week (Monday-Friday) should be used instead of calendar dates (May 11-May 15) when displaying messages. The TTI driver simulator study outcomes specified the need to keep overall messages at or below the four-unit maximum recommended in existing guidelines. Researchers found that presenting five units of information on sequential PDMS resulted in low comprehension rates. However, when message length is limited to four units, it appears that the use of sequential PDMS increases comprehension rates comparable to those obtained by presenting the same information at a single location on a large dynamic message sign (DMS). Comprehension may be enhanced by repeating one of the units of information on both PDMS.

Message Phase

The NY-guideline defines “phase of messages” as “one frame of a message, which includes the units of information and the display time.” According to the guideline, each phase of a message should be independent of one another and motorists are expected to understand them independently. Generally, DMS are categorized into two groups: single-phase and two-phase messages.

The VA-guideline states that DMS displaying a single message on one screen are called a single-phase message. Single-phase messages are always preferable to two-phase messages, as motorists can comprehend single-phase messages faster. Single-phase messages are preferred for non-traffic and non-emergency messages such as ozone alerts, non-event travel times, and safety campaign messages. When more information should be displayed than can fit on a single phase, a DMS may use a two-phase message if visibility (either geometric or weather-related) permits. No more than two phases should be displayed per message (VDOT, 2016).

Dutta et al. (Dutta et al., 2004) studied the understandability of two-phase temporal messages on a DMS via a mid-level Driving Simulator (DS) to realize the maximum performance of the DMS. They concluded that drivers noticeably benefited from repeated two-phase messages in the case of sight obstruction. However, with no obstruction, repeating a message had no statistically significant effect on selecting the correct direction compared to non-repeating messages. In this regard, the NY-guideline asserts that a two-phase DMS should only be used when it is definite that, at usual speeds, motorists have enough time to read the entire message.

Message Priorities

The MO-guideline describe the following message hierarchy to help DMS operators determine the priority of different types of messages when several requests are made to display different messages on the same sign at the same time. The DMS messages shall be prioritized in the following order unless overridden by a supervisor:

- Emergencies, such as evacuations or closures, required by DOT, the State Emergency Management Agency (SEMA), local law enforcement or the military.
- Hazardous and/or uncommon road conditions that require motorists to alter their driving, such as severe weather conditions, accidents, work zone activities or other incidents. Traffic operators should contact their floor supervisor when multiple incidents are taking place along the same route.
- Traveler information and suggested alternative routes for delays and/or congestion caused by planned or unplanned events. Alternative routes are suggested with caution; sufficient trailblazing must be provided.
- Child abduction alerts originating in the local area
- Travel times
- Ozone alerts
- Advance date or time notice for scheduled incidents such as lane closures, road closures, moving operations or special events.
- Approved standard public service messages associated with special campaigns (i.e., work zone awareness week, share the ride) or other public information that improves highway safety and reduces congestion. Approval should be coordinated through the TMCs for participation in such campaigns. Using the DMS Request Form, messages should be

submitted, with suggested input from TMC staff, to Central Office Community Relations staff for endorsement. The DMS Message Approval Board will follow its guidelines to approve or reject submitted messages.

- When circumstances exist such that no message regarding safety or traveler information as defined by the previously listed priorities is warranted, messages shall be displayed on all DMSs in Missouri. Messages shall regularly be rotated so that a variety of information is displayed to the traveling public. No message shall be excluded from the rotation unless otherwise approved by Traffic and Community Relations staffs (MoDOT).

Xuan et al. (Xuan & Kanafani, 2014) narrowed their study to accident messages displayed on freeway DMS and studied their effect on drivers' route choice behavior. The purpose was to determine the real effect of accident messages on DMS and compare two commonly used statistical models. They analyzed the share of total flow heading to off-ramps or freeway interchanges (diversion rate hereafter) at diverging locations and used the change in diversion rate as the indicator of behavior change. Insights were drawn from two case studies. The results showed that accident messages on DMS have a slight effect on diversion rate when compared to visible congestion.

According to Montes (Montes C., 2008) (FDOT hereafter), the priority order for DMS messages is:

a) Conditions which require motorists to act or alter their driving;
b) Traffic incidents, hazardous and/or uncommon road conditions, work zone activities, and severe weather conditions;
c) America's Missing: Broadcast Emergency Response (AMBER) Alerts;
d) Law Enforcement Officer (LEO) Alerts;
e) Traveler information related to special events, emergencies, and incidents impacting mobility and safety; and,
f) Blank Sign: In the absence of accurate travel time information, at locations where travel time information would not be useful, or when not being preempted with other messages listed above.

According to the Oregon DOT (ODOT, 2013), daily and seasonal occurrences or site-specific operations objectives may alter the priority for displaying messages. The standard priority of displayed messages is the following:

1. Drawbridge operations, road or ramp closures, and emergency situations;

2. Incident or crash;

3. Lane control or queue warning messages;

4. Adverse weather or environmental conditions and related regulations such as chain restriction information, icy conditions, and tsunami warnings;

5. Construction or maintenance operations;

6. Amber Alert messages (see Section X for additional information);

7. Traffic operations information associated with special events such as car shows or sports events (see Section X for additional information);

8. Travel time information (see Section X for additional information);

9. Air quality alerts as approved by the Region Traffic Engineer/designee (see Section X for additional information);

10. Public Service Announcements approved by the State Traffic-Roadway Engineer (see Section X for additional information); and

11. Test messages.

Two common statistical methods were used for analysis and comparison: a correlation analysis and a causality analysis. Both analytical methods considered the effect of visible congestion. The correlation analysis compared the diversion rate with and without DMS accident messages, while the causality analysis compared the diversion rate right before and after DMS accident messages are turned on or off. Using empirical data from three study sites, a causality analysis was executed, and the result showed that the real effect of DMS accident messages on diversion rate was insignificant. However, the correlation analysis showed a positive correlation between DMS accident messages and diversion rate, indicating that this analysis cannot be used to draw causal inferences and that other factors have played a role in changing the diversion rate.

Schroeder et al. (Schroeder & Demetsky, 2011) investigated the impacts of existing message strategies to determine messages that maximize diversion for specific circumstances and develop new messages for future deployment. An analysis was done for various message types and split into two diversion scenarios: (1) an incident on the primary freeway, I-95, encourages diversion off I-95 traffic to an alternate route, I-295; and (2) an incident on an intersecting freeway, I-295, encourages exiting I-295 traffic to remain on I-95 as an alternate route. The outcomes showed trends in which specific words in messages were more effective than others in achieving diversion when the percentage of diverted traffic was used as the performance measure. Transportation agencies are frequently asked to post public service announcements on DMS when they are not being used for traffic-related purposes. It has been suggested that these messages are a distraction to drivers and result in queuing, creating mobility and safety hazards.

Schroeder et al. (Schroeder & Demetsky, 2011) used speed as the performance measure and showed minimal impacts on traffic flow from the display of non-traffic messages during weekday non-peak hours. The study recommended that (1) travel time estimates for both the primary and alternate routes or the length/time of the delay should be provided on DMS; (2) specific wording, as noted in the text, should be used to induce diversion or simply to provide information; (3) messages should be displayed in “Title Case” instead of “ALL CAPS” (i.e., all letters in a word are capitalized) for low-frequency messages; and (4) left-justified or “staircase” messages should be used. Further, non-traffic messages should be one-phase messages and should be displayed only during non-peak periods to minimize the potential for queuing. Jeremy and Michael state that if the recommendations of their research are implemented, the enhanced effectiveness of diversion strategies will result in reductions of delay, fuel consumption, and emissions, as well as the potential for secondary accidents created by major incidents and other traffic flow disruptions.

Communicating Time or Date

The VA-guideline explains that for certain message types about events in the future, such as planned or ongoing roadwork or special events, the times or dates of the occasions may be required in the DMS message. Messages are written differently for events happening within the

next seven days and for those occurring more than seven days in the future. The VA-guideline also clarifies that there may be some message types that have content of either low or high priority. Weather-related information, for example, may relate to heavy fog or water across a roadway which necessitates message formats that express high priority. On the other hand, the CA-guideline emphasizes that advance notification should not be displayed more than seven days before the special event or upcoming roadwork.

According to the VA-guideline, to increase or decrease the relative urgency of a message, the following guidelines should be followed:

- Use command style messages when the situation is urgent, and an immediate control action is required by the driver. Examples of command style messages include: SLOW DOWN or REDUCE SPEED.
- Use notification style messages when an immediate control action is not required, or the situation is not urgent. Examples of notification style messages include: USE CAUTION, USE ALTERNATE ROUTE or STORM WARNING.
- USE CAUTION should be used only for unverified events, such as reports of debris or a hazardous pothole.

Additionally, messages relating to maintenance should clearly differentiate between planned and unplanned/emergency roadwork.

- Planned roadwork messaging, whether active or future, should include ROAD WORK, a location, and an impact.
- Unplanned roadwork must contain EMERGENCY ROAD WORK (or EMER on a PDMS), a location, and an impact (VDOT, 2016).

Mortazavi et al. (Mortazavi, Pan, Jin, Odioso, & Sun, 2009) examined the collaboration efforts of the California Center for Innovative Transportation (CCIT) with California Department of Transportation (Caltrans) District 4, to deploy three DMS displaying transit information in addition to highway travel time. Their team conducted both qualitative and quantitative analyses to evaluate the design and success of the project. The system operating performance analysis showed that the transit signs were operating effectively and that there often was a significant advantage in taking the train. In general, traffic during the afternoon peak hours proved more severe, suggesting a greater potential transit advantage than during the morning commute.

Nicholas J. Garber and Srivatsan Srinivasan (Garber & Srinivasan, 1998) used radar to assess the effect of the duration of exposure of the DMS on its effectiveness in reducing speeds and influencing speed profiles in work zones. They also studied the impact of length of the work zone and vehicle type on speed reductions. Three work zone sites in southwest Virginia were selected for the study. Automatic traffic counters collected speed and volume data for the population at the beginning, middle and end of each work zone. Also, the speeds of individual drivers who triggered the DMS by exceeding the threshold speed were also recorded (using a video camera) at two other locations within the work zone to study the behavior of high-speed drivers and compute their average speed reduction in response to the warning message.

The results of the study indicated that the duration of exposure to the DMS did not have a significant impact on speed characteristics and driver behavior. Therefore, the DMS continued to be effective in controlling speeds in work zones for projects of long duration. It was also determined that the drivers exceeding the speed limit, in both interstate work zones, had on

average reduced their speeds by around eight mph (12.86 km/h) at the middle of the work zone. At the third site, the speed reductions at the middle of the work zone were about 10 mph (16.08 km/h). There were no distinctive differences among the different types of vehicles regarding speed reduction. The study also established that in longer work zones, drivers who reduced their speeds in response to the speed control effort frequently tended to speed back up as they approach the end of the work zone. This indicates that very long work zones might warrant the installation of a second DMS to maintain speed reductions through the work zone.

Several states have similar guidelines about DMS. Table 2 compares state DMS practices by message content, length, and type. In addition, Figure 1 to Figure 6 show examples of DMS messages from different states.

Table 2. Nationwide Comparison of DMS Practices

State	Message Content	Message Length	Message Type
Texas	- Reason - Location - Advice	**At most:** - **8 words** at 55 mph - **7 words** at 65 mph - **6 words** at 70 mph	Accident, Construction Weather Advisory, Public Service, Sign Testing, Amber Alert
California	- Problem - Location - Effect statement	**At most:** - **3 units of information** on a single message phase. - **4 units of information** in the entire message when traffic operating speeds are 35 mph or more. - **5 units of information** in the entire message when traffic operating speeds are less than 35 mph.	Early Warning Messages Advisory Message, Alternative Route
New York	- Problem - Location - Action or Effect	**3 units of information** at speed equal to or greater than 55 mph	Early Warning Messages, Advisory Message, Alternative Route
Missouri	- What happened? - Where? - What is the effect on traffic? - For whom is the advisory? - What is advised?	No more than **3 lines**, with no more than **20 characters** per line	Emergencies, Hazardous, Traveler Information and Suggested Alternative Routes for Delays and/or Congestion, AMBER Alerts, Travel Times, Ozone Alerts, Advance Date or Time Notice for Scheduled Incidents, Public Service
Virginia	- What: situation the motorists will encounter - Where: location of the event - Advice: the action motorists should take	No more than **3 lines**, with no more than **20 characters** per line	Travel Time, Queue Warning, Unplanned/ Emergency Road Work, Road/Ramp/Tunnel Closures and Drawbridge Operations, Road Work and Maintenance Activities, Adverse Weather, Environmental and Roadway Conditions, Special Events (Active), Emergency

			Messages, Missing Person Alerts, Future Special Events
Florida	- Problem - Location - Effect - Attention - Action	Maximum of eight words at speeds of 55 miles per hour (mph) Maximum of seven words at speeds of 65 mph; and, Maximum of six words at speeds of 75 mph	Emergency, Incident Management Traffic Management, Roadway Closures for construction or maintenance activities, Weather Condition, Special Events Safety Campaigns, Travel Time Information, AMBER Alerts, LEO Alerts, Test Messages; and Blank Sign
Michigan	- Problem - Location - Action		Crash, DisabledVehicle, Congestion, Construction, Other Abandoned Vehicle Maintenance, Weather, Special Event, Amber Alerts
Oregon	- Problem - Location - Action - A time period if needed - Attention	Only one unit of information should appear on each line of the VMS. A unit of information should not be more than four words.	Adverse Weather Conditions and Chain-up Requirements, Amber Alerts, Special Events,Travel Time Information, Air Quality Alerts, Public Service Announcements, Test Messages

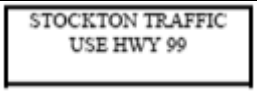
PHASE 1			
UNITS OF INFO.	INFORMATION	MOTORIST QUESTION	CMS ANSWER
1 1 1	Problem Location Effect	What happened? Where? What is the effect on traffic?	
PHASE 2			
UNITS OF INFO.	INFORMATION	MOTORIST QUESTION	CMS ANSWER
1 1	Audience Action	Who is message for? What is advised?	

Figure 2. DMS Examples in California

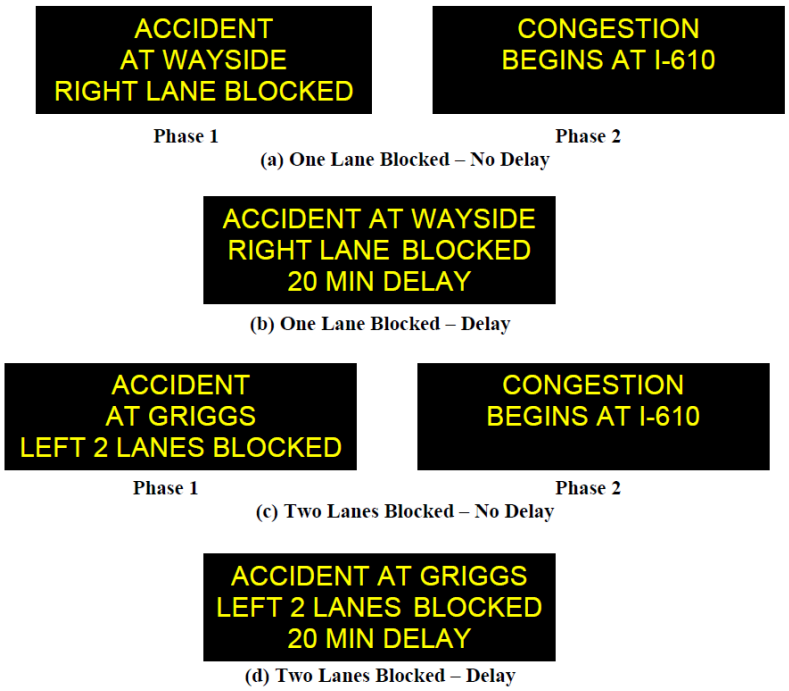


Figure 3. DMS Examples in Texas

Approved example for DMS located along the SAME route

21 characters

18 characters

Approved example for DMS located along an INTERSECTING route

21 characters

18 characters

Figure 4. DMS Examples in Maryland

Basic VMS Message Elements	Basic VMS Message to Satisfy Motorist Information Needs	Final Message
Incident Descriptor *Incident Location* *Lanes Closed* *Closure Location* *Action*	MAJOR ACCIDENT PAST I-80 ALL LANES BLOCKED USE OTHER ROUTES	FREEWAY BLOCKED PAST I-80 USE OTHER ROUTES
	(4 Units of Information)	*(3 Units of Information)*

Figure 5. DMS Examples in New Jersey

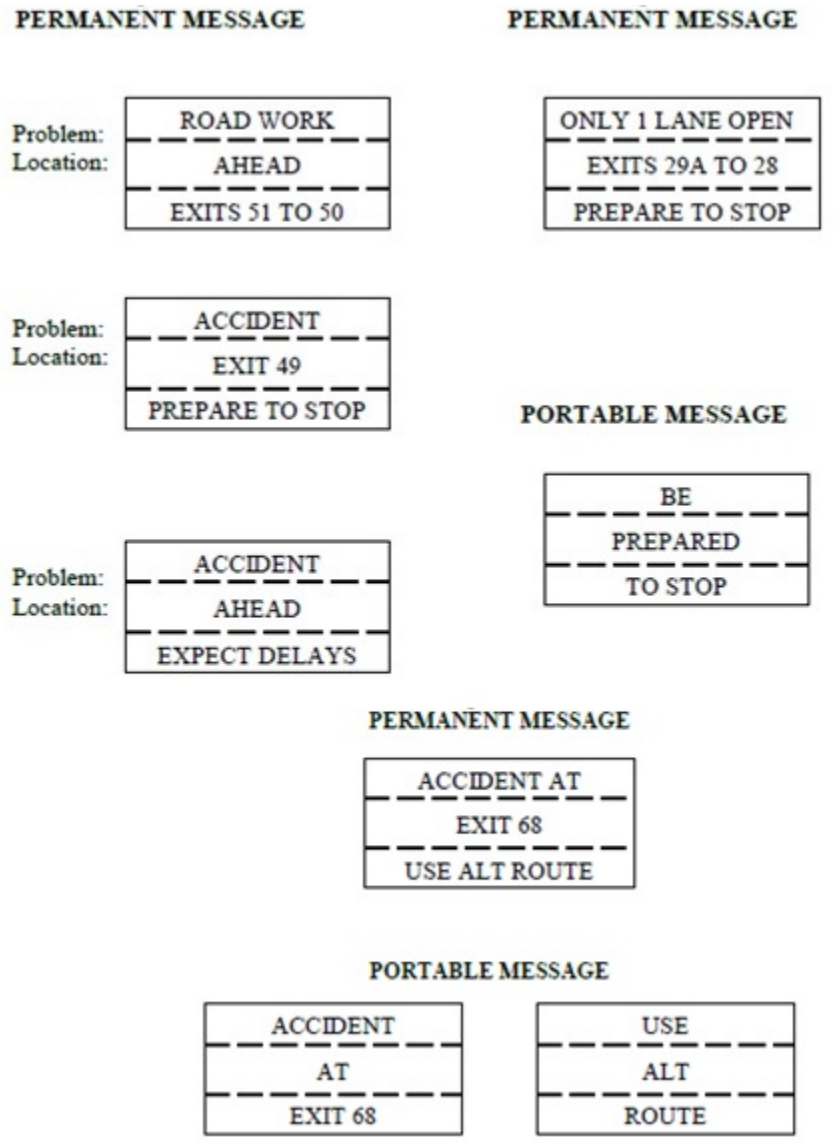


Figure 6. DMS Examples in New York

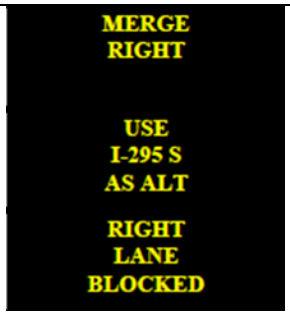
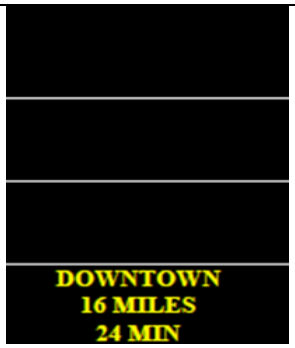
Message Type	Phase 1	Phase 2
Traffic Incidents		
Travel Time		

Figure 7. DMS Examples in Virginia

DMS Best Practices

This section summarizes the information on DMS best practices to provide a comprehensive comparison of content, type, the length of the message, and standards. The comparison includes different types of information pertinent to DMS settings such as: abbreviation standards, message content, and types of DMS. DMS settings and policies are similar among the states.

Virginia

Message priority

According to the State of Virginia changeable-message-sign policy, when multiple messages compete for display on the same DMS, messages supporting a lane impact take precedence over all others. These lane impact messages shall be displayed on the appropriate DMS until the related impact ends or another lane impact occurs closer in proximity to the appropriate DMS.

Tables 3 and 4 address this issue.

Table 3. Message Priority: Lane Impact

Lane Impact Note: Event proximity to the changeable message sign (CMS) is the determining factor when there are multiple messages (supporting events with lane impact) competing for display on the same CMS.	
Events impacting a lane	• Traffic incidents and crashes • Debris • Road/ramp/tunnel operations • Drawbridge operations • Road work • Traffic detours • Queue Warnings
Dedicated Lane Control	• Reversible Roadway Critical Signs • Active Traffic Management • Hard Shoulder Running • HOV/HOT/Managed Lanes (open/closed/price)

Table 4. Message Priority: No Lane Impact

No Lane Impact **Note: The following are listed in order of priority. The Regional Traffic Operations Manager (RTOM) has the authority to override.**	
Lane Control	• Non-Critical Reversible Roadway Signs • HOV Diamond Lane
Travel Advisory Messages	• Travel Time information
Events not impacting a lane	• Traffic incidents and crashes • Road work
Severe Weather Warnings	• Adverse weather and roadway conditions
Special Event Management	• Soft diversions, related Info (e.g. parking)
Emergency Alerts	• Amber, Senior, and Leo Alerts
Future Impacts	• Special Events • Roadwork
Environmental Messages	• Ozone/Air Quality advisory messages
Campaign Messages	• Safety campaigns (e.g. Buckle Up) • Wildlife warning campaigns
Public Service Announcements	• VDOT public meeting notice

Message format

a. Dynamic Features and Animation

Dynamic features for a message displayed on a DMS are prohibited. These include flashing text/lines, fading, exploding, dissolving, moving messages, animation, looming, scrolling messages, or other features meant to draw attention to the sign, except for flashing arrows that may be used on a truck-mounted DMS only. Also, the following features should be avoided:

- Flashing an entire one-phase message
- Flashing one line of a one-phase message
- Alternating text on one line of a three-line DMS, while keeping the other two lines of text the same

b. Travel time

Travel time messages sent to DMS should be timely and accurate. Therefore, certain DMS may not be able to support travel time messages due to a limitation of availability, location, communication or the possibility of creating conflicting messages.

A DMS shall NOT be considered for use to display travel times if:

- The DMS is dedicated for use in HOV lanes.
- The DMS is dedicated to gate control.
- The DMS can support only one line of text.
- The DMS uses a dial-up connection.

Travel time messages should follow the same general format and should only be posted for one of the following configurations. Table 5 shows the general format of travel time used in DMS and Tables 6 and 7 illustrate the example of travel time.

Table 5. Travel-Time General Format

Single Destination	Multiple Destinations	Alternate Routes
1-495 15 MILES 25 MIN	TRAVEL TIME TO: I-495 15 MI 25 MIN US-29 25 MI 40 MIN	TIME TO DC VIA: 495 E 15 MI 45 MIN 495 W 25 MI 40 MIN

Table 6. Virginia Sample Permanent DMS Message Library

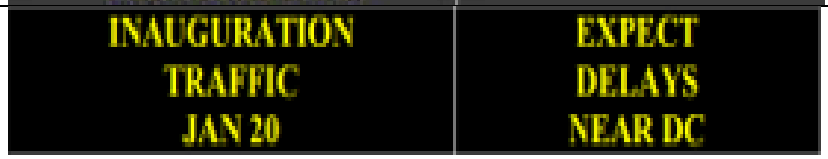
Permanent CMS		
Message Type	**Phase 1**	**Phase 2**
Traffic Incidents	DISABLED VEHICLE AHEAD MERGE LEFT	DOWNTOWN 10 MILES 12 MIN
	CRASH 5 MILES AHEAD LEFT LN BLOCKED	TRAVEL TIME 5 MILES 9 MIN
	MAJOR CRASH AT EXIT 75	THRU TRAFFIC USE I-295 SOUTH AS ALTERNATE
	CRASH 564 WEST PAST RUNWAY	HRBT 15 MILES 18 MIN
	DEBRIS PAST EXIT 291	LEFT LANE BLOCKED PAST I-464
Diversion to Alternate/Other Routes	MAJOR CRASH AT EXIT 180 2 RIGHT LANES	USE ROUTE 33 AS ALTERNATE ROUTE
	CRASH AT NORTHAMPTON 2 LEFT LANES	USE OTHER ROUTE
	MAJOR CRASH AT EXIT 81 2 RIGHT LANES	THRU TRAFFIC USE I-295 SOUTH AS ALTERNATE
	ROAD WORK 2 LANES CLOSED MM 150	USE ROUTE 1 AS ALTERANTE

Table 6. Continued

Permanent CMS		
Message Type	**Phase 1**	**Phase 2**
HOV/HOT/Managed Lane Messages	HOV LANES TO WASHINGTON CLOSED OPEN TO ALL TRAFFIC – LEFT ENTRANCE 1 MILE HOV CLOSED DO NOT ENTER	
Travel Time	US-1 EXIT 126 26 MILES 23 MIN VA-54 ASHLAND 30 MILES 26 MINUTES ROANOKE / I-581 30 MILES 54 MINUTES CRASH BEFORE EXIT 69 RIGHT LN BLOCKED	DOWNTOWN 16 MILES 24 MIN
Queue Warning	TRAFFIC DELAYS AT EXIT 190 TRAFFIC DELAYS PAST I-264 TRAFFIC DELAYS PAST MM 161	DOWNTOWN 19 MILES 33 MIN HRBT 12 MILES 18 MIN I-495 10 MILES 20 MIN
Unplanned/ Emergency Road Work	EMERGENCY ROADWORK 5 MILES AHEAD EMERGENCY ROADWORK PAST EXIT 247 EMERGENCY ROADWORK 15 MILES AHEAD	TRAVEL TIME XX MILES XX MIN LEFT LANE CLOSED PAST LEE HALL TRAVEL TIME XX MILES XX MIN

Permanent CMS		
Message Type	**Phase 1**	**Phase 2**
Road/Ramp/Tunnel Closures and Drawbridge Operations	3RD ST TUNNEL CLOSED USE ALT ROUTE	
	DOWNTOWN TUNNEL CLOSED	I-264 TRAFFIC USE I-464 NORTH
	DRAWBRIDGE OPEN STOP AHEAD	
Road Work and Maintenance Activities	ROAD WORK I-66 WEST AT I-495	2 RIGHT LANES CLOSED AT EXIT 49
	ROAD WORK EXIT 1B RAMP NARROWS	TRAVEL TIME XX MILES XX MIN
	ROAD WORK RAMP TO I-495 S CLOSED	FOLLOW DETOUR
Adverse Weather, Environmental, and Roadway Conditions	WINTER STORM WARNING TONIGHT	TRAVEL TIME XX MILES XX MIN
	BLACK ICE POSSIBLE USE CAUTION	
	STANDING WATER PAST EXIT 16	LEFT LANE BLOCKED PAST WITCHDUCK
Special Events (Active)	ART MUSEUM PARKING SHUTTLES	USE EXIT 4E TO CIVIC CENTER
	RACE TRAFFIC USE EXIT 60	TRAVEL TIME XX MILES XX MIN
Emergency Messages	MAJOR DELAYS I-395 N IN DC USE ALT ROUTE	
	I-95 NORTH CLOSED AT EXIT 61 FOLLOW DETOUR	DOWNTOWN 15 MILES 30 MIN

Table 6. Continued

Permanent CMS		
Message Type	**Phase 1**	**Phase 2**
Missing Person Alerts		
Future Special Events		
Future Roadwork		
Ozone Advisory Messages		

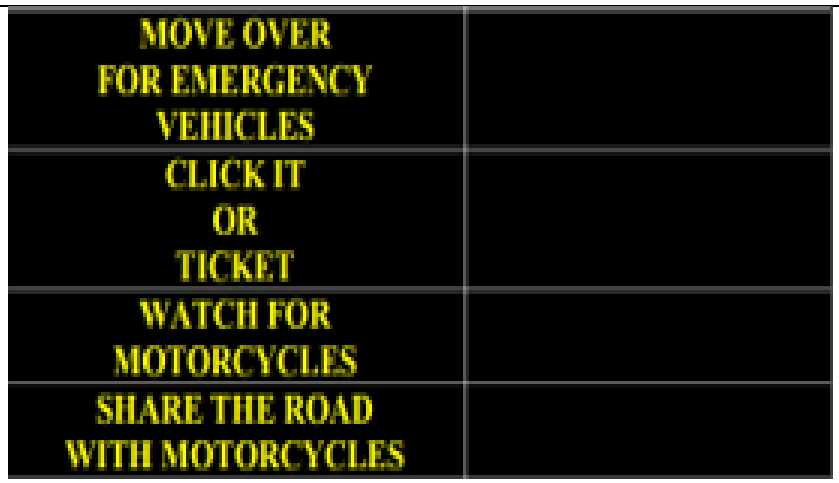
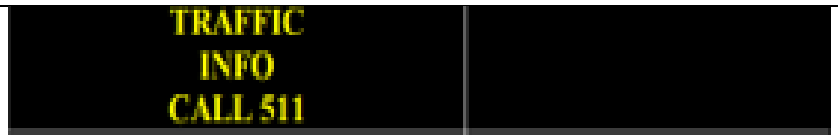
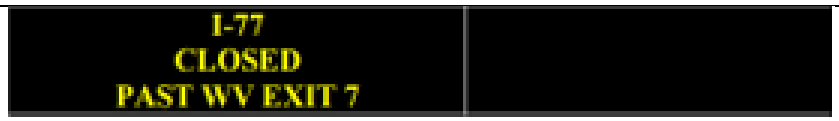
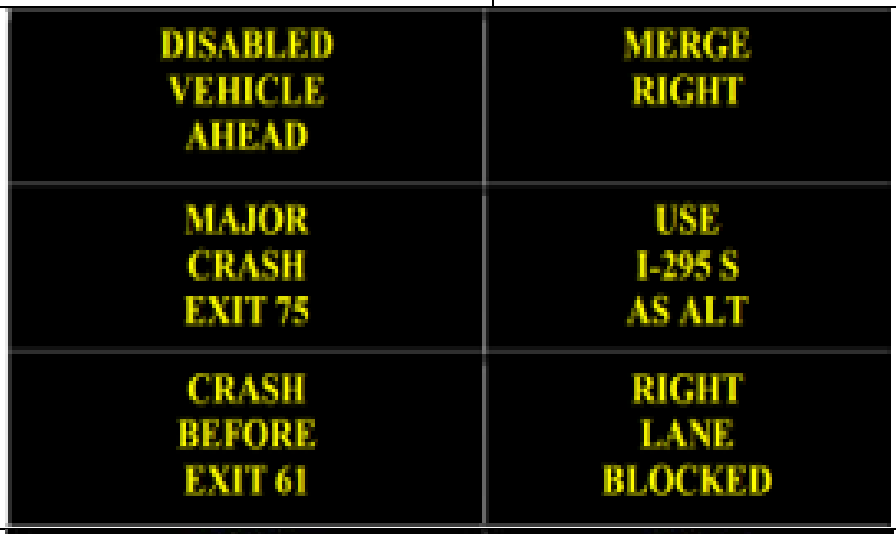
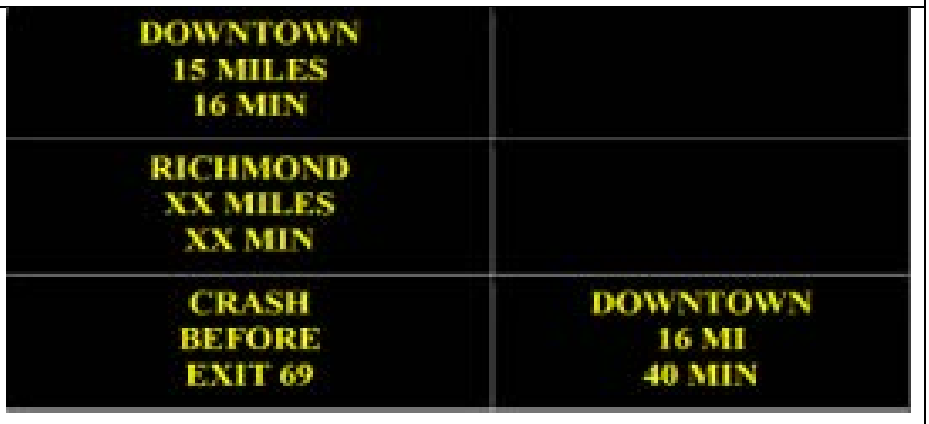
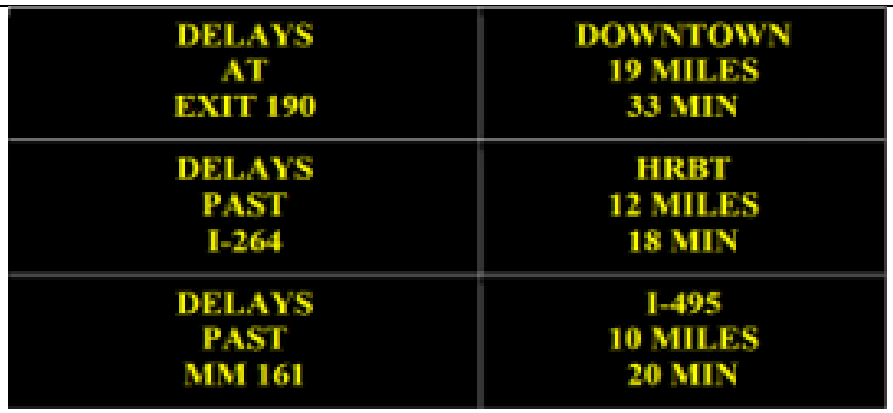
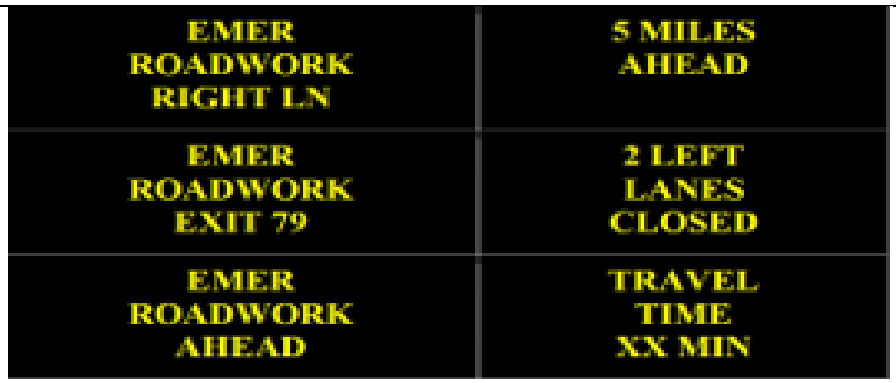
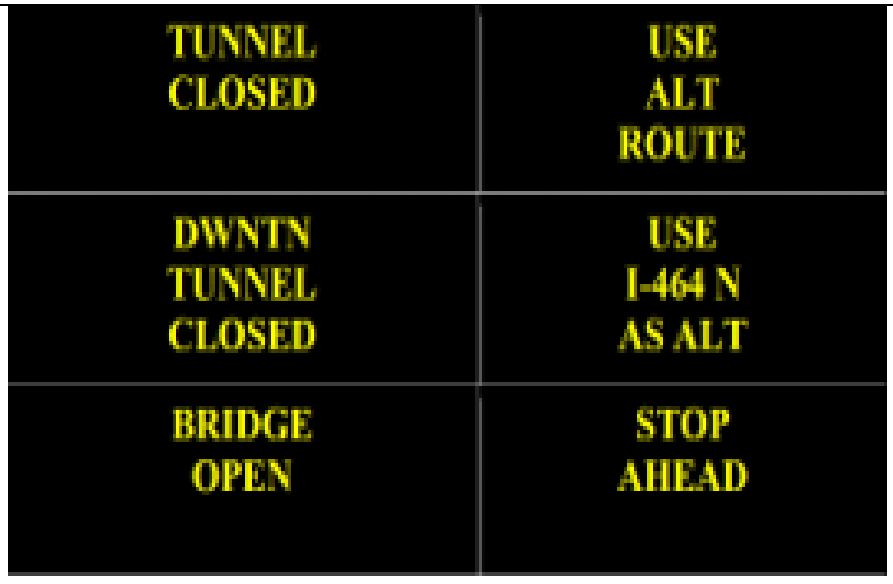
Safety Campaigns/ Motorcycle Safety	
Wildlife Warning Campaigns	
Test Messages	
Messages for Other States or Transportation Agencies	
Other Sources of Traveler Information	
Public Hearing	

Table 7. Virginia Sample Portable DMS Message Library

Permanent CMS		
Message Type	**Phase 1**	**Phase 2**
Traffic Incidents		
HOV/HOT/Managed Lane Messages		
Travel Time		

Queue Warning	
Unplanned/ Emergency Road Work	
Road/Ramp/Tunnel Closures and Drawbridge Operations	

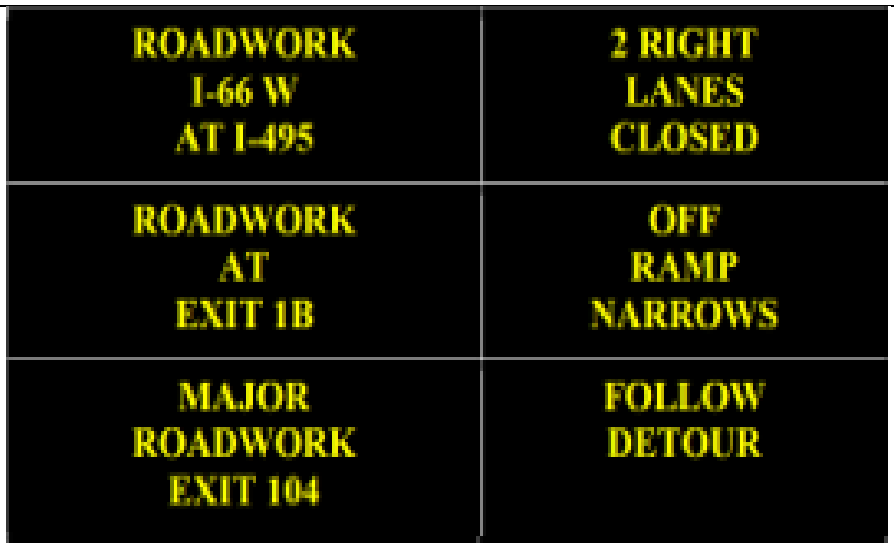
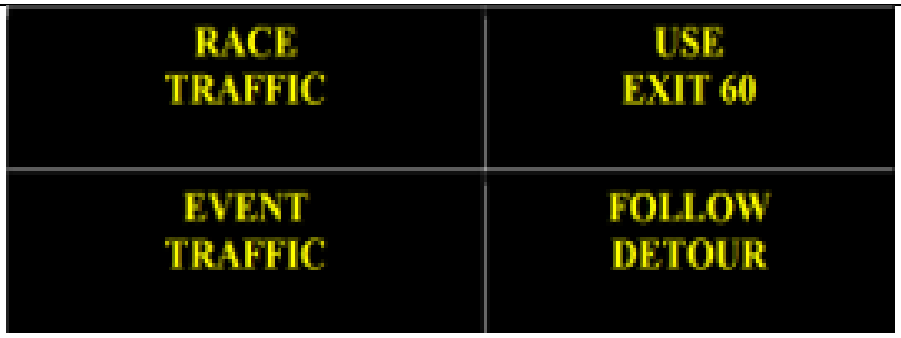
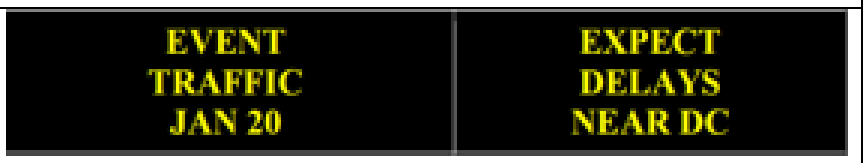
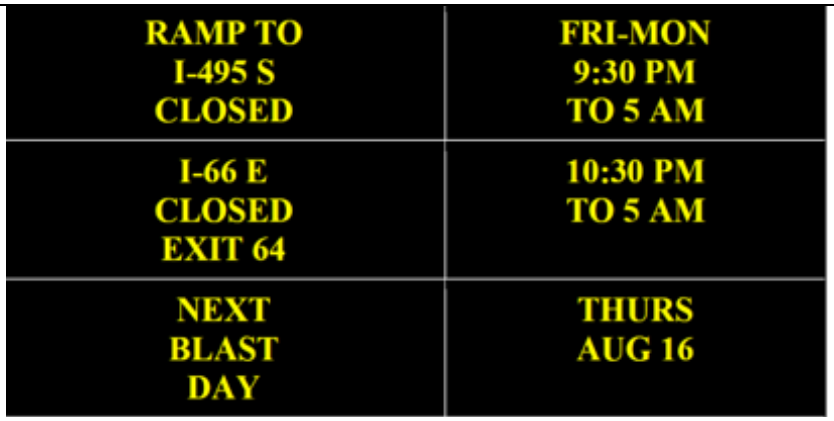
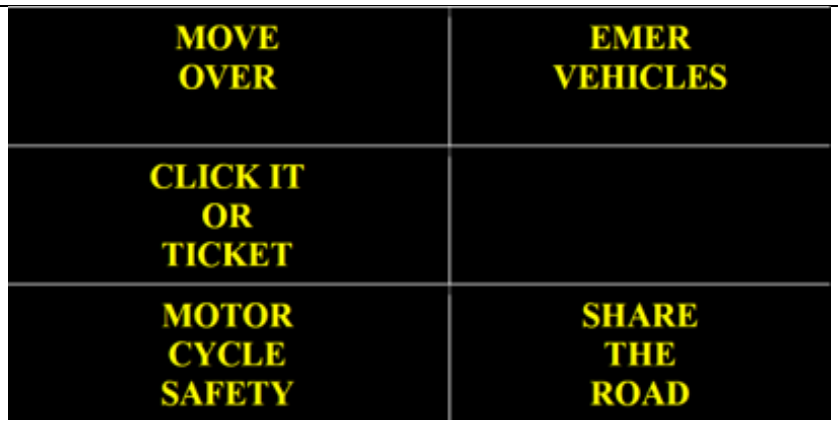
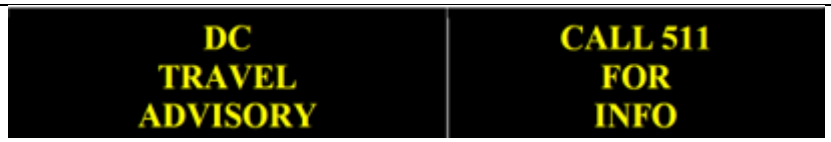
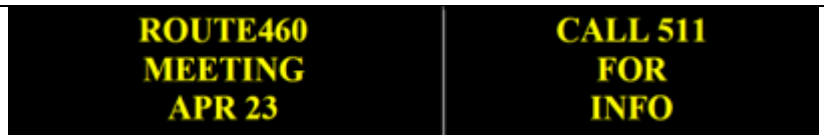
Road Work and Maintenance Activities		
Adverse Weather, Environmental, and Roadway Conditions		
Special Events (Active)		

Table 7. Continued

Permanent CMS		
Message Type	**Phase 1**	**Phase 2**
Emergency Messages		
Missing Person Alerts		
Future Special Events		
Future Roadwork		
Ozone Advisory Messages		

Safety Campaigns/ Motorcycle Safety	
Wildlife Warning Campaigns	
Test Messages	
Messages for Other State or Transportation Agencies	
Other Sources of Traveler Information	
Public Meeting Information	

California

Usage

While emphasizing the credibility of DMS, the guideline classifies types of messages into three categories and differentiates planned and unplanned events as shown in the following Tables 8, 9 and 10.

Table 8. DMS Message Types and Uses

MESSAGE TYPE	USES-INFORMATION RELATED TO
Early Warning	**Traffic Safety/End of Queue Protection** • Unexpected Traffic • Slow Traffic • Stopped Traffic
Advisory	**Guidance** • Post-Event Congestion • Advance Notice • Major Closure • Major Special Event • Emergency Security Messages • Adverse Roadway Conditions • Lanes Blocked (Temporary Duration) • Lanes Closed (Long Duration) • Freeway/Highway/Ramp/Connector Closed **Congestion** • Expected Travel Times • Expected Delays **Alerts that have been approved and requested by CHP's ENTAC:** • AMBER Alert – Child Abduction Information • Blue Alert – Assault on a law enforcement officer
Alternative Route	**Guidance** • Soft Detour (Optional Detour) • Hard Detour (Required Detour)

Table 9. DMS Usage for Planned Events

PLANNED EVENT	EXAMPLES
Construction Activity	Lane Closures, Detours,Change in Lane Pattern,Special Speed Control Meaures
Maintenance Activity	Lane Closures, Moving Closures
Permit Activity	Utility Work, Encroachment Work, Special Event, Filming, Transportation Loads
Special Event	Ballgames, Concerts, Festivals, Parades
Operational Feature	High- Occupancy Vehicle, Reversible, Exclusive or Contraflow Lanes, Ramp Meters
Design Feature	Drawbridges, Tunnels, Ferry Services
Safety Campaigns	Seat belts, Phone use, DUI

Table 10. DMS Usage for Unplanned Events

UNPLANNED EVENT	EXAMPLES
Accident	Jackknife, Fatal, Overturn, Spilled Load
Hazardous Material (HAZMAT) Spill/Release	Chemical Spill, Oil Spill, Toxic Cloud, Refinery Fire
Natural Disaster	Flood, Slide, Fire, Earthquake, Tornado
Police Activity*	Bomb Threat, Terrorist Attack, Hostage/Kidnap Situation, Suicide Attempt
Severe Weather	Fog, Dust, Wind, Snow, Ice
*A CMS may be used for police activity that directly impacts the motorist or travel way.	

Location

The guideline emphasizes that the most appropriate locations for installing or placing a DMS are in advance of major decision points, such as interchanges or intersections, where motorists can respond to specific information displayed on the DMS. A DMS should be located as close to the edge of the traveled way (ETW) as possible to maximize visibility. Figures 8 and 9 show the location of the DMS.

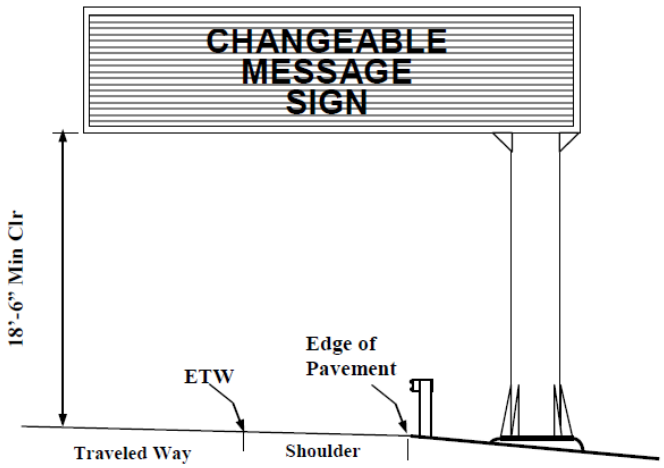


Figure 8. Simple overhead hybrid signs

Figure 9. Example of a Permanent DMS in California

Content

One of the units of information is the location statement (see Table 11). As shown in Table 12, location statement information should be useful whether motorists are familiar or unfamiliar with the area. If exit numbers are posted, the operator should use them in the location statement. Since exit numbers are determined by mile-based increments, they are a preferred location reference. The location can also be referenced by distance or prominent landmarks.

Table 11. Message Anatomy Examples

PHASE 1			
UNITS OF INFO.	INFORMATION	MOTORIST QUESTION	CMS ANSWER
1 1 1	Problem Location Effect	What happened? Where? What is the effect on traffic?	ACCIDENT AT EXIT 12 TRAFFIC JAMMED
PHASE 2			
UNITS OF INFO.	INFORMATION	MOTORIST QUESTION	CMS ANSWER
1 1	Audience Action	Who is message for? What is advised?	STOCKTON TRAFFIC USE HWY 99

Table 12. Units of Information Breakdown

UNITS OF INFO.	INFORMATION	MOTORIST QUESTION	CMS ANSWERS (examples)
1	Problem/Descriptor	What happened?	ACCIDENT HIGH WINDS FLOODING
1	Location	Where?	AT EXIT 12 AT LONG BEACH BL 15 MILES AHEAD
1	Lane Closed (blocked)	What is Closed (blocked)?	2 LT LANES CLSD FREEWAY CLOSED SINGLE LANE ONLY
1	Effect	What is the Effect on Traffic?	TRAFFIC JAMMED 25 MIN DELAY
1	Audience	Who is the Message for?	COLISEUM STOCKTON TRAFFIC
1	Action	What is Advised?	USE HWY 99 PREPARE TO STOP USE EXIT 24

The guideline emphasizes the following key points about the unit of information.

a. Limit each line of the DMS to one unit of information whenever possible. No more than two units of information on a line.
b. It is acceptable (when space is needed) to convey a unit of information over multiple lines.
c. No more than three units of information on a single message phase.
d. No more than four units of information in the entire message when traffic operating speeds are 35 mph or more.
e. No more than five units of information in the entire message when traffic operating speeds are less than 35 mph.
f. Only one unit of information on a single line. Finish one unit of information before starting another.
g. Compatible units of information should be displayed on the same message phase.
h. A single unit of information should not be split among two phases.

The guideline also differentiates the early warning messages as shown in Figure 10.

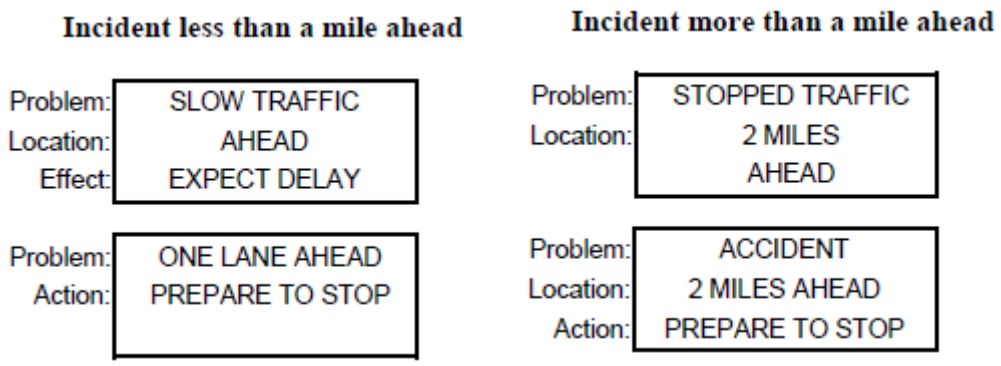


Figure 10. Early Warning Messages

For travel time messages, again with the emphasis on credibility, the guideline recommends that messages should only be used in regions or corridors that experience recurring congestion, where traffic conditions are dynamic enough that they are not viewed as static messages. The format of the message will differ slightly depending on the number of destinations (targets) shown in the message but should be limited to one-phase. Examples are shown in Figure 11.

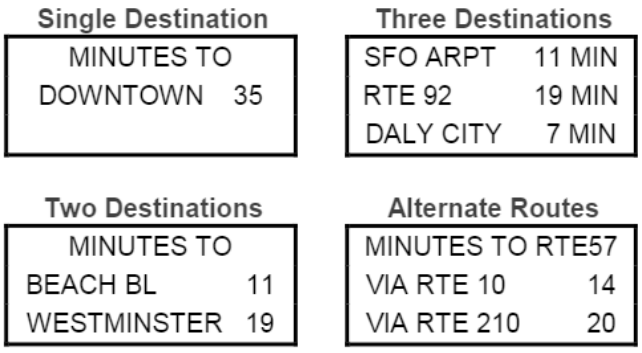


Figure 11. Travel Time Messages

Finally, California also uses DMS for safety-campaign messages. Examples are shown in Figure 12.

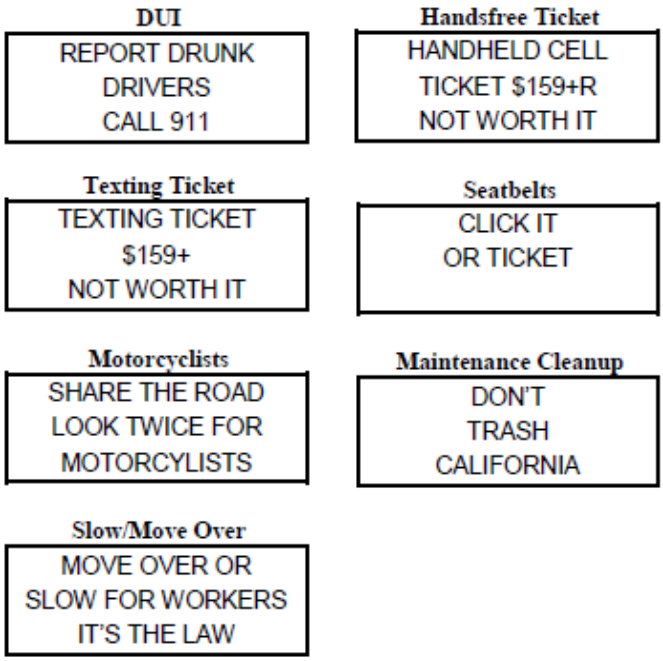


Figure 12. Safety Campaign Messages

Abbreviations

Acceptable abbreviations from the Manual on Uniform Traffic Control Devices (MUTCD) are provided in Table 13. Some abbreviations should be followed with a prompt word as shown in Table 13, and Table 14 shows the abbreviations that should be avoided because of misunderstanding

Table 13. Acceptable Abbreviations

WORD	ABBREVIATION	POTENTIAL PROMPT WORD
Access	ACCS	ROAD
Afternoon/Evening	PM	
Ahead	AHD	ACCIDENT *
Alternate	ALT	ROUTE
Avenue	AVE, AV	
Bicycle	BIKE	
Blocked	BLKD, BLOCKD	LANE *
Boulevard	BLVD, BL	
Bridge	BRDG	(Name) *
Canyon	CYN	
Center	CNTR	
Chemical	CHEM	SPILL
Circle	CIR	
Closed	CLSD, CLOSD	LANE *
Condition	COND	TRAFFIC *
Congested	CONG	TRAFFIC *
Construction	CONST	AHEAD
Crossing (other than highway-rail)	XING	
Do Not	DONT	

WORD	ABBREVIATION	POTENTIAL PROMPT WORD
Downtown	DWNTN	TRAFFIC
Drive	DR	
East	E	(Route #)
Emergency	EMER	
Entrance, Enter	ENT	
Exit	EX, EXT	NEXT *
Express	EXP	LANE
Expressway	EXPWY	
Feet	FT	
FM Radio	FM	
Freeway	FWY, FRWY	
Friday	FRI	
Frontage	FRNTG	ROAD
Hazardous	HAZ	CONDITIONS
Hazardous Material	HAZMAT	
Highway	HWY	
Hour(s)	HR	
Information	INFO	
Interstate	I	(Route #)
Junction/Intersection	JCT	
Lane	LN	
Lanes	LNS	
Left	LT, LFT	LANE
Local	LOC	TRAFFIC
Lower	LWR	LEVEL
Maintenance	MAINT	
Major	MAJ	ACCIDENT
Mile	MI	
Miles Per Hour	MPH	
Minor	MNR	ACCIDENT
Minute(s)	MIN	(Number) *
Monday	MON	
Morning/Late Night	AM	
Nights	NITES	
Normal	NORM	
North	N	(Route #)
Oversized	OVRSZ	LOAD
Parking	PRKNG	
Parkway	PKWY	
Pavement	PVMT	ROUGH *
Pedestrian	PED	
Prepare	PREP	TO STOP
Required	REQ	CHAINS *
Right	RT, RHT	LANE
Road	RD	
Roadwork	RDWK	(Distance) AHEAD
Route	RTE	(Route #)
Saturday	SAT	
Service	SERV	
Shoulder	SHLDR	
South	S	(Route #)
Speed	SPD	

WORD	ABBREVIATION	POTENTIAL PROMPT WORD
Street	ST	
Sunday	SUN	
Telephone	PHONE	
Temporary	TEMP	
Thursday	THURS	
Traffic	TRAF	
Tuesday	TUES	
Two-Way Intersection	2-WAY	
Two-Wheeled Vehicles	CYCLES	
Upper	UPR	LEVEL
US Numbered Route	US	(Route #)
Vehicle(s)	VEH	ALL *
Visibility	VISB	REDUCED *
Warning	WARN	
Wednesday	WED	
West	W	(Route #)
Will Not	Wont	

Table 14. Abbreviations to be Avoided

ABBREVIATION	INTENDED WORD	MISINTERPRETATIONS
ACC	Accident	Access (Road)
CLRS	Clears	Colors
DLY	Delay	Daily
FDR	Feeder	Federal
L	Left	Lane (Merge)
LT	Light (Traffic)	Left
PARK	Parking	Park
POLL	Pollution (Index)	Poll
RED	Reduce	Red
STAD	Stadium	Standard
WRNG	Warning	Wrong

Sample messages

Table 15, below, provides examples of DMS message.

Table 15. Examples of Permanent DMS Messages

EVENT/SCENARIO	PREFERRED	AVOID	COMMENTS
Abbreviation	E 10 AT MILIKEN 3 LT LANES CLSD	E 10 AT MILIKEN 3 LT LNS CLSD	➢ A string of abbreviations makes it more difficult to comprehend. ➢ Avoid using 3 or more *consecutive* abbreviations.
Use of *ST*, *RD*, and *AVE*	ACCIDENT AT GENESEE AV LT LANE BLOCKED		➢ The modifiers of surface street names (such as, ST, RD, AVE) are not required and can be omitted. ➢ The modifiers should be omitted if doing so allows room for more important words. ➢ The modifiers are required if more than one street in the area have identical numeric names. - In this case, there was an 8th St and an 8th Ave.
	ACCIDENT AT LOS CARNEROS SINGLE LANE ONLY	ACCIDENT LOS CARNEROS RD SINGLE LANE ONLY	
	3 RT LANES CLOSD AT 8TH AVE TRAFFIC JAMMED		
Use of Numbers	ACCIDENT AT 17TH ST	ACCIDENT AT SEVENTEENTH ST	➢ Use numbers whenever possible.
	N 5 AT GENESEE 2 LT LANES CLOSD	N 5 AT GENESEE TWO LT LNS CLSD	
"HWY", "FWY",. "RTE", "I", or "SR"	ACCIDENT AT 5-FWY	ACCIDENT AT SR-55	➢ .Common Caltrans practice is to use "HWY", "FWY" or "RTE" to address the subject route. Be careful "RTE" doesn't get confused with "RT". "CA" can also be used for state routes. ➢ "SR" is not considered a common abbreviation to the public and should not be used. ➢ "I" is still used to indicate "Interstate," especially when space is limited
	ACCIDENT AT HWY-57		
	ACCIDENT AT I-5		

EVENT/SCENARIO	PREFERRED	AVOID	COMMENTS
Single phase messages are preferred	3 RT LANES CLSD AT ROSEMEAD BL TRAFFIC JAMMED	3 RT LANES CLSD AT ROSEMEAD BL TRAFFIC JAMMED	➢ . This information can be displayed on a single phase 3 line message, rather than a 2 phase message.
	3 RT LANES CLSD AT MICHILLINDA TRAFFIC JAMMED	3 RT LANES CLSD MICHILLINDA AVE TO BALDWIN AVE TRAFFIC JAMMED	➢ The location of the beginning of the closure is useful to motorists. The lane closure limits are not as critical. In this case, forgoing the closure limits kept the message to a single phase.
Congestion after an incident is cleared from the roadway	TRAFFIC JAMMED CITRUS TO GRAND 30 MIN DELAY		➢ Providing congestion limits is very effective and useful for motorists. ➢ When pressed for space, a dash can be used to replace the word "TO," when conveying the limits between two points. ➢ Use "TO instead of "AT" if the CMS is located in the traffic queue.
	HEAVY TRAFFIC ROSEMEAD – GRAND		
	TRAFFIC JAMMED TO ROSEMEAD		
	SOUTH 880 JAMMED FRUITVALE TO HEGENBERGER RD		➢ Advising of congestion that is on a different freeway than the CMS.
CMS is on the same route as the incident	2 LFT LANES BLKD AT LAKE AVE	2 LEFT LANES AT LAKE BLOCKED	➢ No need to display the freeway route number. ➢ *Problem* stated on one line and *Location* stated on another.

EVENT/SCENARIO	PREFERRED	AVOID	COMMENTS
Only one lane is open.	E 60 AT PECK RD SINGLE LANE ONLY SINGLE LANE ONLY AT GOVERNOR DR	E 60 AT PECK 3 RT LANES BLKD	➢ ."Single Lane Only" has a great impact, and provides a good description of the conditions to the motorists.
Off ramp or Freeway Connector closed	FAIRFAX EXIT CLOSED EAST 580 EXIT CLOSED	FAIRFAX OFF-RAMP CLOSED E 580 CONNECTOR CLOSED	➢ The word "Exit" is preferred when referring to an off ramp or freeway connector
Freeway Connector closed with recommended detour	W 10 EXIT CLOSED DETOUR USE VALLEY EXIT EAST 60 EXIT CLOSED USE EAST 10 TO SOUTH 710 SOUTH 5 EXIT CLOSED DETOUR USE WEST 60 TO S 710	W 10 CONNECTOR CLOSED	➢ If a detour is in place, the word "Exit" is preferred when referring to a freeway connector.

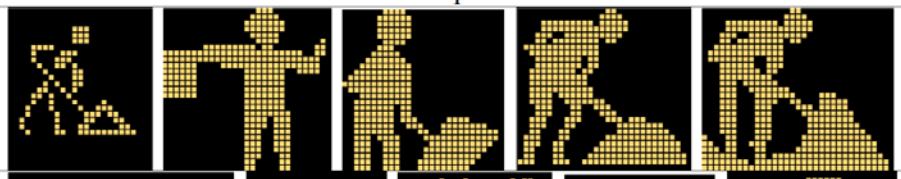
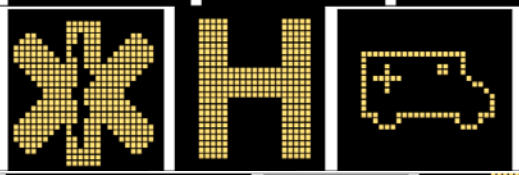
EVENT/SCENARIO	PREFERRED	AVOID	COMMENTS
Freeway Connector (both directions) closed	RTE 10 EXITS CLOSED		
	ACCIDENT HWY 101 EXITS BLOCKED		
Off ramp partially blocked	ACCIDENT FAIRFAX EXIT BLOCKED		
Freeway Connector closed on another route	N 710 TO W 105 EXIT CLOSED		
	NORTH 710 TO WEST 105 EXIT CLOSED		
Freeway Closed with recommended Detour	FREEWAY CLOSED AT CAPITOL AV USE NEXT 2 EXITS		
	FREEWAY CLOSED AT WESTLAKE BL DETOUR USE LINDERO CYN EXIT		

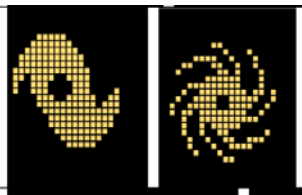
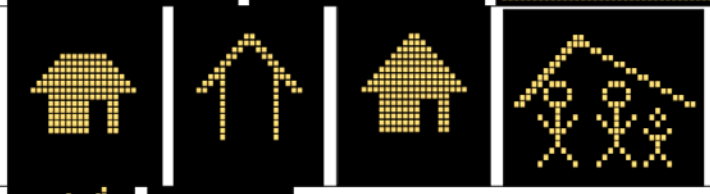
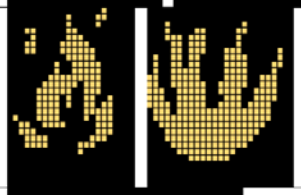
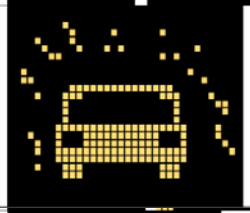
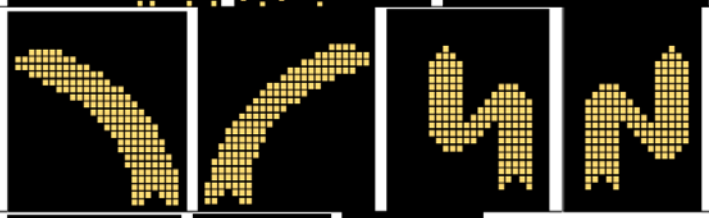
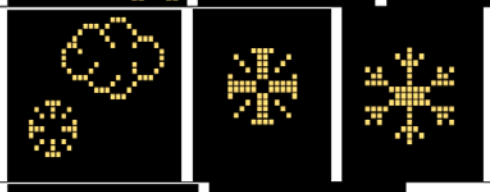
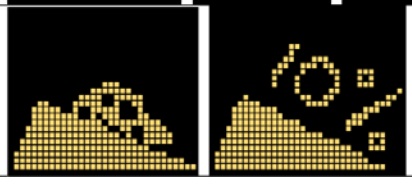
EVENT/SCENARIO	PREFERRED	AVOID	COMMENTS
More Example Messages	TRAFFIC INFO TUNE TO 1620 AM		ADDITIONAL INFORMATION ➢ The only desirable punctuation is a dash - avoid periods, commas, quotes, etc. ➢ The dash in between the *direction* and *route* # is optional and can be omitted. In some cases, the dash can improve the "aesthetics" of the message. ➢ Make sure reference is a major cross street with signing on freeway. ➢ Always use the word accident if accident involved.
	SLOW DENSE FOG AHEAD		
	TOLL LANES CLOSED		
	ANAHEIM POND EXIT BALL RD		
More Example Messages	CAUTION FLOODING AHEAD		➢ For off route incidents, use affected route and direction after the word "ACCIDENT". ➢ Only use the word "AHEAD" on signs one mile or less from an accident scene or event. ➢ Limit messages to two lines or one phase when possible
	HIGH WINDS THRU TEJON PASS		

Connecticut

In research that studied the use of graphics-aided DMS to help elderly drivers better understand messages, Connecticut collected graphical signs from different all over the world. Based on a simulator-based study, it was concluded that drivers responded faster to messages displayed with graphical symbols although with slightly less accuracy than text-only messages for younger drivers. Examples of these images are provided in Table 16.

Table 16. DMS Graphics Images

Message	Graphics
Road Work	
Accident	
Congestion	
Emergency Vehicles	
High Wind	
Lane Shift	
Slippery Road	
Seat Belt	

Hurricane	
Bridge Out	
Shelter	
Fire	
Fog Poor Visibility	
Soft Shoulder	
Sharp Turn	
Snow or Ice	
Steep Grade	

New Jersey

Unit of information

Like most of the other states, New Jersey illustrates unit of information as shown in Table 17.

Table 17. Unit of Information

Question	Answer	Unit of Info
1. What happened?	ACCIDENT	1 unit
2. Where?	AT EXIT 12	1 unit
3. What effect on traffic?	MAJOR DELAY	1 unit
4. Who is advisory for?	NEW YORK	1 unit
5. What is advised?	USE ROUTE 46	1 unit

In this regard, DMS are subject to the instructions shown in Table 18 and Figure 13.

Table 18. Unit of Information Instructions

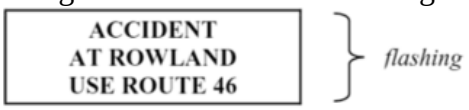
ENTIRE MESSAGE:
- No more than *4 units* of information for operating speeds of 35 mph or more.
- No more than *5 units* of information for operating speeds less than 35 mph

LENGTH OF MESSAGE FRAME:
- No more than *3 units* of information.

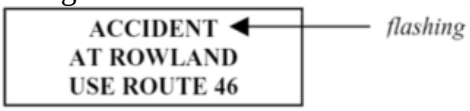
LENGTH OF MESSAGE LINE:
- No more than *2 units* of information.

Maximum Number of Units of Information Allowed in VMS Message			
Condition	Light-Emitting Diode VMS		
	0-35 mph	36-55 mph	56-70 mph
Mid-Day	5 units	4 units	4 units
Sun Washout	5 units	4 units	4 units
Sun Backlight	4 units	4 units	3 units
Nighttime	4 units	4 units	3 units

Flashing an entire one-frame message.



Flashing one line of a one-frame message.



Alternating text on one line of a three-line DMS while keeping the other two lines of text the same.

Figure 13. Dynamic features to avoid

Travel Time examples
Figure 14 shows the examples of travel time

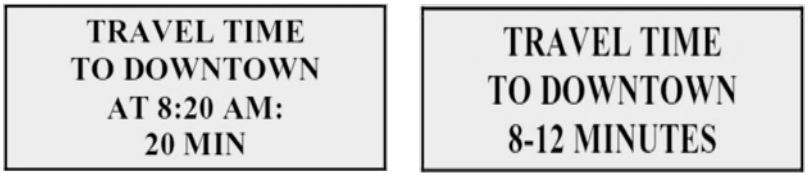


Figure 14. Travel Time Example

Delay examples
Figure 15 shows the delay message exampls.

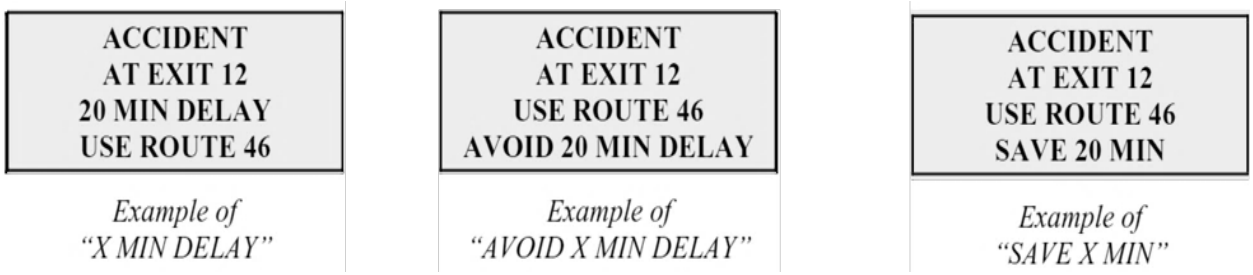
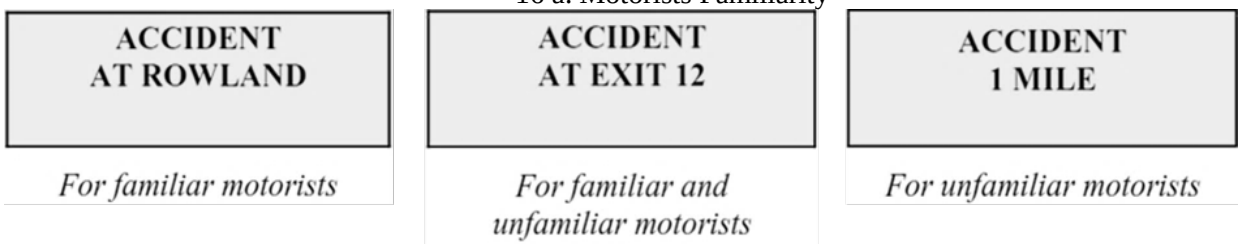


Figure 15. Delay Examples

Closure examples
Figure 16 show the examples of closure.

16 a. Motorists Familiarity



16 b. Word Choice

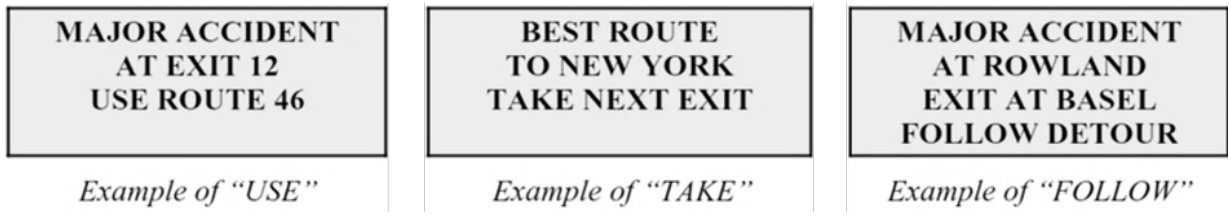


Figure 16. Closure Examples

In closure events, the guideline recommends using the following terms as shown in Tables 19, 20, 21 and 22:

- *Action:*
  - *When motorists are not advised to take an alternative route (no diversion action)*

PREPARE TO STOP

REDUCE SPEED

STAY ON [route number] [cardinal direction]

  - *When motorists are advised to take an alternative route*

EXIT AND USE OTHER ROUTES

USE OTHER ROUTES

- *Reason:*

The guideline also suggests providing motorists with the reason for the action recommended on DMSs. The reasons are as follows:

AVOID DELAY

AVOID MAJOR DELAY

SAVE [number] MINUTES

BEST ROUTE TO [destination]

- *Location:*

Some recommended examples are as follows:

[number] MILES (AHEAD)

AT [highway, street name]

BEFORE [highway, street name]

NEAR [highway, street name]

PAST [highway, street name]

- *Lanes closed/blocked:*

[number] LANES BLOCKED

[number] LANES CLOSED

[number] LANES OPEN

- *Effect on travel:*

DELAY

MAJOR DELAY

[number] MINUTES DELAY

- *Roadwork descriptors:*

CONSTRUCTION

ROADWORK

Table 19. Large DMS vs. Portable DMS Examples for Lane Blockage

Message Characteristics Highlights	Large DMS		Portable DMS	
	Frame 1	**Frame 2**	**Frame 1**	**Frame 2**
• "ACCIDENT" for Incident Descriptor message element. • Incident (Blockage) Location message element. • Lanes Blocked message element. • No Action message element.	ACCIDENT AT ROWLAND DR RIGHT LANE BLOCKED		ACCIDENT AT ROWLAND	RIGHT LANE BLOCKED
• "MAJOR ACCIDENT" for Incident Descriptor message elements.	MAJOR ACCIDENT AT ROWLAND 3 RIGHT LANES BLOCKED			
• "TRUCK ACCIDENT" for Incident Descriptor message element.	TRUCK ACCIDENT AT ROWLAND 3 RIGHT LANES BLOCKED			
• Highway name (number) for Incident (Blockage) Descriptor message element. • No Action message element	ACCIDENT NEAR I-287 2 RIGHT LANES BLOCKED		ACCIDENT NEAR I-287	2 RIGHT LANES BLOCKED
• Replacing Incident Descriptor message element with lanes Blocked message element.	2 RIGHT LANES BLOCKED NEAR I-287			
• Action message element. • No diversion	ACCIDENT PAST ROWLAND	2 RIGHT LANES BLOCKED PREPARE TO STOP		
• Action message element. • No diversion. • Replacing Incident Descriptor message element with Lanes Blocked message element.	2 RIGHT LANES BLOCKED PAST ROWLAND	PRPARE TO STOP		
	2 RIGHT LANES BLOCKED PAST ROWLAND PREPARE TO STOP			

Table 20. Large DMS vs. Portable DMS Examples When all Lanes are Blocked

Message Characteristics Highlights	Large DMS		Portable DMS	
	Frame 1	Frame 2	Frame 1	Frame 2
• "ACCIDENT" for Incident Descriptor message element. • Incident (Blockage) Location message element. • Lanes Blocked message element. • No Action message element.	(Does not apply in this case.)			
• "MAJOR ACCIDENT" for incident Descriptor message element.	MAJOR ACCIDENT AT ROWLAND DR ALL LANES BLOCKED			
• "TRUCK ACCIDENT" for Incident Descriptor message element.	TRUCK ACCIDENT AT ROWLAND ALL LANES BLOCKED			
• Highway name (number) for Incident (Blockage) Location message element. • No Action message element.	MAJOR ACCIDENT NEAR I-287 ALL LANES BLOCKED		ACCIDENT NEAR I-287	ALL LANES BLOCKED
• Combining Incident Descriptor and Lanes Closed message elements.	FREEWAY BLOCKED NEAR I-287			
• Action message element. • No diversion.	MAJOR ACCIDENT PART ROWLAND	ALL LANES BLOCKED PREPARE TO STOP		
• Action message element. • No diversion. • Combining Incident Descriptor and Lanes Closed message elements.	FREEWAY BLOCKED PAST ROWLAND	PREPARE TO STOP		
	FREEWAY BLOCKED PAST ROWLAND PREPARE TO STOP			

Table 21. Examples of Improved Messages for Incidents

Old Message		Recommended Message		Notes
First Frame	Second Frame	First Frame	Second Frame	
ACCIDENT AHEAD USE CAUTION		ACCIDENT AT [location]		• It is best to give the location of the incident. Knowledge of the incident location is useful to motorists to make diversion and other driving decisions. • ***AHEAD*** is redundant and need not be displayed because it is understood by motorists that the lane closure is ahead on the freeway.

ACCIDENT AHEAD 21ST STREET USE CAUTION		ACCIDENT AT 21ST STREET 2 LEFT LANES CLOSED		• **AT** should be displayed before the location of the incident. • Knowledge of the number of lanes closed is useful to motorists to evaluate the potential amount of delay. • Knowledge of which lanes are closed is useful to motorists to determine which lanes they should use to travel past the incident. • ***AHEAD*** is redundant and need not be displayed because it is understood by motorists that the lane closure is ahead on the freeway.
ACCIDENT AHEAD I-84 EXPECT DELAYS		ACCIDENT AT [location] 2 LEFT LANES CLOSED		• It is best to give the location of the incident rather that the information that the accident is on I-84. If the VMS is on I-84, it will be understood by motorists that the accident is on I-84 and it need not be displayed. • Knowledge of the incident location is useful to motorists to make diversion and other driving decisions. • Knowledge of the number of lanes closed is useful to motorists to evaluate the potential amount of delay. • Knowledge of which lanes are closed is useful to motorists to determine which lane they should use to travel past the incident. • ***AHEAD*** is redundant and need not be displayed because it is understood by motorists that the lane closure is ahead on the freeway.
ACCIDENT AHEAD RIGHT LANES USE CAUSTION		ACCIDENT AT [location] 2 RIGHT LANES CLOSED		• It is best to give the location of the incident rather than the information that the accident is ahead. Knowledge of the incident location is useful to motorists to make diversion and other driving decisions. • Knowledge of the number of lanes closed is useful to motorists to evaluate the potential amount of delay. • ***AHEAD*** is redundant and need not be displayed because it is understood by motorists that the lane closure is ahead on the freeway.

ACCIDENT AHEAD ONE RIGHT LANE OPEN	ACCIDENT AHEAD BROOK BRIDGE EXPECT DELAYS	ACCIDENT AT BROOK BRIDGE 2 LEFT LANES CLOSED		• The current message has five units of information and can be reduced to three units. • Knowledge of the number of lanes closed is useful to motorists to evaluate the potential amount of delay. • Knowledge of which lanes are closed is useful to motorists to determine which lanes they should use to travel past the incident. • ***AHEAD*** is redundant and need not be displayed because it is understood by motorists that the lane closure is ahead on the freeway.
ACCIDENT AHEAD REDUCE SPEED MERGE LEFT	RIGHT LANE CLOSED AHEAD DRIVE CAREFULLY	ACCIDENT AT [location] RIGHT LANE CLOSED		• The current message has five units of information and can be reduced to three units. • It is best to give the location of the accident. Knowledge of the accident location is useful to motorists to make diversion and other driving decisions. • Knowledge of the number of lanes closed is useful to motorists to evaluate the potential amount of delay. • ***AHEAD*** is redundant and need not be displayed because it is understood by motorists that the lane closure is ahead on the freeway. • ***MERGE LETF*** is redundant to ***RIGHT LANE CLOSED*** and can be omitted.
ALL LANES CLOSED AHEAD KEEP RIGHT		FREEWAY CLOSED	EXIT AT [location] FOLLOW DETOUR	• ***FREEWAY CLOSED*** is used rather than ***ALL LANES CLOSED*** because it is shorter and means the same thing to motorists. • Telling motorists where to exit is useful. • Telling motorists to follow a detour that is set up because of the closure gives motorists the assurance that they will have positive guidance along the alternative route. • The recommended message is placed on two frames because research has shown that no more than three units of information should be displayed on a message frame. The second frame in the recommended message has three units of information.

ACCIDENT IH-84 EAST AT ROWLAND	USE ALTERNATE ROUTES	ACCIDENT AT ROWLAND	USE OTHER ROUTES	• If the VMS is located on I-84 East, the accident is understood to be on I-84 East and it need not be displayed. • ***OTHER*** is used rather than ***ALTERNATE*** because it is shorter and easier to read and will be understood by motorists.
		ACCIDENT ON I-84 EAST AT ROWLAND	USE OTHER ROUTES	• If the VMS is located on a cross freeway to I-84 East, then ***ON I-84 EAST*** must be displayed. • ***I-84*** should be used rather that ***IH-84***. Human factors research by TTI revealed that motorists do not understand "IH".
IH-84 EAST ACCIDENT AT ROWLAND	USE ALTERNATE ROUTES	ACCIDENT AT ROWLAND USE OTHER ROUTES		• If the VMS is located on a cross freeway to I-84 East, then ON I-84 EAST must be displayed. • The problem ***ACCIDENT*** should always be on the top line. • ***OTHER*** is used rather than ***ALTERNATE*** because it is shorter and easier to read and will be understood by motorists.
IH-84 EAST ACCIDENT DOWNTOWN	TWO RIGHT LANES CLOSED	ACCIDENT NEAR DOWNTOWN 2 RIGHT LANES CLOSED		• If the VMS is located on I-84 East, the accident is understood to be on I-84 East and it need not be displayed. • The problem ***ACCIDENT*** should always be on the top line. • 2 should be used rather that ***TWO*** because it is shorter and more easily read by motorists. • ***NEAR*** is displayed in front of DOWNTOWN to reduce possibility of confusion as to the location of the accident.
IH-84 EB AT ROWLAND MAJOR ACCIDENT		MAJOR ACCIDENT AT ROWLAND 2 LANES CLOSED		• The incident should be displayed on the top line followed by location. • The word ***AT*** should be separated from the first unit of information and be placed with the location of the incident (second unit of information). A message line should not contain portions of two different units of information. • Knowledge of the number of lanes closed is useful to motorists to evaluate the potential amount of delay. • Human factors research conducted by TTI revealed that a large majority of motorists do not understand the meaning of the abbreviation ***EB***.

IH-84 EAST ACCIDENT AT ROWLAND	USE ALTERNATE ROUTES	FREEWAY CLOSED AT ROWLAND USE OTHER ROUTES		• ***FREEWAY*** is used rather that ***I-84 EAST*** because it is shorter and easier to read and is well understood to mean the freeway on which the motorist is traveling. • The word ***CLOSED*** from the first unit of information should be separated from the word ***AT*** from the second unit of information. A message line should not contain portions of two different units of information. • ***OTHER*** is used rather than ***ALTERNATE*** because it is shorter and easier to read.
IH-84 EB AT ROWLAND FREEWAY CLOSED	2 LEFT LANES CLOSED EXPECT DELAY	ACCIDENT AT ROWLAND 2 LEFT LANES CLOSED		• If the VMS is located on I-84 East, the accident is understood to be on I-84 East and it need not be displayed. • The word ***AT*** should be separated from the first unit of information and be placed with the location of the incident (second unit of information). A message line should not contain portions of two different units of information. • Knowledge of the number of lanes closed is useful to motorists to evaluate the potential amount of delay. • ***AHEAD*** is redundant and need not be displayed because it is understood by motorists that the accident is ahead on I-84. • The abbreviation **BE** should not be used. Recent human factors studies conducted by **TTI** indicated that a large percentage of motorists would not understand abbreviation **BE**. • When two lanes are closed due to an accident, most motorists will ***EXPECT DELAYS***. Thus, it can be omitted.
IH-84 EB AT ROWLAND FREEWAY CLOSED	AVOID DELAY USE ALTERNATE ROUTE	FREEWAY CLOSED AT ROWLAND USE OTHER ROUTES		• The current message has five units of information and can be reduced to three units. • The incident should be displayed on the top line followed by the incident location. • Human factors research conducted by TTI revealed that a large majority of motorists do not understand the meaning of the abbreviation ***EB***.

				• ***OTHER*** is used rather than ***ALTERNATE*** because it is shorter and easier to read and will be understood by motorists.
FREEWAY CLOSED AT ROWLAND MAJOR ACCIDENT	ALL TRAFFIC EXIT ROWLAND	FREEWAY CLOSED	EXIT AT ROWLAND USE SERVICE RD	• The current message has five units of information and can be reduced to three units. • ***FREEWAY CLOSED*** is used rather than ***MAJOR ACCIDENT*** because it represents the immediate problem the motorists will face. • If the freeway is closed, the motorists will understand that ***ALL TRAFFIC*** must exit. The recommendation is to tell the motorists that they should ***EXIT AT WASHINGTON*** and the ***USE SERVICE ROAD*** to bypass the incident.
MAJOR ACCIDENT AT ROWLAND ON MAIN LANES	AVOID DELAY USE ALTERATE ROUTE	MAJOR ACCIDENT AT ROWLAND USE OTHER ROUTES		• Information that the accident is ***ON MAIN LANES*** will be understood by motorists and it need not be displayed. • ***OTHER*** is used rather than ***ALTERNATE*** because it is shorter and easier to read. • The motorist would assume that if told to use other routes the motorist would avoid delay. Thus, ***AVOID DELAY*** need not be displayed.
MAJOR ACCIDENT AT ROWLAND CLEARED AT 5:10	2 LEFT LANES CLOSED EXPECT DELAY	MAJOR ACCIDENT AT ROWALAND CLEARED AT 5:10		• Conflicting information is given in the current message. The first message frame states that the accident was cleared at 5:10; the second frame states that two lanes are closed. The recommended message assumes that the former is true.

Table 22. Examples of Improved Messages for Roadwork

Current Message		**Recommended Message**		**Notes**
First Frame	**Second Frame**	**First Frame**	**Second Frame**	
LEFT LANE CLOSED AHEAD EXPECT DELAY		LEFT LANE CLOSED AT [location] EXPECT DELAY		• It is best to give the location of the lane closure. Knowledge of the lane closure location is useful to motorists to make diversion and other driving decisions. • ***AHEAD*** is redundant and need not be displayed because it is understood by motorists that the lane closure is ahead on the freeway.

RIGHT TWO LANES CLOSED KEEP LEFT		2 RIGHT LANES CLOSED AT [location]		• It is best to give the location of the lane closure. Knowledge of the lane closure location is useful to motorists to make diversion and other driving decisions. • 2 should be used rather that ***TWO*** because it is shorter and more easily read by motorists. • ***KEEP LEFT*** is redundant and need not be displayed.
IH-84 REDUSED TO ONE LANE AHEAD	ROWLAND TO WOODWARD EXPECT DELAY	2 LANES CLOSED FROM ROWLAND TO WOODWARD		• The current message has five units of information and can be reduced to three units. • If the VMS is located on I-84, the lanes closures are understood to be on I-84 and it need not be displayed. • Giving the limits of the lane closures as was done in the current message is an excellent means of informing motorists the extent of the closure and where they may return to the freeway should they decide to divert.
		1 LANE OPEN FROM ROWLAND TO WOODWARD		
LANE CLOSURE BEGIN TUESDAY 8 P.M. – 6 A.M.	LANE CLOSURE TUES – THURS 8 P.M. – 6 A.M.	1 LANE CLOSED TUES – THURS 8 PM – 6 AM		• The current message has two frames with only the middle line changing information between frames. Motorists may not notice the subtle change of only the middle line. The message can be reduced to a simple one-frame, three-unit message. • ***TUES – THURS*** is more descriptive than ***BEGIN TUESDAY.*** However, including it in the message would result in a five-unit message.
LEFT TWO LANES CLOSED AT ROWLAND CONSIDER DETOUR		21 LEFT LANES CLOSED AT ROWLAND USE OTHER ROUTES		• The word ***CLOSED*** in the first unit of information should be separated from the second unit of information and be placed with the problem (first unit of information). A message line should not contain portions of two different units of information. • 2 should be used rather that ***TWO*** because it is shorter and more easily read by motorists. • ***USE OTHER ROUTES*** is used rather than ***CONSIDER DETOUR***. DETOUR implies to motorists that positive guidance will be provided along a route in the form of trailblazers for motorists to follow around the incident and/or police control.
RIGHT TWO LANES CLOSED DOWNTOWN		2 RIGHT LANES CLOSED NEAR DOWNTOWN		• 2 should be used rather that ***TWO*** because it is shorter and more easily read by motorists. • ***NEAR*** is displayed in front of DOWNTOWN to reduce possibility of

				confusion as to the location of the lane closure.
CAUTION INTERSTATE 84 EASTBOUN	RIGHT THREE LANES CLOSED AHEAD	3 RIGHT LANES CLOSED AT [location]		• This current message has five units of information that can be reduced to three units. • If the VMS is located on I-84 East, the lane closures are understood to be on I-84 East and it need not be displayed. • 3 should be used rather than ***THREE*** because it is shorter and more easily read by motorists. • It is best to give the location of the lane closure. Knowledge of the lane closure location is useful to motorists to make diversion and other driving decisions. • The long word ***INTERSTATE*** should not be used; instead, use I-.
IH-84 EASTBOUND	RIGHT THREE LANES CLOSED	3 RIGHT LANES CLOSED AT [LOCATION]		• If the VMS is located on I-84 EAST, the lane closures are understood to be on I-84 EAST and it need not be displayed. • 3 should be used rather that **THREE** because it is shorter and more easily read by motorists. • It is best to give the location of the lane closure. Knowledge of the lane closure location is useful to motorists to make diversion and other driving decisions.
IH-84 EAST DOWNTOWN ROAD WORK	THRU TRAFFIC USE LEFT TWO LANES	ROADWORK NEAR DOWNTOWN	THRU TRAFFIC USE LEFT 2 LANES	• The problem, ***ROADWORK,*** should be displayed on the first line. • If the VMS is located on I-84 East, the roadwork is understood to be on I-84 East and it need not be displayed. • 2 should be used rather than **TWO** because it is shorter and more easily read by motorists. • The second message frame is reformatted slightly to enhance readability.
IH-84 EAST ROAD WORK	AT ROWLAND ON RAMP	ROADWORK AT ROWLAND 2 LANES CLOSED		• The problem, **ROADWORK,** should be displayed on the first line. • Since the VMS is located on I-84 East, the roadwork is understood to be on I-84 East and it need not be displayed. • 2 should be used rather that **TWO** because it is shorter and more easily read by motorists. • The message should include the number of lanes that are closed.

US-59 SB EXIT RAMP CLOSED UNTIL DEC 1998	DETOUR US-59 NORTH TO MUNSONS	ROMP TO US-59 S CLOSED	USE US-59 NORTH TO MUNSON	• The current message has six units of information and must be reduced to a maximum of four units. This is accomplished by omitting the least relevant unit of information, namely, **UNTIL DEC 1998.** About six days prior to the opening of the ramp, the VMS can display the day of the week when the ramp will be open, if the agency desires. • The abbreviation **SB** should not be used. Recent human factors studies conducted by **TTI** indicated that a large majority of motorists do not understand the meaning of the abbreviation **SB**.

Texas

The guideline provides examples for mixed conditions as shown in Tables 23, 24 and 25.

Table 23. Combination of Roadwork Descriptor with Lane Closed Message Elements

Message Elements	Revised Message Elements
<u>Roadwork on Same Freeway (US-75 North) as DMS (US-75 North)</u> Roadwork Descriptor **ROADWORK** Lane Closure Location **PAST ARAPAHO RD** Lanes Closed **LEFT 2 LANES CLOSED**	**LEFT 2 LANES CLOSED** **PAST ARAPAHO RD**
Closed Roadway Due to Roadwork on Same Freeway (US-75 North) as DMS (US-75 North) Roadwork Descriptor **ROADWORK** Lane Closure Location **PAST ARAPAHO RD** Lanes Closed **ALL LANES CLOSED** Location of Closure **AT ARAPAHO RD** Audience for Action **US-75 NORTH TRAFFIC** Action **EXIT AT ARAPAHO RD** **FOLLOW DETOUR**	**FREEWAY CLOSED** **EXIT AT ARAPAHO RD** **FOLLOW DETOUR**

Table 24. Combination of Roadwork Descriptor, Closure Location and Lanes Closed Message Element

Message Elements	Revised Message Elements
Roadwork on Different Highway (I-635 West) than DMS (US-75 North) Roadwork Descriptor **ROADWORK** Closure Location **ON I-635 WEST** **FROM HILLCREST RD** **TO PRESTON RD** Lane Closed **ALL LANES CLOSED**	**I-635 WEST CLOSED** **FROM HILLCREST** **TO PRESTON**

Table 25. Combination of Location Closure Message Element and Action Message Element

Message Component and Message	Revised Message
Closed Roadway Due to Roadwork on Same Freeway as DMS *Roadwork Descriptor* **ROADWORK** *Lane Closure Location* **PAST ARAPAHO RD** *Lanes Closed* **ALL LANES CLOSED** *Location of Closure* **AT ARAPAHO RD** *Audience for Action* **US-75 NORTH TRAFFIC** *Action* **EXIT AT ARAPAHO RD** **FOLLOW DETOUR**	**FREEWAY CLOSED** **EXIT AT ARAPAHO** **FOLLOW DETOUR**

Comparison of DMS content before and after police arrival is also provided in Table 26.

Table 26. Before and After Police Arrival

Base DMS Message Elements	Base DMS Message to Satisfy Motorist Information Needs	Final Message
Incident Descriptor Incident Location Lanes Closed Closure Location Action	MAJOR ACCIDENT PAST I-22 ALL LANES CLOSED AT I-22 USE OTHER ROUTES	FREEWAY CLOSED AT I-22 USE OTHER ROUTES
	(5 Units of Information)	(3 Units of Information)

Missouri

Missouri, like most of the other states, follows the MUTCD, which provides policies, standards, and guidelines at the national level. Since the two sections of the MUTCD that address DMS are mentioned in the Missouri guideline of DMS, the MUTCD abbreviation standards are provided in Tables 27, 28 and 29.

Abbreviations Used on Traffic Control Devices

Table 27. Acceptable Abbreviations

Word Message	Standard Abbreviation
Afternoon / Evening	PM
Alternate	ALT
AM Radio	AM
Avenue	AVE, AV
Bicycle	BIKE
Boulevard	BLVD*
Bridge	(See Table 1A-2)
CB Radio	CB
Center (as part of a place name)	CTR
Circle	CIR*
Civil Defense	CD
Compressed Natural Gas	CNG
Court	CT*
Crossing (other than highway-rail)	X-ING
Drive	DR*
East	E
Electric Vehicle	EV
Expressway	EXPWY*
Feet	FT
FM Radio	FM
Freeway	FRWY, FWY*
Friday	FRI
Hazardous Material	HAZMAT
High Occupancy Vehicle	HOV
Highway	HWY*
Hospital	HOSP
Hour(s)	HR, HRS
Information	INFO
Inherently Low Emission Vehicle	ILEV
International	INTL
Interstate	(See Table 1A-2)
Junction / Intersection	JCT
Lane	(See Table 1A-2)
Liquid Propane Gas	LP-GAS
Maximum	MAX
Mile(s)	MI
Miles Per Hour	MPH
Minimum	MIN
Minute(s)	MIN
Monday	MON
Morning / Late Night	AM
Mount	MT
Mountain	MTN
National	NATL
North	N
Parkway	PKWY*
Pedestrian	PED
Place	PL*
Pounds	LBS
Road	RD*
Saint	ST
Saturday	SAT
South	S
State, county, or other non-US or non-Interstate numbered route	(See Table 1A-2)
Street	ST*
Sunday	SUN
Telephone	PHONE
Temporary	TEMP
Terrace	TER*
Thursday	THURS
Thruway	THWY*
Tons of Weight	T
Trail	TR*
Tuesday	TUES
Turnpike	TPK*
Two-Way Intersection	2-WAY
US Numbered Route	US
Wednesday	WED
West	W

*This abbreviation shall not be used for any application other than the name of a roadway.

Table 28. Abbreviations That Shall be Used Only on Portable DMS

Word Message	Standard Abbreviation	Prompt Word That Should Precede the Abbreviation	Prompt Word That Should Follow the Abbreviation
Access	ACCS	—	Road
Ahead	AHD	Fog	—
Blocked	BLKD	Lane	—
Bridge	BR*	[Name]	—
Cannot	CANT	—	—
Center	CNTR	—	Lane
Chemical	CHEM	—	Spill
Condition	COND	Traffic	—
Congested	CONG	Traffic	—
Construction	CONST	—	Ahead
Crossing	XING	—	—
Do Not	DONT	—	—
Downtown	DWNTN	—	Traffic
Eastbound	E-BND	—	—
Emergency	EMER	—	—
Entrance, Enter	ENT	—	—
Exit	EX	Next	—
Express	EXP	—	Lane
Frontage	FRNTG	—	Road
Hazardous	HAZ	—	Driving
Highway-Rail Grade Crossing	RR XING	—	—
Interstate	I-*	—	[Number]
It Is	ITS	—	—
Lane	LN	[Roadway Name]*,Right, Left, Center	—
Left	LFT	—	—
Local	LOC	—	Traffic
Lower	LWR	—	Level
Maintenance	MAINT	—	—
Major	MAJ	—	Accident
Minor	MNR	—	Accident
Normal	NORM	—	—
Northbound	N-BND	—	—
Oversized	OVRSZ	—	Load
Parking	PKING	—	—
Pavement	PVMT	Wet	—
Prepare	PREP	—	To Stop
Quality	QLTY	Air	—
Right	RT	Keep, Next	—
Right	RT	—	Lane
Roadwork	RDWK	—	Ahead, [Distance]
Route	RT, RTE	Best	—
Service	SERV	—	—
Shoulder	SHLDR	—	—
Slippery	SLIP	—	—
Southbound	S-BND	—	—
Speed	SPD	—	—
State, county, or other non-US or non-Interstate numbered route	[Route Abbreviation determined by highway agency]**	—	[Number]
Tires With Lugs	LUGS	—	—
Traffic	TRAF	—	—
Travelers	TRVLRS	—	—
Two-Wheeled Vehicles	CYCLES	—	—
Upper	UPR	—	Level
Vehicle(s)	VEH, VEHS	—	—
Warning	WARN	—	—
Westbound	W-BND	—	—
Will Not	WONT	—	—

* This abbreviation, when accompanied by the prompt word, may be used on traffic control devices other than portable changeable message signs.

** A space and no dash shall be placed between the abbreviation and the number of the route.

Table 29. Unacceptable Abbreviations

Abbreviation	Intended Word	Common Misinterpretation
ACC	Accident	Access (Road)
CLRS	Clears	Colors
DLY	Delay	Daily
FDR	Feeder	Federal
L	Left	Lane (Merge)
LT	Light (Traffic)	Left
PARK	Parking	Park
POLL	Pollution (Index)	Poll
RED	Reduce	Red
STAD	Stadium	Standard
WRNG	Warning	Wrong

Message Priorities

The DMS messages shall be prioritized in the following order unless overridden by a supervisor.

1) Emergencies, such as evacuations or closures, required by MoDOT, the State Emergency Management Agency (SEMA), local law enforcement or the military.
2) Hazardous and/or uncommon road conditions that require motorists to alter their driving, such as severe weather conditions, accidents, work zone activities or other incidents.
3) Traveler information and suggested alternative routes for delays and/or congestion caused by planned or unplanned events.
4) Child abduction alerts originating in the local area
5) Travel times
6) Child abduction alerts originating outside the local area
7) Ozone alerts
8) Advance date or time notice for scheduled incidents such as lane closures, road closures, moving operations or special events.
9) Approved standard public service messages associated with special campaigns (i.e., work zone awareness week, share the ride) or other public information that improves highway safety and reduces congestion.

Table 30 lists the prioritization of the messages and Figure 17 provides an example of a permanent DMS.

Table 30. Prioritization of Messages

Major Accident Occurs Downstream of:	Give Message Priority to:
Major accident	Upstream major accident
Minor accident	Upstream minor accident
Roadwork with lane closure	Downstream major accident
Roadwork with freeway closure	Upstream roadwork
Incident (stalled vehicle, load spill, debris in roadway) requiring lane closure	Downstream major accident
Incident requiring total freeway closure	Upstream incident

Figure 17. A Permanent DMS in Missouri

Florida

Travel Time

In Florida, travel time is considered the default display on DMS. In fact, it is stressed in the Florida Department of Transportation Policy that the "default display on DMS shall be travel time display." According to the Florida DMS guideline, travel time on a range basis as shown in Figure 18 is considered appropriate to avoid a loss in credibility.

Figure 18. Example of a Simple Permanent DMS

They also provide examples of travel time messages using the hybrid signs, which display both static and dynamic messages on a single sign. Examples are provided in Figures 19 and 20.

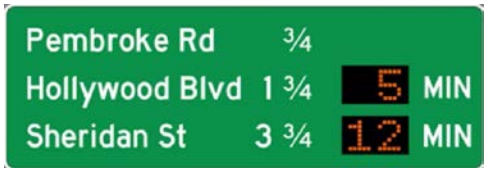


Figure 19. Simple Overhead Hybrid Signs

Figure 20. Comparative Hybrid Signs

Abbreviation Standards

The abbreviation standards, shown below, are almost the same among the states. The most agreed-upon abbreviation standards, both unacceptable and acceptable ones, are shown in Tables 31 and 32 respectively.

Table 31. Unacceptable Abbreviations

Abbreviation	Intended Word	Common Misinterpretation
ACC	Accident	Access (Road)
CLRS	Clears	Colors
DLY	Delay	Daily
FDR	Feeder	Federal
L	Left	Lane (merge)
LT	Light (Traffic)	Left
PARK	Parking	Park
POLL	Pollution (Index)	Poll
RED	Reduce	Red
STAD	Stadium	Standard
WRNG	Warning	Wrong

Table 32. Acceptable Abbreviations

Word Message	Standard Abbreviation
Afternoon/ Evening	PM
Alternate	ALT
Avenue	Ave, AV
Bicycle	BIKE
Boulevard	BLVD
Cannot	CANT
CB Radio	CB
Center	CNTR
Circle	CIR
Civil Defense	CD
Compressed Natural Gas	CNG
Court	CT
Crossing (other than highway-rail)	XING
Diesel Fuel	D
DO Not	DONT
Drive	DR
East	E
Eastbound	E-BND
Electric Vehicle	EV
Emergency	EMER
Entrance, Enter	ENT
Expressway	EXPWY
Feet	FT
FM Radio	FM
Freeway	FRWY, FWY
Friday	FRI
Hazardous Material	HAZMAT
High Occupancy Vehicle	HOV
Highway	HWY
Highway-Rail Grade Crossing Pavement Marking	RXR
Hospital	H
Hour(s)	HR
Information	INFO
Inherently Low Emission Vehicle	ILEV
It Is	ITS
Junction / Intersection	JCT
Kilogram	Kg
Kilometer(s)	Km
Kilometers Per Hour	Km/h
Lane	LN
Left	LFT

Word Message	Standard Abbreviation
Liquid Propane Gas	LP-GAS
Maintenance	MAINT
Meter(s)	M
Metric Ton	T
Mile(s)	MI
Miles Per Hour	MPH
Minute(s)	MIN
Monday	MON
Morning / Late Night	AM
Normal	NORM
North	N
Northbound	N-BND
Parking	PKING
Parkway	PKWY
Pedestrian	PED
Place	PL
Pounds	LBS
Right	RHT
Road	RD
Saturday	SAT
Service	SERV
Shoulder	SHLDR
Slippery	SLIP
South	S
Southbound	S-BND
Speed	SPD
Street	ST
Sunday	SUN
Telephone	PHONE
Temporary	TEMP
Terrace	TER
Thursday	THURS
Tons of Weight	T
Traffic	TRAF
Trail	TR
Travelers	TRAVLRS
Tuesday	TUES
Two-Way Intersection	2-WAY
Two-Wheeled Vehicles	CYCLES
US Numbered Route	US
Vehicles	VEH
Warning	WARN
Wednesday	WED
West	W
Westbound	W-BND
Will Not	WONT

Oregon

DMS message library

In Tables 33, 34, 35, 36, and 37, the '/' mark separates lines on a phase and are not part of the message. "LEFT" is generally interchangeable with "RIGHT" (and vice versa) in this list of standard messages.

Table 33. Traffic Management

Phase 1	Phase 2	Abbreviations & Notes
ABRUPT / EDGE / LEFT		
ABRUPT / EDGE / LEFT		
DO NOT PASS / STAY IN LANE		
DO NOT STOP / NO PARKING / NO SHOULDER		
EXIT CLOSED AHEAD / USE NEXT EXIT		
LEFT EXIT OPEN		
HEAVY TRAFFIC / AHEAD / PREPARE TO SLOW		
HEAVY TRAFFIC / AHEAD / PREPARE TO STOP		
LANE / NARROWS / AHEAD		
LANES SHIFT LEFT / AHEAD		
LANES SHIFT RIGHT / AHEAD		
LANE ENDS / MERGE LEFT		
LANE ENDS / MERGE RIGHT		
LEFT EXIT OPEN		
LEFT LANE CLOSED / MERGE / RIGHT		
LEFT LANE CLOSED / 1000 FT		
LEFT LANE CLOSED / X MILE / MERGE RIGHT		
LEFT LANE NARROWS / NO TRUCKS		
LEFT 2 LANES / CLOSED / USE RIGHT LANE		
MERGE / LEFT		
MERGE / RIGHT		
MERGE AHEAD / TRAFFIC ENTERS / ON LEFT		
MERGE AHEAD / TRAFFIC ENTERS / ON RIGHT		
NO CENTER STRIPE / KEEP RIGHT		
NO LANE LINES / USE CAUTION		
NO LANE LINES / KEEP RIGHT / EXCEPT TO PASS		
NO SHOULDER / DO NOT STOP		
RIGHT EXIT OPEN		
RIGHT LANE CLOSED / MERGE LEFT		
RIGHT LANE CLOSED / 1000 FT		
RIGHT LANE CLOSED / X MILE / MERGE LEFT		
RIGHT LANE NARROWS / NO TRUCKS		
RIGHT 2 LANES / CLOSED / USE LEFT LANE		
ROAD CLOSED AHEAD / LOCAL TRAFFIC ONLY		note: only use AHEAD for advance
ROAD CLOSED AHEAD / USE DETOUR		note: only use AHEAD for advance
ROAD CLOSED X MILE(S) / USE DETOUR		
ROAD NARROWS / AHEAD		
ROUGH PAVEMENT / AHEAD / PREPARE TO SLOW		(PAVEMNT)
ROUGH ROAD AHEAD / SLOW		
SHARP CURVE AHEAD / SLOW		
SLOW TRAFFIC AHEAD / PREPARE TO SLOW		
SOFT SHOULDER / USE CAUTION		(SHOULDR)
STAY IN LANE / NO LANE CHANGES		
STEEP GRADE / SLOW TRUCKS		

SUNKEN PAVEMENT / SLOW	
TRAFFIC DELAYS / PREPARE TO SLOW	
TRAFFIC DELAYS / PREPARE TO STOP	
TRUCKS CROSSING RD / USE CAUTION	(XING; CROSSING)
TWO-WAY / TRAFFIC AHEAD	(2 WAY)
WARNING / CROSS TRAFFIC / AHEAD	
WATCH FOR TRUCKS / TRUCKS ENTER RIGHT	
YIELD AHEAD	
YIELD AHEAD / YIELD TO ONCOMING	(ONCOMING)

Table 34. Work Zone Management

Phase 1	Phase 2	Abbreviations & notes
CREW PAINTING / CENTER LINE / KEEP TO RIGHT		(PAINTING)
DETOUR AHEAD / FOLLOW / DETOUR SIGNS		
DETOUR NEXT LEFT / FOLLOW / DETOUR SIGNS		
DETOUR 1000 FT / FOLLOW / DETOUR SIGNS		
DETOUR / X MILE(S) / AHEAD	FOLLOW / DETOUR / SIGNS	(XX MI)
FLAGGER AHEAD / I MILE / PREPARE TO STOP		
FLAGGER AHEAD / PREPARE TO STOP		
FRESH OIL / ON ROAD / SLOW		
FRESH TAR / ON ROAD / SLOW		
MEDIAN WORK AHEAD / USE RIGHT LANE		
MEDIAN WORK / KEEP RIGHT		
MOWERS IN MEDIAN / MOWING / NEXT ¼ MILES		
MOWERS IN MEDIAN / MOWING / NEXT X MILES		
RAMP CLOSED AHEAD / USE NEXT EXIT		
PILOT CAR / I MILE / PREPARE TO STOP		
PILOT CAR AHEAD / PREPARE TO STOP		
ROAD WORK AHEAD / NEXT X MILE(S)		
ROAD WORK AHEAD / USE LEFT LANE		
SHOULDER WORK / WORK ON SHOULDER		
SHOULDER WORK / SHOULDER CLOSED / X MILES		(XX MI)
SHOULDER WORK / AHEAD / USE CAUTION		
SHOULDER WORK / AHEAD / USE LEFT LANE		

SHOULDER WORK / WORKERS / ON SHOULDER	
SLOW MOVING WORK / PREPARE TO SLOW	
SLOW MOVING WORK / LEFT LANE CLOSED	
SLOW MOVING WORK / KEEP RIGHT	
SLOW MOVING WORK / SHOULDER CLOSED	(SHOULDR)
SLOW MOVING WORK / MEDIAN CLOSED	
SNOW BLOWERS AHEAD / DO NOT PASS	
SNOW BLOWERS AHEAD / PLEASE USE CAUTION	
SNOW BLOWERS AHEAD / USE LEFT LANE	
SNOW PLOW AHEAD / DO NOT PASS	
STRIPING TRUCKS / AHEAD / CENTER LANE CLOSED	(STRIPING or PAINT)
STRIPING WORK / RIGHT / USE LEFT LANE	(STRIPING or PANIT)
STRIPING WORK / CENTER / KEEP RIGHT	(STRIPING or PAINT)
SURVEY WORK AHEAD / PREPARE TO STOP	
SURVEY WORK AHEAD / PREPARE TO SLOW	
SURVEY WORK AHEAD / USE LEFT LANE	
SWEEPER AHEAD / USE CAUTION	
SWEEPER AHEAD / USE LEFT LANE	
TUNNEL CLOSED / AHEAD / EXPECT DELAYS	
TUNNEL CLOSED AHEAD / DETOUR NEXT LEFT	
TUNNEL CLOSED / AHEAD / USE OTHER ROUTE	
TUNNEL CLOSED / AHEAD / PREPARE TO STOP	
USE DETOUR ROUTE / FOLLOW DETOUR / SIGNS	
USE DETOUR ROUTE / TURN NEXT RIGHT	
WET PAINT / STAY IN LINE	
WORKERS AHEAD / WATCH FOR WORKERS	
WORKERS IN MEDIAN / WATCH FOR WORKERS	
WORKERS IN ROAD / PLEASE SLOW	
WORKERS IN TUNNEL / PLEASE SLOW	

Table 35. Incident Management

WEATHER-RELATED		
ACTIVE SLIDES AHEAD / REDUCE / SPEED		
BLACK ICE LIKELY / USE / CAUTION		
BLOWING DUST AHEAD / NEXT X MILE(S)		
BLOWING DUST AHEAD / SLOW / TURN ON LIGHTS		
BLOWING SNOW AHEAD / NEXT X MILE(S)		
BLOWING SNOW AHEAD / SLOW / TURN ON LIGHTS		
DENSE FOG AHEAD / SLOW / TURN ON LIGHTS		
FREEZING FOG AHEAD / SLOW TURN ON LIGHTS		(FREEZING)
FREEZING FOG LIKELY / USE CAUTION		(FREEZING)
ICE ON BRIDGES / SLOW / USE CAUTION		
ICE ON ROAD / SLOW / USE CAUTION		
ROAD FLOODED / SLOW		
ROCKS ON ROADWAY / USE CAUTION		
SLIDE BLOCKS ROAD / PREPARE TO STOP		
SLIDE ON ROAD / KEEP RIGHT		
Phase 1	**phase 2**	**Abbreviations & notes**
SNOW BLOWERS AHEAD / DO / NOT / PASS		
SNOW BLOWERS AHEAD / USE CAUTION		
SNOW BLOWERS AHEAD / USE LEFT LANE		
SNOW PLOW AHEAD / DO NOT PASS		
SNOW ZONE / CHAINS REQUIRED / ALL VEH		
SNOW ZONE / CHAINS REQUIRED / OVER 10,000 LBS		(REQUIRD; OVER 10K)
SNOW ZONE / CARRY CHAINS		
WATCH FOR ICE / NEXT X MILE(S)		(XX MI)
WATER ACROSS ROAD / USE CAUTION		
NON-WEATHER EVENTS		
BURN AREA AHEAD / SLOW / TURN ON LIGHTS		
DEBRIS ON ROAD / KEEP LEFT		
DEBRIS ON ROAD/ RIGHT / LANE / CLOSED		
DEBRIS ON ROAD / PREPARE TO STOP		
DEBRIS ON ROAD / EXPECT DELAYS		
DENSE SMOKE AHEAD / STOP ON / SHOULDER ONLY		(SHOULDER)
DENSE SMOKE AHEAD / SLOW / TURN ON LIGHTS		
DENSE SMOKE AHEAD / PREPARE TO SLOW		
DENSE SMOKE AHEAD / PREPARE TO STOP EXTREME FIRE DANGER / USE CAUTION FIRE AHEAD / PREPARE TO SLOW	(Requires State traffic-Roadway Engineer approval for use)	
FIRE AHEAD / PREPARE TO STOP		
FIRE AHEAD / STOP ON / SHOULDER ONLY		(SHOULDER)
FREEWAY BLOCKED / AHEAD / PREPARE TO STOP		

FREEWAY CLOSED / AHEAD / ALL VEH MUST EXIT	
FREEWAY CLOSED / USE NEXT EXIT	
FREEWAY CLOSED / FOLLOW / DETOUR SIGNS	
SIGNAL OUT / ALL-WAY STOP AHEAD	
SIGNAL OUT / YIELD TO VEHICLE / ON RIGHT	
STALLED VEHICLE / AHEAD / PREPARE TO STOP	
STALLED VEHICLE / AHEAD / SHOULDER CLOSED	(SHOULDER)
STALLED VEHICLE / AHEAD / RIGHT LANE CLOSED	
STALLED VEHICLE / ON RAMP / KEEP LEFT	(ON EXIT; ON ENTRY)
CRASH AHEAD / CENTER LANE CLOSED	
CRASH AHEAD / EXPECT DELAYS	
CRASH AHEAD / LEFT LANE CLOSED	
CRASH AHEAD / LEFT 2 LANS / CLOSED	
CRASH AHEAD / KEEP RIGHT	
CRASH AHEAD / PREPARE TO STOP	
CRASH AHEAD / USE CAUTION	
CRASH AHEAD / USE CENTER LANE	

Table 36. Bridges

Phase 1	Phase 2	Abbreviations & notes
BRIDGES:		
BRIDGE CLOSED / AHEAD / USE DETOUR		
BRIDGE CLOSED / AHEAD / FOLLOW DETOUR		
BRIDGE OUT / AHEAD / USE DETOUR		
BRIDGE OUT / AHEAD / USE OTHER ROUTE		
BRIDGE WORK / AHEAD / LANES NARROW		
BRIDGE WORK / AHEAD / PREPARE TO STOP		
BRIDGE WORK / AHEAD / USE CENTER LANE		
BRIDGE WORK / AHEAD / WORKERS ON ROAD		
BRIDGE WORK / AHEAD / SLOW		
ONE LANE BRIDGE / PREPARE TO STOP		

Table 37. Trucks

Phase 1	Phase 2	Abbreviations & notes
TRUCKS:		
ALL TRUCKS / EXIT RIGHT		
ALL OVERSIZE / VEHICLES / MUST EXIT		(OVERSIZE)
ALL TRUCKS / USE RT LANE		(LEFT/CNTR LN)
ALL TRUCKS / KEEP RIGHT		
ALL TRUCKS / USE LOW GEAR		
ESCAPE RAMP 1 / CLOSED / TRUCKS USE RAMP 2		
ESCAPE RAMP / CLOSED		
OVERSIZE MUST EXIT / NEXT EXIT X MILE(S)		(OVERSIZE) (XX MI)
TRUCKS OVER 80,000 / MUST EXIT		
TRUCKS OVER 80,000 / USE NEXT EXIT		

Additional standard messages for display on permanent variable message signs

The messages shown in Table 38 may be modified, and new messages may be composed as deemed necessary by the Region Traffic Engineer/Manager or his/her designee. Consult Table 1A-1 in the MUTCD for a listing of acceptable abbreviations.

Table 38. Additional Standard DMS Messages

Phase 1	Phase 2
FREEWAY CLOSED AT EXIT nn	I-84 BOISE USE EXIT yyy DETOUR ROUTE OR203
FREEWAY CLOSED xx MILES	I-5 SEATTLE USE NEXT EXIT FOLLOW DETOUR SIGNS
FREEWAY BLOCKED KEEP RIGHT PREPARE TO STOP	
BRIDGE CLOSED Xx MILES	ALL TRAFFIC USE I-405 LEFT LANES
SNOW ZONE	CARRY CHAINS OR TRACTION TIRES
SNOW ZONE	CHAINS REQUIRED** ON VEHICLES TOWING OR OVER 10000 GVW
SNOW ZONE CHAINS REQUIRED	TRACTION TIRES ALLOWED ON VEH UNDER 10000 GVW
DENSE FOG AHEAD LOW VISIBILITY	
EXTREME HAZARD FREEZING FOG	
WATCH FOR ICE NEXT xx MILES	
CRASH AHEAD USE RIGHT LANE*	
CRASH AHEAD PREPARE TO STOP	
CRASH xx MILES AHEAD LEFT LANE CLOSED	
CRASH xx MILES AHEAD	I-5 SEATTLE USE I-405 LEFT LANES
CRASH xx MILES AHEAD	CITY CENTER EXIT LLOYD BLVD
CRASH xx MILES AHEAD	FWY CLOSED AT NE 43RD AVE
CRASH xx MILES AHEAD	ALL TRAFFIC USE I-405 RIGHT LANES

CONSTRUCTION xx MILES AHEAD	WATCH FOR LANE RESTRICTIONS
SWEEPER AHEAD USE RIGHT LANE	
ROAD WORK xx MILES AHEAD USE RIGHT LANE	
SHOULDER WORK USE RIGHT LANE	
EVENT PARKING EXIT nn	
EVENT PARKING EXIT LLOYD BLVD	
EVENT PARKING FOLLOW I-5 SEATTLE	
EVENT PARKING USE I-5 RIGHT LANES	THRU TRAFFIC USE I-405 LEFT LANES
EVENT PARKING FOLLOW I-5 EXIT nn	
EXPO CNTR PARKING EXIT 306B RIGHT LANE ONLY	THRU TRAFFIC PORTLAND-SALEM LEFT LANE
TRUCKS ESCAPE RAMP UNDER REPAIR	
TRUCKS SECOND ESCAPE RAMP CLOSED	
MOBILE HOMES nn ROAD CLOSED	HIGH WINDS
MOBILE HOMES nn EXIT CLOSED	ROAD CONSTRUCTION
OVERSIZED VEH USE EXIT nn	I-84 CLOSED TO OVERSIZED VEH
TRAVEL TIME INFO VLY JCT-LINCOLN CITY xx MIN	
SIGN UNDER SYSTEMS TEST ODOT TEST	ODOT TEST SYSTEMS TEST
OREGON DEPARTMENT OF TRANSPORTATION	SIGN UNDER TEST

Methodology

This study was carried out with the aid of a full-scale high-fidelity driving simulator, available at the Safety and Behavioral Analysis (SABA) Center at Morgan State University. The simulator, pictured in Figure 21, includes a cockpit, three monitors to project front and peripheral views as subjects travel through the virtual network, an ignition key, safety seat belt, and other components necessary for the operation of the vehicle in the simulated environment: steering wheel, hand brake, throttle, signal-light controllers, emergency blinkers, and brake pedals and an automatic gear stick.

Figure 21. Driving Simulator at the SABA Center, Morgan State University

The use of the simulator enables researchers to capture the effect(s) of environmental factors and surrounding traffic on subjects' compliance, diversion and route choice decision(s) -- an essential component missing from SP data collection methods. Data recorded by the driving simulator includes but is not limited to geographic position, speed, acceleration, distance from lane center, distance traveled, offset from the road's shoulder, steering angle, brake and yaw/pitch/roll angle.

Human subjects, henceforth referred to as participants, were asked to drive from a clearly defined origin through the virtual road network to a fixed destination. Participants were free to choose and change routes as they drove through six different scenarios consisting of different DMS contents, types, structure, and length.

Scenario Design

A proprietary software, VR-design studio, developed by FORUM Co. (FORUM8), was used to create six virtual driving scenarios. The VR-Design Studio software is a virtual reality system that allows for the design, creation and manipulation of network elements: road, intersection, median, curbs, traffic signals, and roadside signs. It allows researchers to manipulate traffic characteristics, speed and volume, and even adjust weather conditions. Figure 22 is a snapshot of the simulated virtual environment utilized for this study.

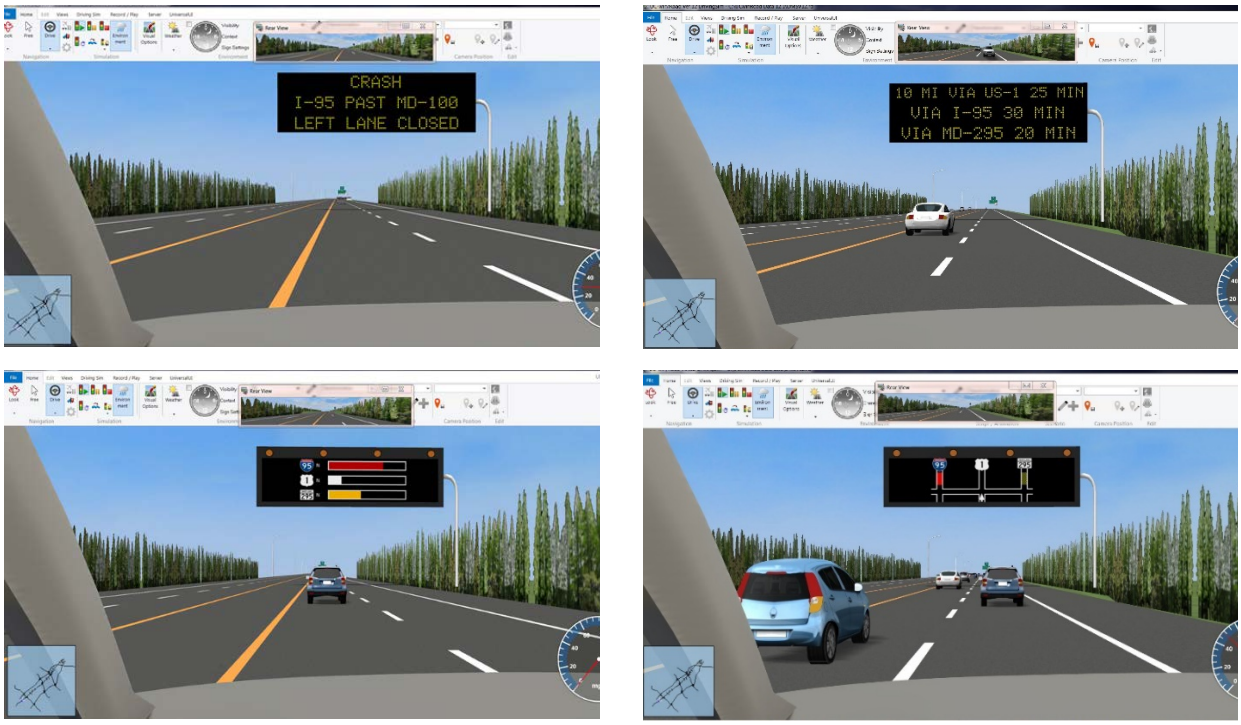


Figure 22. A Screenshot of the Simulated Driving Environment and Some DMS signs

As seen in Figure 22 above, the virtual scenarios are complete with traffic lights, trees, building structures and other objects. Driving behavior data, and brake, throttling and steering handling parameters, as well as route choice data were automatically recorded by the driving simulator. However, for this study, only route information was utilized.

Network Characteristics

A study area of 155 square miles (400 km^2) southwest of the Baltimore metropolitan area was selected for this study. The origin was set at the Washington Blvd-Montevideo intersection while the destination was fixed at M&T Bank Stadium (intersection of Russell Street and Baltimore-Washington Parkway (MD-295). Google Maps was used as the reference to develop all roadway signs, trees and intersections in the virtual network to be very similar to the real world. Realism in simulation sessions was achieved by carefully setting traffic volume and characteristics to emulate those in real-life driving environments.

Figure 23 shows the study network, the origin and destination of the study, and the location of DMS. As seen in Figure 24, the network has 9 decision points (at which participants can switch routes between US-1, I-95 and I-295) and 10 DMS locations; four of which are on US-1, three on I-295 and three on I-95. As presented in Figure 10, there are three routes between the origin and the destination. I-95 is a four-lane interstate route with a maximum speed limit of 65 mph in the study area. Washington Blvd (US-1) is a two-lane highway with a maximum speed limit of 40 mph. The study area has frequent traffic signals on US-1. MD-295 is a two-lane highway which expands into a three-lane highway, with a speed limit of 55 mph. During non-peak hours, I-95 is typically the fastest route, taking between 12 – 16 minutes to reach M&T Bank Stadium from the origin in the study area, whereas MD-295 and US-1 take anywhere between 14 – 18 minutes and 14 – 20 minutes, respectively. In the study, traffic on I-95 was designed to be heavy

to test the reaction of drivers acquainted with I-95. Traffic on US-1 and MD-295 was set to mimic real life non-peak hour conditions. In this study, the three routes are connected via MD-100, I-195 and I-695, respectively.

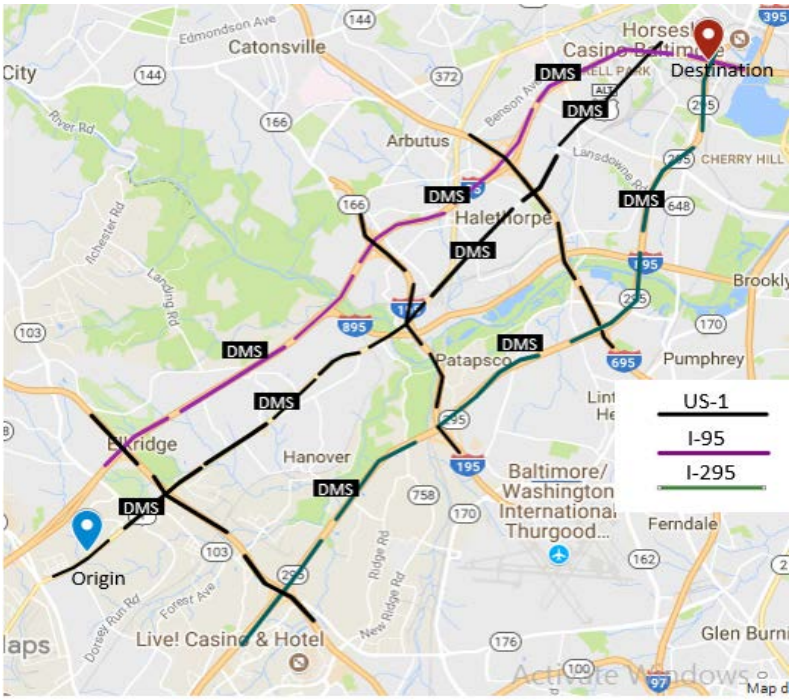
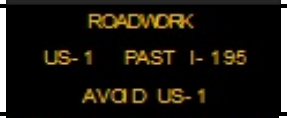
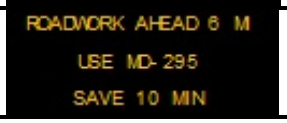


Figure 23. Study Network

A categorical list of some of the DMS displayed in different scenarios of the study is shown in Table 39.

Table 39. Categories of DMS Signs Utilized in This Study

DMS categories	Signs Used
Distance Time with Alternate Routes	5 MI VIA I-95 12 MIN VIA US-1 8 MIN VIA MD-295 5 MIN
Travel Time with Alternate Routes	STADIUM 28 MIN VIA US-1 15 MIN VIA MD-295 12 MIN
Travel Time Without Alternate Routes	STADIUM 12 MIN
Lane Closure Information with Alternate Route	ROADWORK PAST I-195 LEFT LN CLOSED USE MD-295
Crash Related DMS With Advice	CRASH PAST I-695 CONSIDER ALT ROUTE

Delay Related DMS With Advice	
Delay Related DMS Without Advice	
Color Coded DMS (Design II)	
DMS With Avoid Route Advice	
DMS With Save Time Advice	

Tables 40 – 42 and Figures 24-26 present the location and content of the different categories of DMSs utilized for this study.

SCENARIO 1				
	DMS 1	DMS 2	DMS 3	DMS 4
I-95		5 MI VIA I-95 12 MIN VIA US-1 8 MIN VIA MD-295 5 MIN	STADIUM VIA I-95 12 MIN VIA MD-295 5 MIN	3 MI 8 MIN
US-1	10 MI VIA US-1 25 MIN VIA I-95 30 MIN VIA MD-295 20 MIN	5 MI VIA US-1 8 MIN VIA I-95 12 MIN VIA MD-295 5 MIN	STADIUM VIA US-1 8 MIN VIA MD-295 5 MIN	3 MI 5 MIN
MD-295		5 MI VIA MD-295 5 MIN VIA I-95 12 MIN VIA US-1 8 MIN	STADIUM VIA MD-295 5 MIN VIA I-95 12 MIN	3 MI 4 MIN
SCENARIO 2				
	DMS 1	DMS 2	DMS 3	DMS 4
I-95		STADIUM 28 MIN VIA US-1 15 MIN VIA MD-295 12 MIN	STADIUM 12 MIN	STADIUM 8 MIN
US-1	10 MI 25 MIN	STADIUM 15 MIN VIA I-95 28 MIN VIA MD-295 12 MIN	STADIUM 8 MIN	STADIUM 5 MIN
MD-295		STADIUM 12 MIN VIA I-95 28 MIN VIA US-1 15 MIN	STADIUM 5 MIN	STADIUM 4 MIN

Figure 24. DMS Used in Scenarios 1 and 2 of the Simulation Sessions

Figure 24 shows the location and content of the different DMS participants encounter as they travel through the virtual network, used for scenarios 1 and 2, toward the destination.

Table 40: Categories of DMS Used in Scenarios 1 and 2

Travel Time	Scenario 1	Scenario 2
DMS-1	With alternative routes Distance-time	W/O alternative routes Distance-time
DMS-2	With alternative routes Distance-time	With alternative routes Destination-time
DMS-3	With alternative routes Destination-time	W/O alternative routes Destination-time
DMS-4	W/O alternative routes Distance-time	W/O alternative routes Destination-time

As shown in Table 40, different DMS containing distance-time and destination-time information, with and without (w/o) alternative routes, were used in the first two scenarios.

SCENARIO 3				
	DMS 1	DMS 2	DMS 3	DMS 4
I-95		CRASH PAST I-195 2 RIGHT LNS CLOSED USE MD-295	CRASH PAST I-695 CONSIDER ALT ROUTE	CRASH AHEAD 1 MI 2 LEFT LN CLOSED
US-1	CRASH I-95 PAST MD-100 AVOID I-95	ROADWORK PAST I-195 LEFT LN CLOSED USE MD-295	CRASH PAST I-695 CONSIDER ALT ROUTE	ROADWORK AHEAD 1 MI LEFT LN CLOSED
MD-295		ROADWORK PAST I-195 LEFT LN CLOSED KEEP RIGHT	CRASH PAST I-695 CONSIDER ALT ROUTE	ROADWORK AHEAD 1 MI RIGHT LN CLOSED
SCENARIO 4				
	DMS 1	DMS 2	DMS 3	DMS 4
I-95		ROADWORK US-1 PAST I-195 AVOID US-1	CRASH PAST I-695	ROADWORK US-1 PAST I-95
US-1	CRASH I-95 PAST MD-100 LEFT LANE CLOSED	CRASH I-95 PAST I-195 AVOID I-95	ROADWORK PAST I-695	CRASH I-95 PAST MD-295
MD-295		CRASH I-95 PAST I-195 STAY ON MD-295	ROADWORK PAST I-695	CRASH I-95 PAST MD-295

Figure 25. DMS Signs Used in Scenarios 3 and 4 of the Simulation Sessions

Figure 25 shows the location and content of the different DMSs encountered by participants as they travel through the network for scenarios 3 and 4, toward the destination.

Table 41: Categories of DMS Used in Scenarios 3 and 4

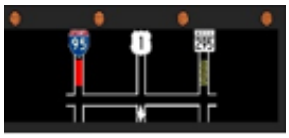
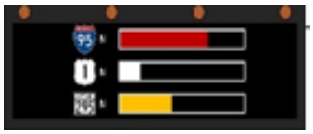
Travel Time	Scenario 3	Scenario 4
DMS-1	With advice Different-route	W/O advice Different-route
DMS-2	With advice Same route	With advice Different route
DMS-3	With advice Same route	W/O advice Same route
DMS-4	W/O advice Same route	W/O advice Different route

As shown in Table 41, different DMS displaying the same route or alternate route information, some with advice and others without advice, were utilized in scenarios 3 and 4.

Figure 26. DMS Signs Used in Scenarios 5 and 6 of the Simulation Sessions

Figure 26 shows the location and content of the different DMS encountered by participants as they travel through the network toward the destination.

Table 42: Categories of DMS Used in Scenarios 5 and 6

Travel Time	Scenario 5	Scenario 6
DMS-1	Color coded  Design I	Color coded  Design II
DMS-2	With advice Save time	With advice Delay time
DMS-3	With advice Delay time	W/O advice Delay time
DMS-4	N/A	N/A

As shown in Table 42, DMS encountered in these scenarios include DMS displaying the expected time saved or delayed if a specific route is used, with and without advice. The first DMS encountered in these scenarios are color coded, to capture participants response/reaction to, and level of comprehension of, pictograms on the DMS.

It is important to note that due to the lack of an exit ramp/decision point after DMS 4 and its proximity to the destination, data for DMS 4 for all scenarios was excluded when analyzing participants' route choice, diversion or compliance behavior.

Survey Questionnaires

Eight surveys, two pre-simulation and six post-simulation surveys, were designed to capture essential information about participants. The first pre-simulation survey captured participants' gender, age, household income, educational status and other socio-economic data as well as participants' familiarity with and trust in messages displayed in DMS as well as their compliance with the messages displayed. The structure of the second pre-simulation survey ensured that participants' familiarity with the study area, route preference, level of comprehension of messages displayed on DMS and order of preference (most preferred to least preferred) of different types of messages were captured. A post simulation survey was filled by the participant, after each of the six scenarios to test participants' comprehension of displayed messages and recollection of DMS encountered.

Recruitment Process

Institutional Review Board (IRB) approval was received before human participants were recruited. Social media, word-of-mouth advertisement, and paper fliers were utilized to recruit participants to drive the simulator. Participants were compensated at the rate of $15 per hour for their involvement in the study. A total of 68 participants were recruited but only 65 completed all scenarios. A total of 390 simulation sessions were conducted and recorded. Participants who were unfamiliar with the driving simulator and/or the virtual driving environments could test drive for 5 to 10 minutes to develop a familiarity with the driving simulator and/or the virtual environment prior to driving the six scenarios. They were also given a 5-minute break between scenarios to avoid fatigue. Rules were set to ensure participants handled the simulator as they would their vehicle in the real world. Warnings, red-light running and speeding tickets, in the form of deduction(s) from compensation/payments, were randomly issued for non-compliance with traffic rules and crashes, to ensure driving realism.

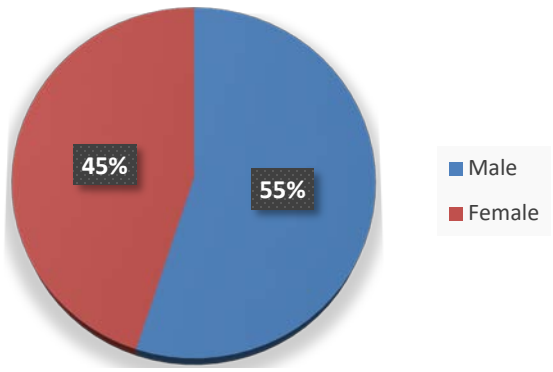
Data

The information collected from the surveys, participants' socio-demographic data and the category of DMS signs were used as predictor variables. Diversion, compliance and route choice were the response variables in the three separate datasets, created for behavioral analysis. In a bid to determine the impact of DMS messages on driver behavior, all the categories of message types were transformed to separate dummy variables. The datasets were unbalanced due to drivers' route choices, with some signs being less frequently encountered. Although a random forest algorithm handles categorical data well, it is biased toward categorical variables with a high number of levels (Strobl et al., 2007). To address this issue, all the categorical variables were converted to dummy variables to improve result interpretability. Descriptive statistics of the socio-demographic and survey data after this transformation, used in all three datasets, are shown in Table 43.

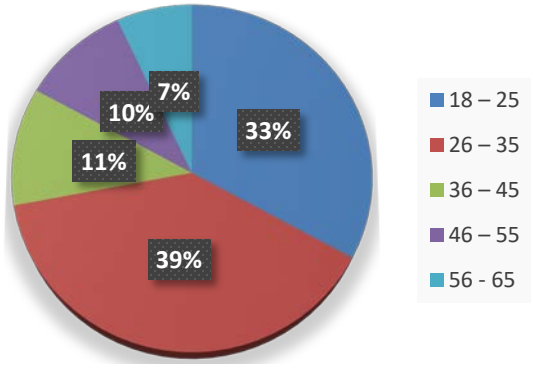
Table 43. Socio-demographic and Survey Data Descriptive Statistics

Variables	Description	Percentage
Gender	Male	55%
	Female	45%
Age	18 – 25	33%
	26 – 35	39%
	36 – 45	11%
	46 – 55	10%
	56 - 65	7%
Familiarity with Study Area	Yes	53%
	Somewhat	28%
	No	13%
Frequency of Travel	Very frequently	25%
	Often	37%
	Occasionally	24%
	Never been there	9%
Route Usually Taken	MD-295	19%
	US-1	5%
	I-95	34%
	Follow my GPS	30%
	Not Sure	8%
DMS Influences Decisions	Always	18%
	Sometimes	77%
	Never	3%
When DMS GPS Conflict	I follow DMS	27%
	I follow GPS	38%

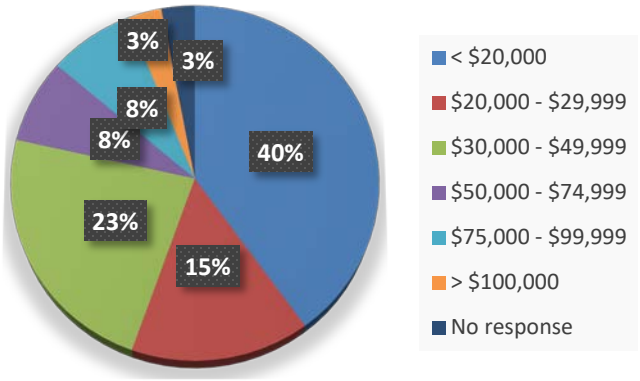
The sum of the percentages for some variables shown in Table 43 may not add up to 100%, as some sections in the survey were left blank by the participants. Analyses were carried out using the open source R-project statistical software (Team, 2013).



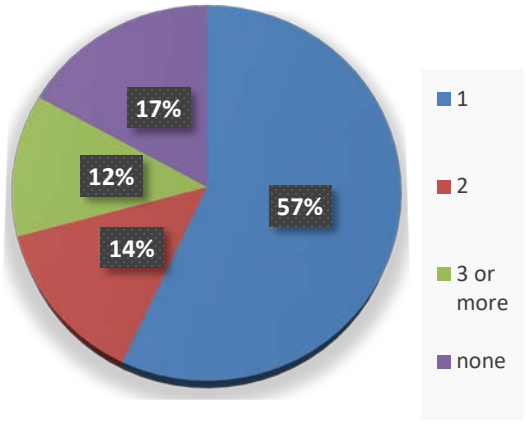
Distribution of participants' gender



Distribution of participants' age group



Distribution of participants' household income



Distribution of participants' car ownership

Figure 27. Participant Characteristics

Figure 27 shows the gender, age and household income distribution of participants as well as the distribution of car ownership. Some 55%, 72%, 40% and 57% of participants were male, between the ages of 18 and 35 years, from households that earn less than $20,000, and owned one car respectively.

Research Findings and Discussion

The findings of this study have been discussed in detail in the preceding sections.

Stated Preference Analysis

Pre-simulation survey questions were structured to gather information about participants' familiarity with the study area and DMS, default response to DMS signs and socio-demographic

characteristics. Participants' responses revealed that 81% were either completely or somewhat familiar with the study area. In addition, 19%, 5%, and 34% of the total number of participants cited MD-295, US-1, and I-95, respectively as the route usually taken when trips are made from the stated origin to the defined destination. Some 30% of the total participants rely on global positioning systems (GPS) while the remaining 8% were uncertain of route preferred as shown in Figure 28.

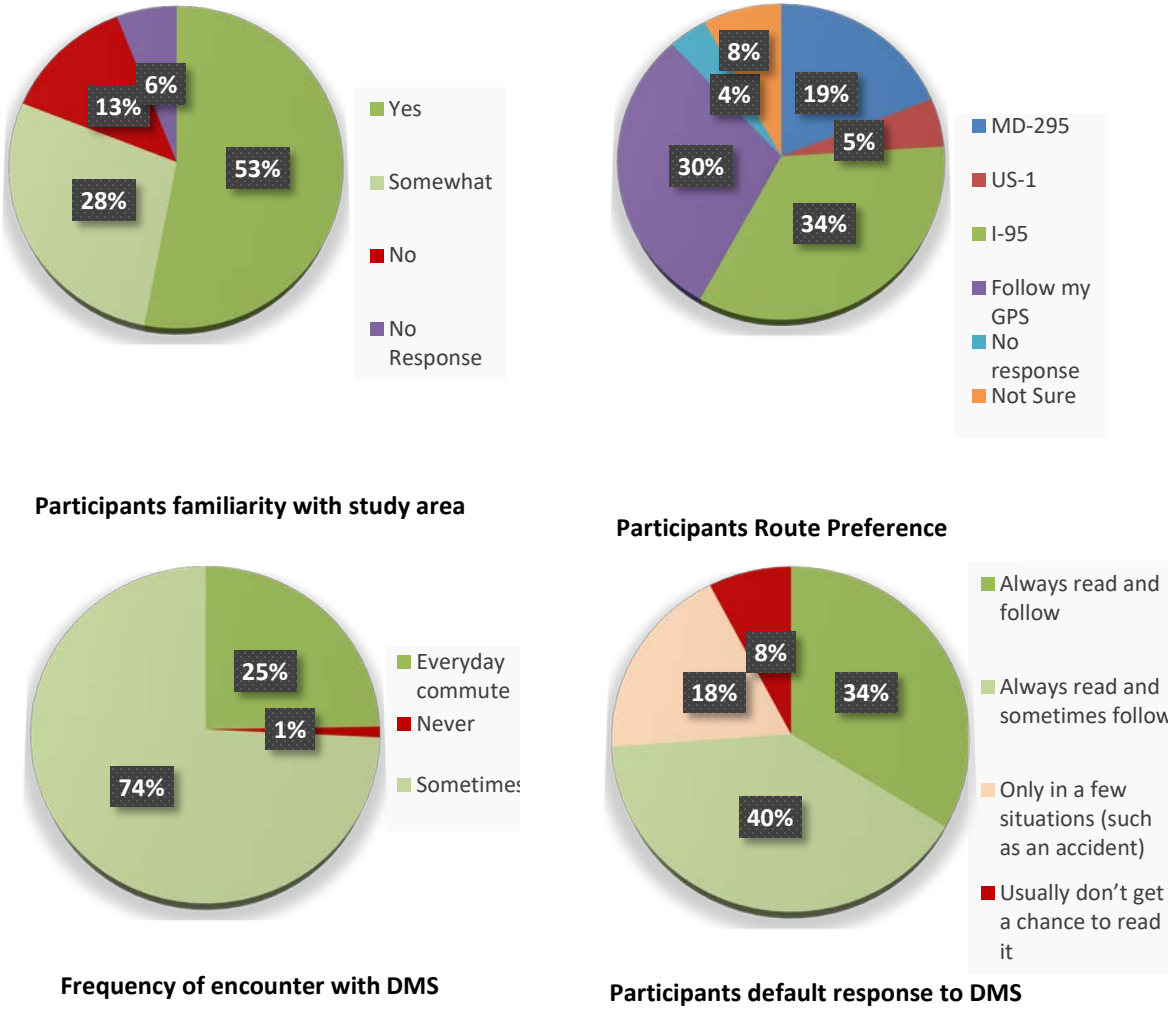


Figure 28. Participant's Stated Preference

Revealed Preference Analysis

Data from driving simulation sessions revealed a disparity between the route choice selected in the survey and route choice during the simulation sessions. This suggests that route choice was influenced by the DMS and environmental conditions. Figure 29 displays the categories of DMS that potentially influenced route choice decisions.

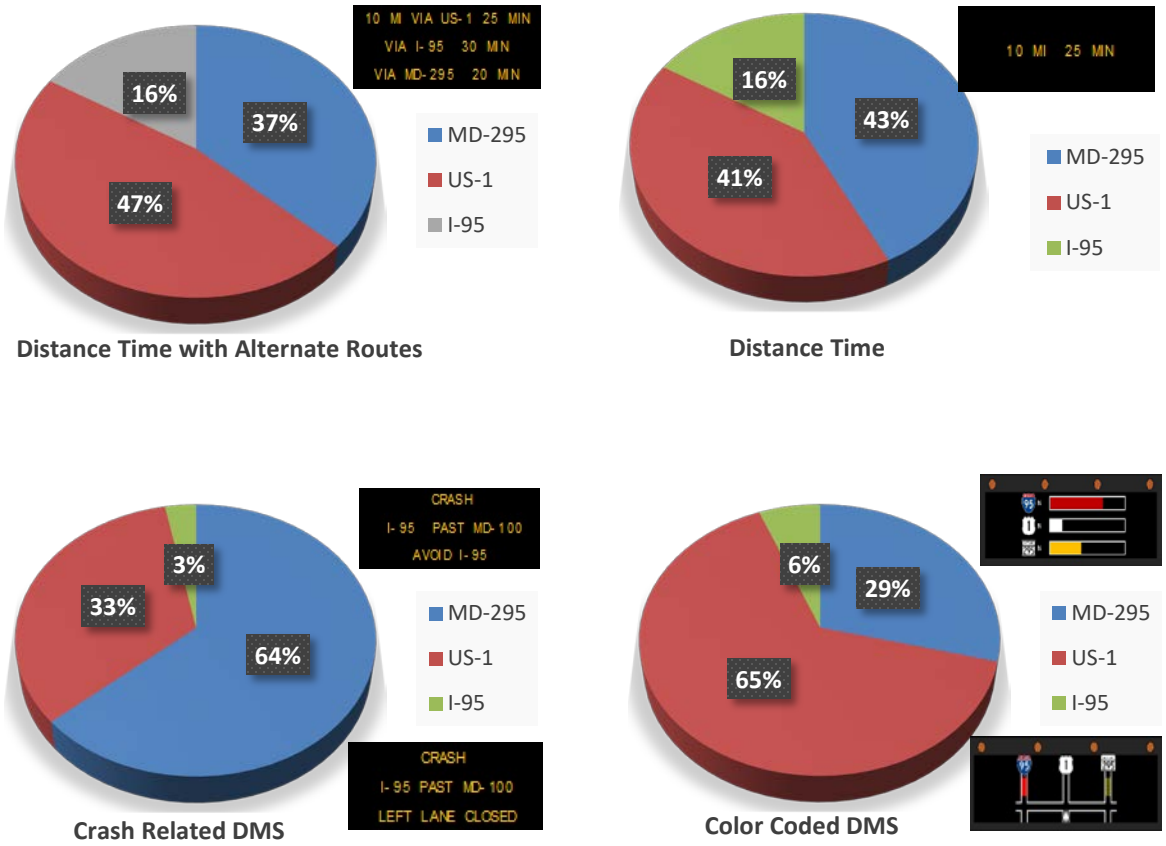


Figure 29. Revealed Route Choice Behavior

Participants stated in the surveys that they would prefer Design II as opposed to Design I. While driving in scenarios 5 and 6, it was found that Design II had higher compliance as shown in Figure 30.

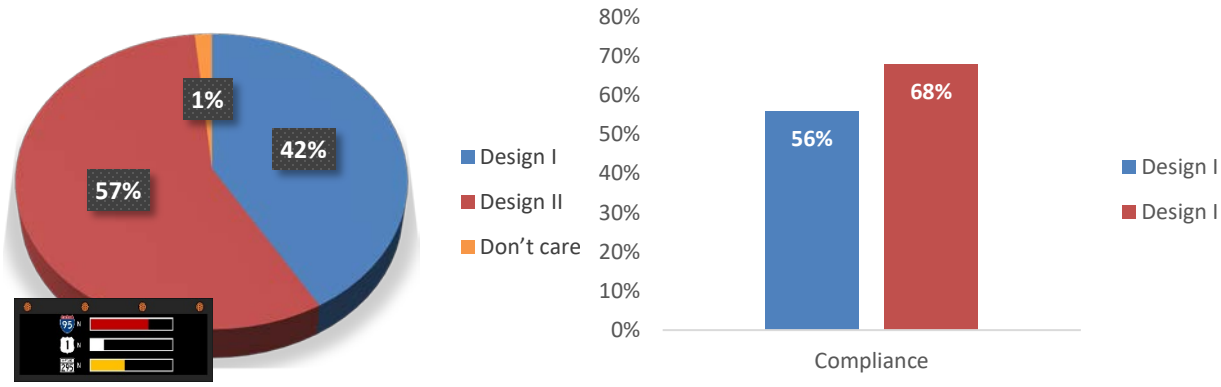


Figure 30. Stated Preference vs. Revealed DMS compliance

Scenario 2 and Scenario 4 were not included in the stated and revealed compliance analysis as the messages on the DMS did not include a suggestion to test compliance. Participants had a lower percentage of actual compliance from what they stated in the post simulation surveys as shown in Figure 31. Only scenario 3 had an equal stated and revealed compliance. This could be attributed to very clear and specific advisory lane closure messages in scenario 3.

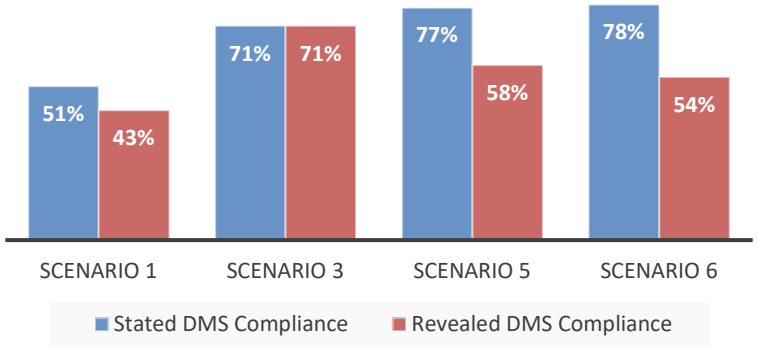


Figure 31. Stated vs. Revealed DMS Compliance

Speed Analysis

Vehicle speed is a function of a driver's throttle and brake handling behavior. Figure 32, generated using data from a randomly selected participant, shows the relationship between driver's throttle and brake handling behavior and vehicle speed.

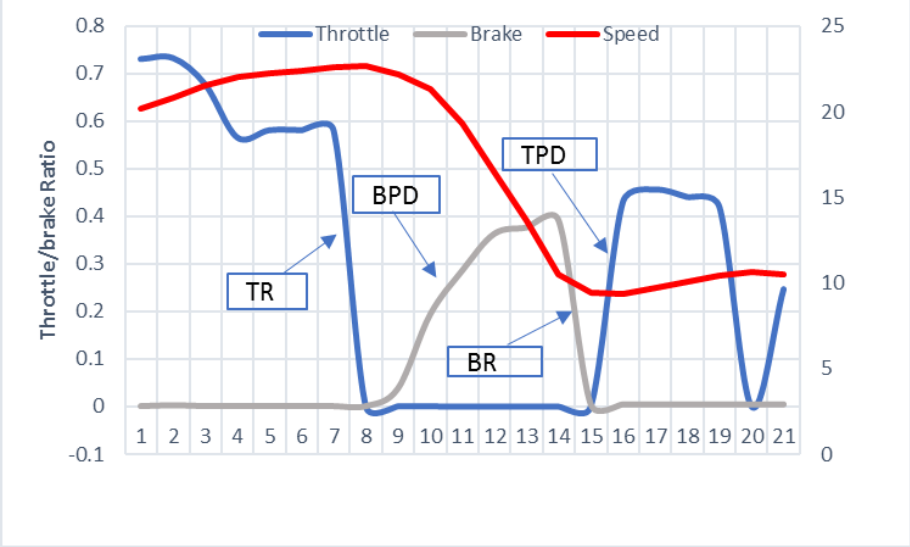


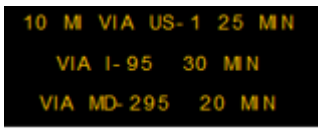
Figure 32: Throttle/Brake Ratio and Resultant Vehicle Speed

In Figure 32, "TR," "TPD," "BR" and" BPD" represent throttle released, throttle pressed down, brake released, and brake pressed down, respectively. It can be seen in the figure that when the brake pedal is pressed down, for instance between the 9th and 13th second interval, the speed

reduces progressively and when the throttle is pressed down as seen between the 15th and 19th second interval, speed increases. Hence a driver's speeding behavior is a function of the driver's brake and throttle handling behavior.

The speeding behavior of drivers within the vicinity of the first DMS sign encountered in scenarios 1 to 6 was analyzed. Table 44 shows the content of the DMS.

Table 44. DMS Signs Used for Speed Analysis

DMS1-Scenario 1	
DMS1-Scenario 2	
DMS1-Scenario 3	
DMS1-Scenario 4	
DMS1-Scenario 5	
DMS1-Scenario 6	

DMS1 in scenarios 1 to 6 is located along Washington Blvd, 2276 ft from the trip origin. The speed analysis was performed based on three pre-DMS and one post-DMS segments. Figure 33 shows the segments, segments lengths and position of each segment relative to the DMS.

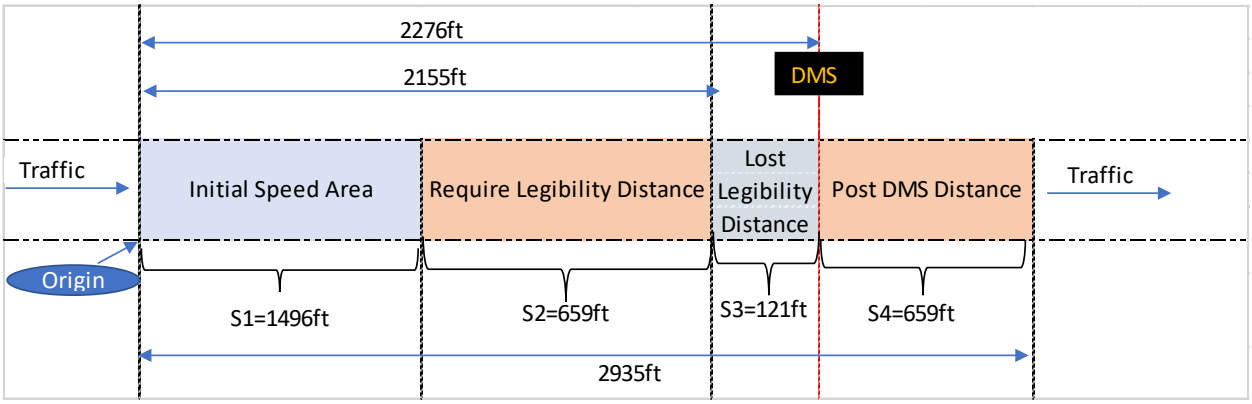


Figure 33. Description of the Segments utilized for DMS Speed Analysis

In Figure 33, S1, S2, S3 and S4 represent the lengths of the four segments pictured above: the initial speed area, required legibility, lost legibility and post DMS distances. The initial speed area is the area, prior to the DMS sign, in which over 85% of participants accelerate. The required legibility distance is the distance from the point where the DMS display becomes legible to the point just before the DMS, at which legibility is lost. The lost legibility distance is the distance from the point before the DMS, at which the DMS becomes illegible, to the point where the DMS is located. The post DMS distance is an arbitrary distance after the DMS sign. For the speed analysis, required legibility distance and lost legibility distance were determined by driving through the scenarios and keeping records of the distances at which the DMS display became legible and the distance, just before the DMS, at which legibility is lost. S1, on the other hand, was determined by analyzing the data to find the distance before the required legibility distance, within which most participants consistently increased speed and S4 was arbitrarily set to be equal to S2.

From the average speed of the participants plotted for S1 through S4, eight trends were determined possible depending on increase or decrease of speed in each segment relative to the immediate prior segment. These trends are shown in Figure 34.

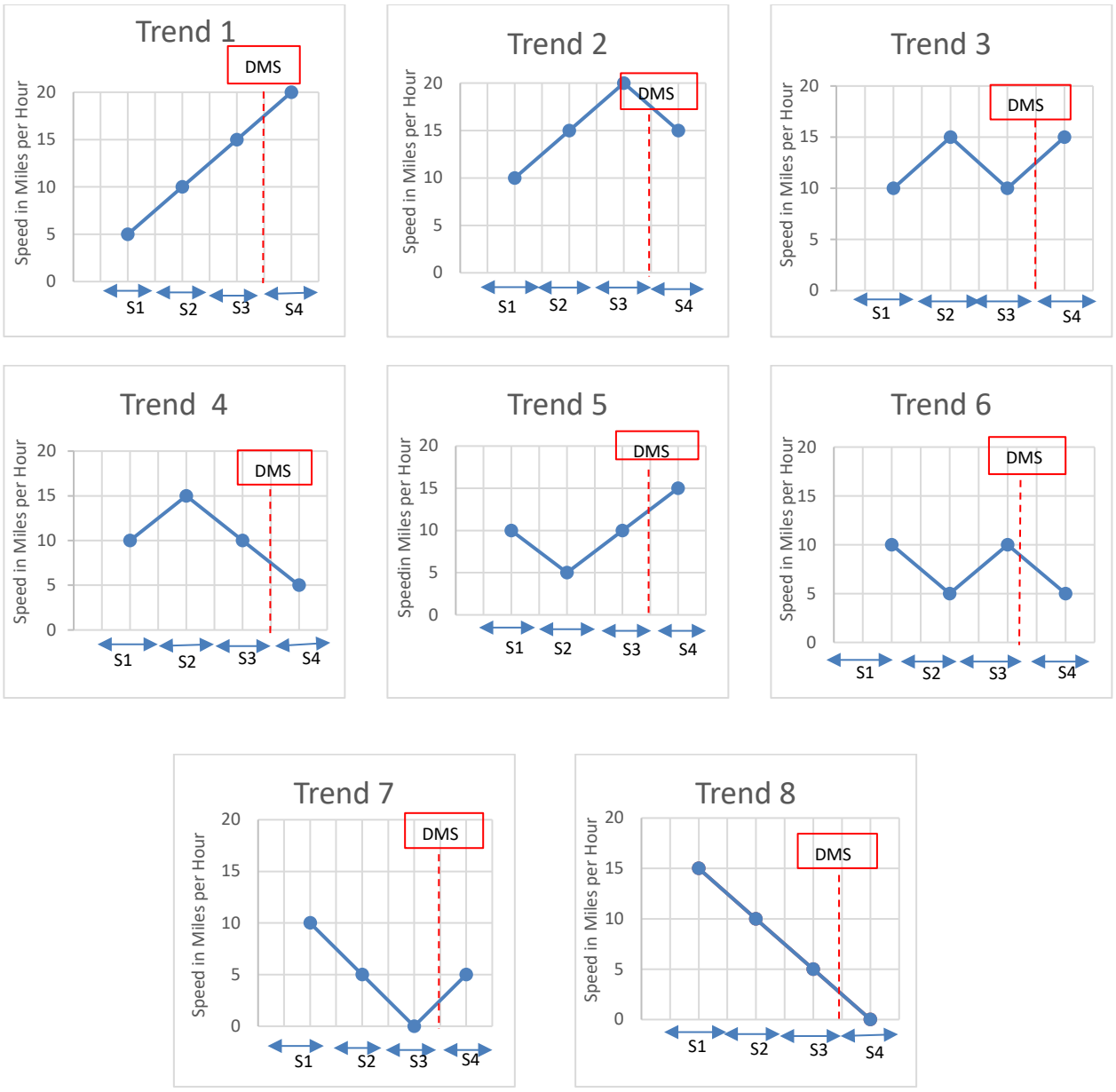
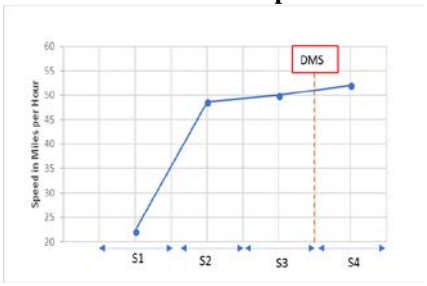
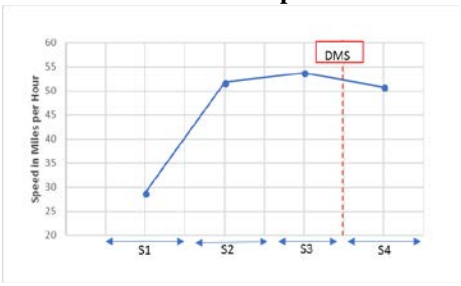
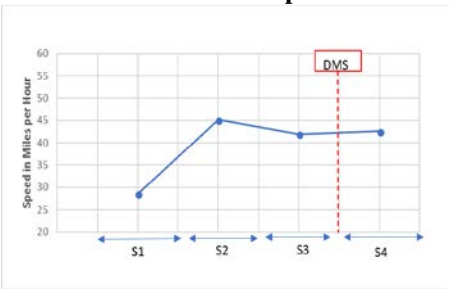
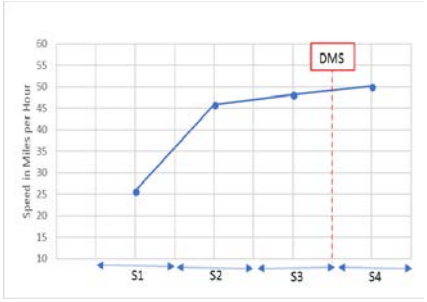
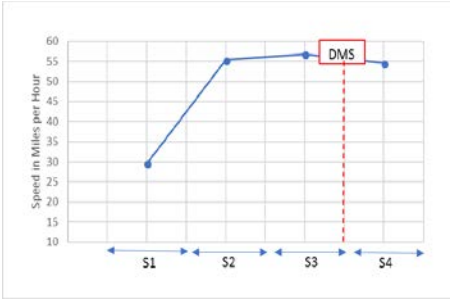
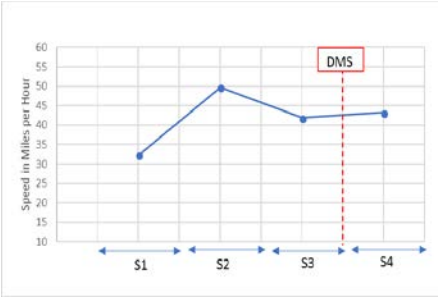
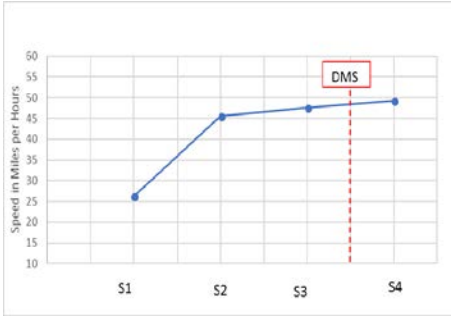
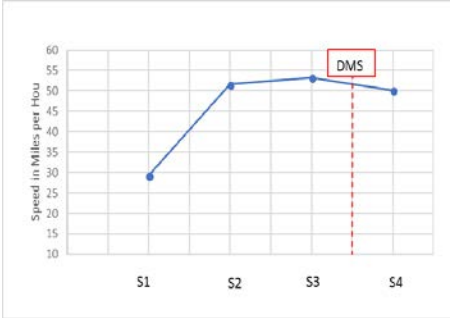
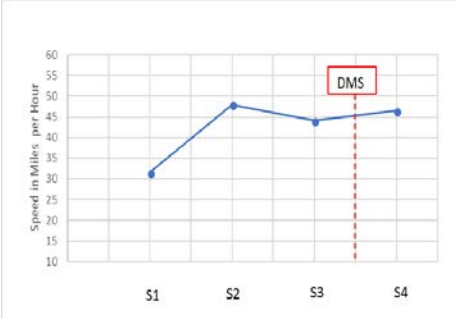


Figure 34. Possible Speed Trends Within the Vicinity of DMSs

Drivers' speed behavior was analyzed to find the speed trends adopted by different proportions of drivers as well as the aggregate speed of drivers within the vicinity of the DMS of interest. The results of the analysis are presented in Table 45 as shown below:

Table 45: Speed Reaction to DMS1 for Scenarios 1 to Scenario 6

	Trend 1	Trend 2	Trend 3
DMS1 Scenario 1	**40% of Participants** 	**15% of Participants** 	**13% of Participants** 
DMS1 Scenario 2	**46% of Participants** 	**13% of Participants** 	**10% of Participants** 
DMS1-Scenario 3	**38% of Participants** 	**17% of Participants** 	**24% of Participants** 

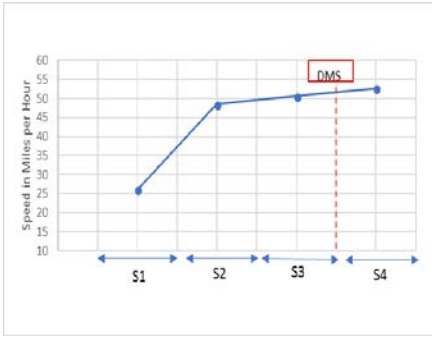
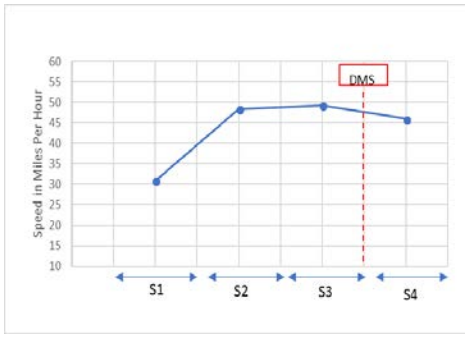
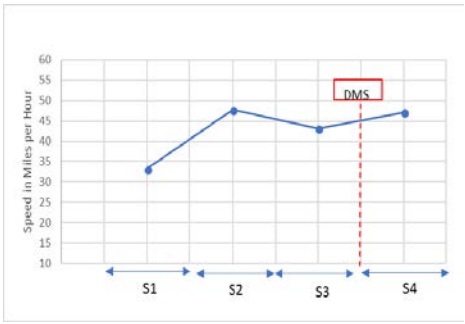
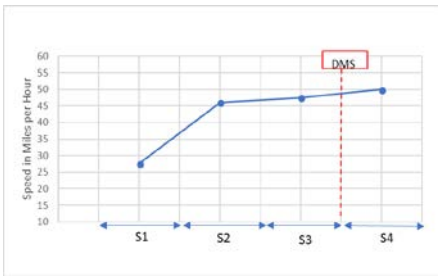
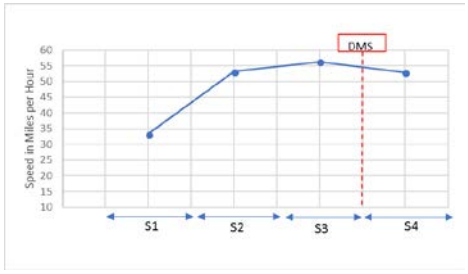
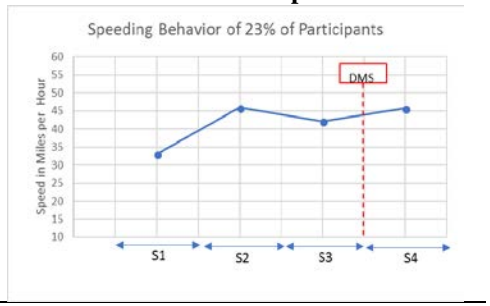
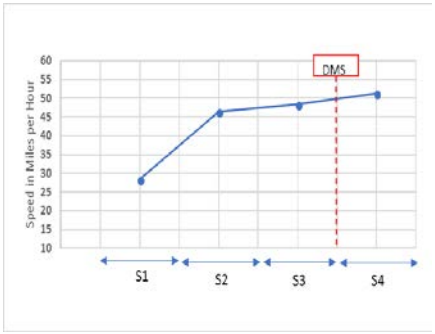
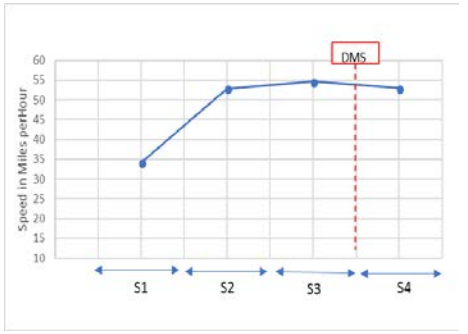
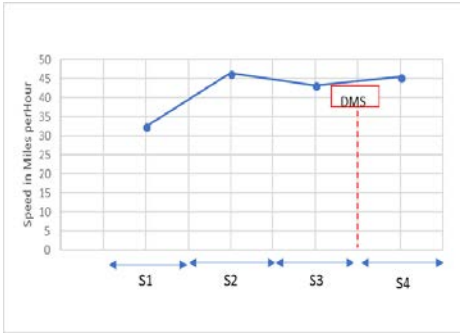
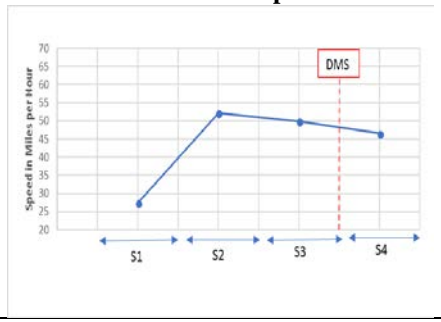
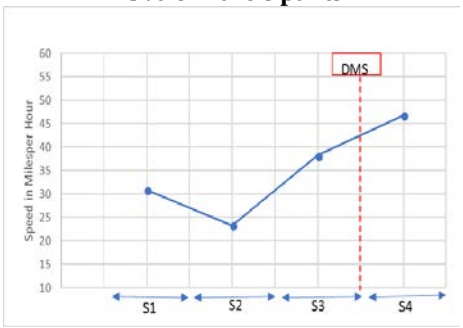
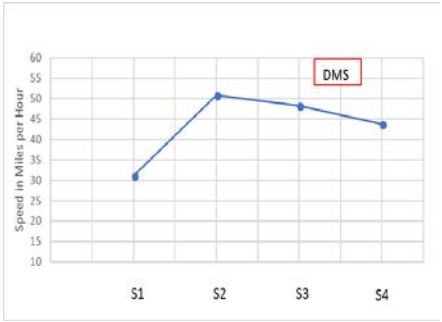
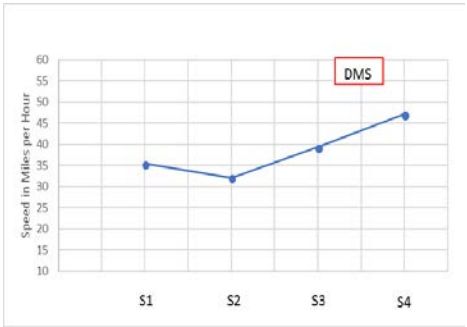
	Trend 1	Trend 2	Trend 3
DMS1-Scenario 4	**39% of Participants** 	**11% of Participants** 	**23% of Participants** 
DMS1- Scenario 5	**50% of Participants** 	**8% of Participants** 	**23% of Participants** 
DMS- Scenario 6	**32% of Participants** 	**8% of Participants** 	**32% of Participants** 

Table 45 (Continued)

	Trend 4	Trend 5	Trend 6
DMS1 Scenario 1	**32% of Participants** 	**0% of Participants**	**0% of Participants**
DMS1 Scenario 2	**28% of Participants** 	**3% of Participants** 	**0% of Participants**
DMS1-Scenario 3	**20% of Participants** 	**2% of Participants** 	**0% of Participants**

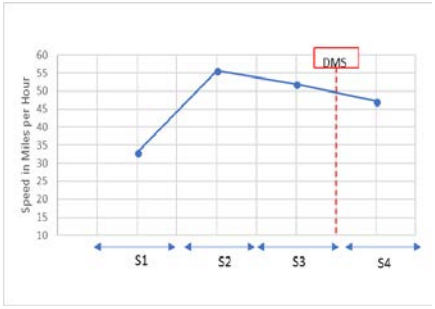
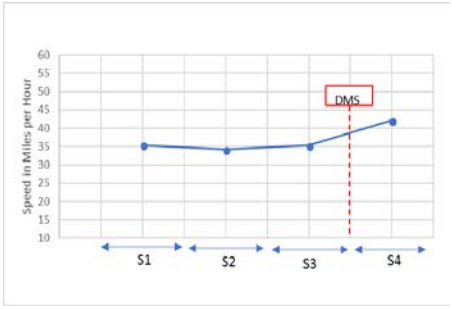
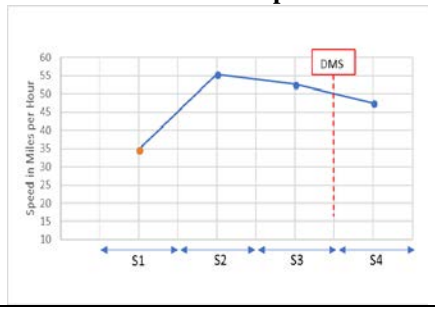
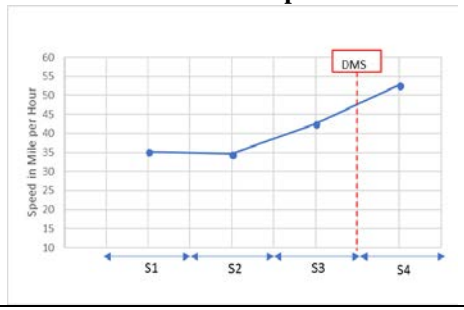
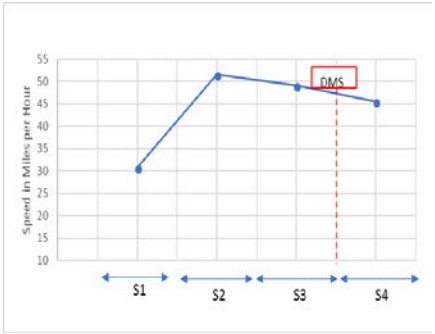
	Trend 4	Trend 5	Trend 6
DMS1-Scenario 4	**24% of Participants** 	**3% of Participants** 	**0% of Participants**
DMS1- Scenario 5	**18% of Participants** 	**2% of Participants** 	**0% of Participants**
DMS- Scenario 6	**28% of Participants** 	**0% of Participants**	**0% of Participants**

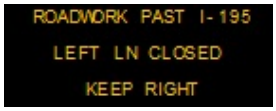
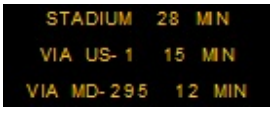
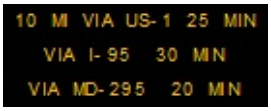
Table 45 shows the speed trends and proportion of participants that adopted each speed trend near DMS1 in scenarios 1 to 6. Of the eight possible trends, only trends 1 through 5 were adopted by participants. Trend 1, with an increasing average speed from S1 through S4, was adopted by the largest percentage of participants for all scenarios.

ANOVA analyses were carried out on the participants' average speed in S1 through S4 for each scenario and on average speeds in corresponding segments across scenarios. Results of the ANOVA analysis yielded p-values greater than 0.05 which means that observed differences in speed were not statistically significant. This could possibly be due to the participants encountering DMS for the first time as the scenario starts and they are still gradually coming up to speed.

Speed Analysis based on 'Units of Information'

The DMS used in this study were classified based on the number of units of information each DMS conveys. Out of the three possible routes where DMS were deployed, only the DMS on MD-295 were used for this analysis. Speed analysis on I-95 and US-1 would not have been appropriate due to heavy traffic on I-95 and frequent stops on US-1 due to the presence of traffic lights. The DMS with the different units of information are shown in Table 46.

Table 46. Units of Information Used for Analysis

Information on DMS	Messages	
2-3 units		
4 units		
5 units		
6-7 units		

The mean speeds of drivers over the sections of S1 to S4 are shown in Table 47.

Table 47. Units of information Descriptive Statistics

Information on DMS	N	Mean Speed (mph)	Std. Deviation
6-7 units	270	38.96	8.11
5 units	205	38.55	3.86
4 units	385	38.93	4.29
2-3 units	620	43.65	13.6

An Ordinary Least Squares (OLS) regression model was built based on the different units of information and the participants' socio-demographic data. Table 48 shows the OLS regression results for DMSs with 2-3 units of information.

Table 48. OLS Regression Results – 2-3 Units

	Coefficient	*Std. Error*	*t-ratio*	*p-value*
2-3 units				
constant	38.335	3.653	10.490	<0.0001*
Male	1.609	1.303	1.235	0.217
26 to 35	7.052	1.822	3.869	0.0001*
36 to 45	0.796	2.178	0.365	0.714
46 to 55	2.05524	2.094	0.981	0.326
>55 age	−0.764	3.231	−0.236	0.812

*The p value is significant at the 0.05 level

The results in Table 48 show that participants in the 26 – 35 age group tend to increase their overall speed while approaching and passing a DMS with 2-3 units of information. Table 49 shows the OLS regression results for DMS with 4 units of information.

Table 49. OLS Regression Results – 4 Units

	Coefficient	*Std. Error*	*t-ratio*	*p-value*
4 units				
constant	37.343	1.257	29.710	<0.0001*
Male	−1.051	0.494	−2.127	0.0341*
26 to 35	2.361	0.707	3.336	0.0009*
36 to 45	−2.856	0.836	−3.414	0.0007*
46 to 55	−0.665	0.864	−0.770	0.4416
>55 age	−0.953	1.138	−0.837	0.4029

*The p value is significant at the 0.05 level

The results in Table 49 show that male participants tend to decrease their speed compared to female participants when DMS portray 4 units of information. Participants in the 26 – 35age group tend to increase their overall speed while participants in the 36 – 45 age group tend to reduce their overall speed while approaching and passing a DMS with 4 units of information. Tables 50 and 51 show the OLS regression results for DMS with 5 units and 6-7 units of information.

Table 50. OLS Regression Results – 5 units

	Coefficient	*Std. Error*	*t-ratio*	*p-value*
5 units				
constant	42.049	2.191	19.190	<0.0001*
Male	−1.250	0.782	−1.597	0.112
26 to 35	0.313	0.875	0.358	0.720
36 to 45	−0.015	1.150	−0.013	0.989
46 to 55	0.831	0.966	0.860	0.391
>55 age	1.987	1.421	1.399	0.163

*The p value is significant at the 0.05 level

Table 51. OLS Regression Results – 6-7 units

	Coefficient	*Std. Error*	*t-ratio*	*p-value*
6-7 units				
constant	35.579	4.117	8.640	<0.0001*
Male	2.096	1.240	1.690	0.092
26 to 35	0.205	1.605	0.128	0.898
36 to 45	−3.166	1.839	−1.722	0.086
46 to 55	0.635	1.666	0.381	0.703
>55 age	−5.547	2.109	−2.630	0.009*

*The p value is significant at the 0.05 level

Table 50 shows that age and gender are not statistically significant for DMS with 5 units of information. Participants over 55 years of age tend to reduce their speeds to read DMS with 6-7 units of information as shown in Table 51.

Diversion Model

For this model and the six scenarios, only DMS preceding an exit ramp, were selected to examine the patterns of diversion in response to messages displayed. In all scenarios, the first DMS encountered by participants was excluded from this behavioral analysis to avoid biases that may arise from a participant's pre-selected choice of route. With the aid of the random forest algorithm, the socio-demographic and survey data, in Table 52, and the DMS categories, in Table 39, were used for this analysis.

Table 52. Descriptive Statistics of Route Diversion Dataset

Variables	Description	Percentage
Distance Time with Alternate Routes	Encountered	11%
	Did not encounter	89%
Travel Time with Alternate Routes	Encountered	22%
	Did not encounter	78%
Travel Time without Alternate Routes	Encountered	12%
	Did not encounter	88%
Lane Closure Information with Alternate Route	Encountered	11%
	Did not encounter	89%
Crash Related DMS With Advice	Encountered	11%
	Did not encounter	89%
Delay Related DMS With Advice	Encountered	22%
	Did not encounter	78%
Delay Related DMS Without Advice	Encountered	11%
	Did not encounter	89%
Diversion	Diverted	42%
	Did not divert	58%

Figure 35 shows the mean decrease in Gini (MDG) score for all the variables used for route diversion analysis. The higher the MDG score, the more important the variables. Four variables (travel time without alternate routes, delay-related DMS with advice, lane closure information with alternate routes, and when DMS/GPS conflict – I follow GPS) stand out and are selected as the important diversion variables.

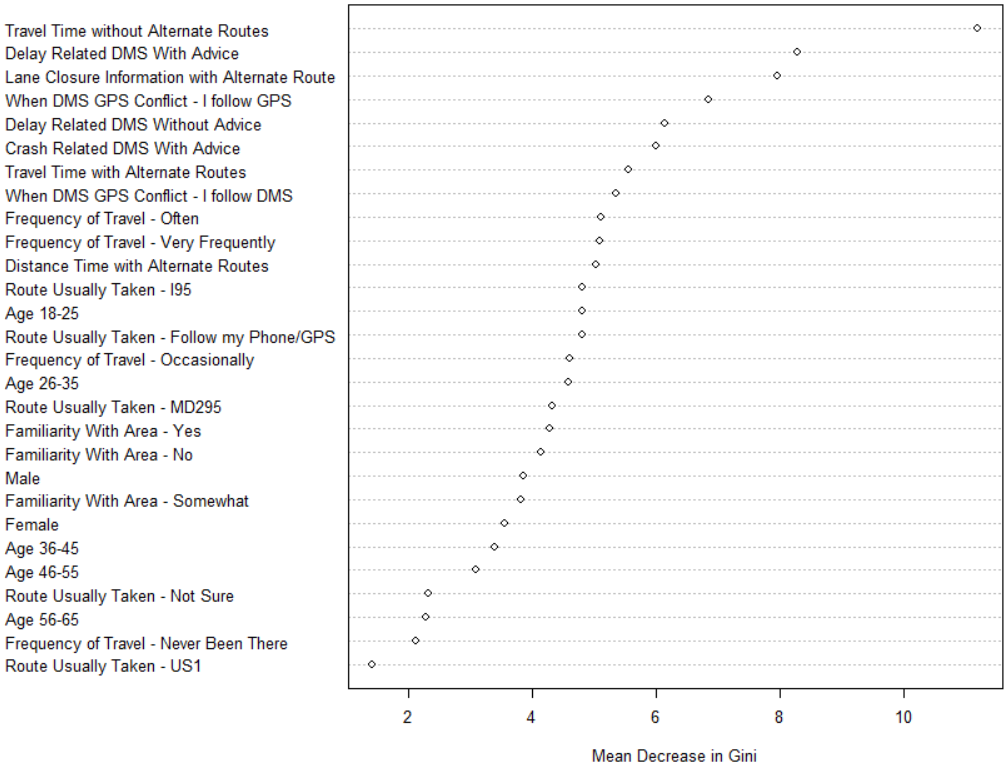


Figure 35. Plot of Variable Importance for Diversion by MDG Score

To determine the trend of influence these variables have on diversion, partial distribution plots (PDPs) were drawn as shown in Figure 36. The PDPs for this dataset are bar charts with binary outcomes with an increasing or decreasing trend as shown in Figure 36.

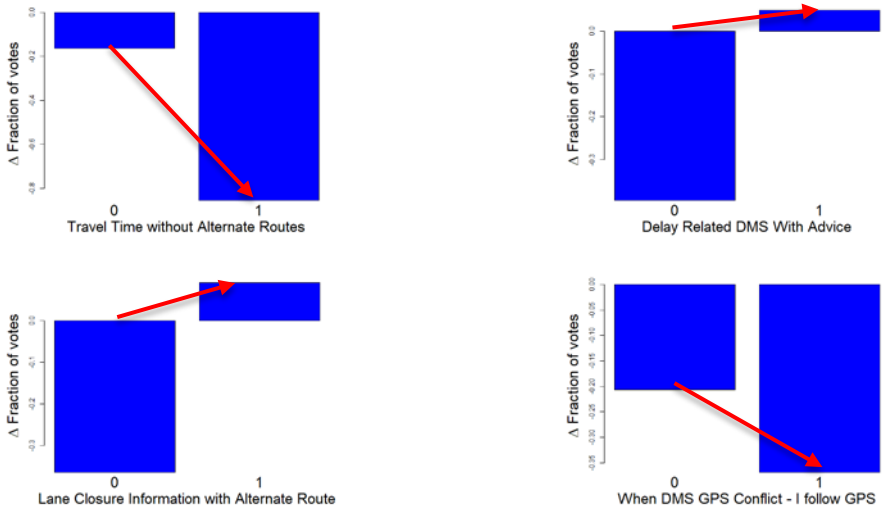


Figure 36. PDPs of Important Variables Impacting Diversion Behavior[2]

Although "travel time without alternate route" is the most important variable, it has a negative influence on diversion which means that it will not cause drivers to divert from their present course. This might be due to the non-provision of any pertinent information related to diversion

[2] The direction of the trend is shown by the red arrows.

other than just the travel time to the destination. Drivers who stated that they would follow their GPS, in case the DMS message conflicts with their GPS, were less likely to divert from the chosen route even in the absence of a navigation system. Delay-related messages with advice and lane closure messages with alternate route information were found to have a positive influence on diversion. This means that DMS displaying such messages will most likely cause drivers to change their route.

Compliance Model

All signs with advisory messages were selected to test compliance. The socio-demographic and survey data as listed in Table 53 and the sign categories listed in Table 39 are used for this behavioral analysis.

Table 53. Descriptive Statistics of Compliance Dataset

Variables	Description	Percentage
DMS Messages	Distance Time with Alternate Routes	18%
	Travel Time with Alternate Routes	18%
	Color Coded DMS	17%
	Lane Closure Information with Alternate Routes	9%
	Crash Related DMS With Advice	8%
	DMS With Avoid Route Advice	4%
	Delay Related DMS With Advice	17%
	DMS With Save Time Advice	9%
Compliance	Complied	53%
	Did not comply	47%

Figure 37 shows the MDG score for all the variables used for DMS compliance analysis. The results show that four variables (color-coded DMS, distance time with alternate routes, crash-related DMS with advice and DMS with avoid route advice) stand out and are selected as the important compliance variables.

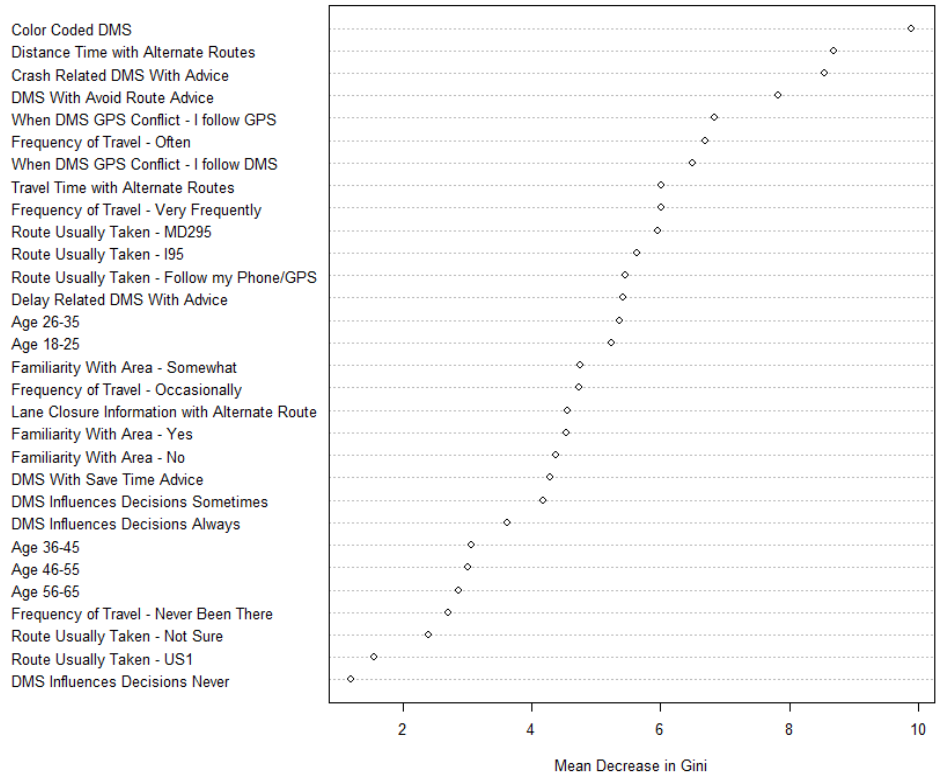


Figure 37. Plot of Variable Importance for Compliance by MDG Score

To determine the trend of influence these variables have on message compliance, PDPs were drawn as shown in Figure 38.

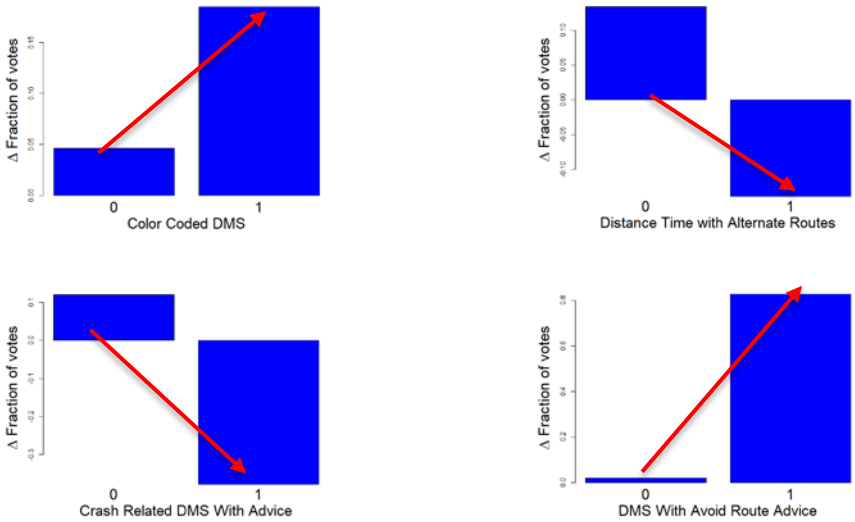


Figure 38. PDPs of Important Variables Impacting Compliance Behavior[3]

[3] The direction of the trend is shown by the red arrows.

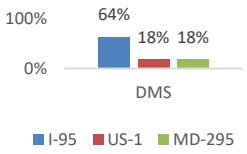
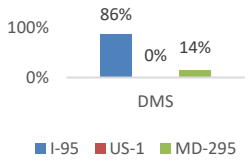
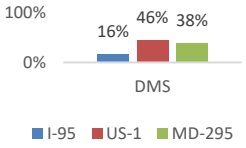
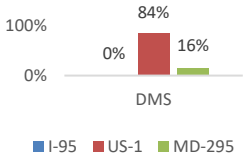
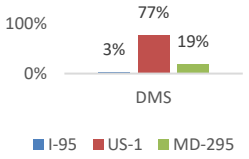
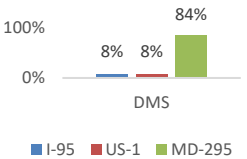
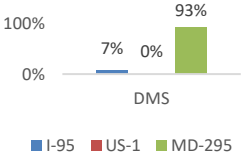
Although a DMS with “distance time with alternate routes” message is an important variable, it has a negative influence on compliance. This may be attributed to the very low travel time differences between the three routes, a maximum difference of 10 minutes among all of them. Results from the compliance analysis also showed that “crash-related DMS with advice” had a high likelihood of non-compliance. This might be because the advice tested in this study was vague and stated “choose alternate route.” Color-coded DMS had a higher likelihood of compliance as it was easy to comprehend (as expressed in survey responses) and the time taken to perceive it is less than alphanumeric text (Richard et al., 2009). “Avoid route” advice, on the other hand, is very specific and is most likely the reason why the compliance rate is high.

Route Choice Analysis

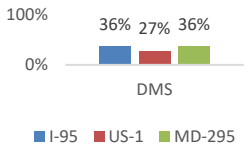
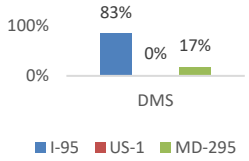
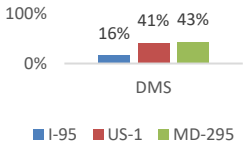
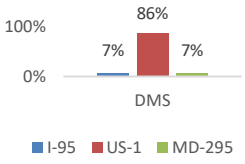
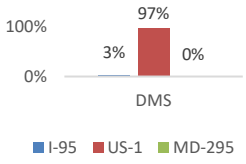
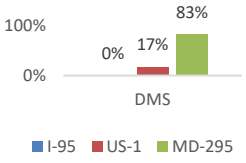
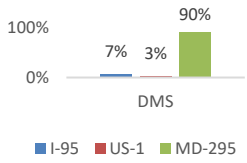
Two route choice analysis was conducted, one by every DMS in each scenario and a route choice model using survey and socio demographic data. They are shown in the next section.

Route Choice – Scenarios 1 & 2

Scenarios 1 and 2 were related to travel time DMS, with or without advice as shown in Figure 24. The route chosen by the participants after passing each DMS in scenario 1 and scenario 2 are shown in Figure 39. For example, 16% of participants chose I-95 after passing DMS 1 and out of these 16%, 64% stayed on I-95 after passing DMS2 on I-95. It can be seen that the initial ‘Distance-time’ messages with or without alternate routes did not significantly impact route choice decisions. DMS with ‘Destination time’ messages with alternate routes in scenario 2 impacted route choice even though only 16% of the participants chose that route. The impact seemed significant only when the travel times on alternate routes were considerably less than the current route as was the case on I-95 DMS2 in scenario 2.

	DMS1	DMS2	DMS3
I-95		 Distance time with Alt Route	
US-1	 Distance time with Alt Route	 Distance time with Alt Route	 Destination time with Alt Route
MD-295		 Distance time with Alt Route	 Destination time with Alt Route

Scenario 1 Route Choice

	DMS1	DMS2	DMS3
I-95		 Destination time with Alt Route	 Destination time
US-1	 Distance time	 Destination time with Alt Route	 Destination time
MD-295		 Destination time with Alt Route	 Destination time

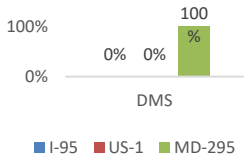
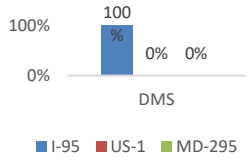
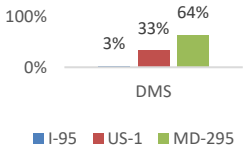
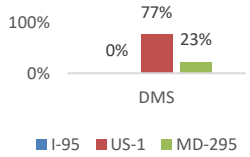
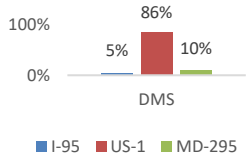
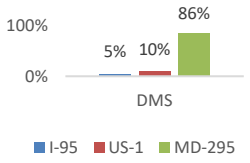
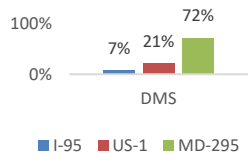
Scenario 2 Route Choice

Figure 39. Route Choice Post DMS Passage (Scenarios 1 & 2)

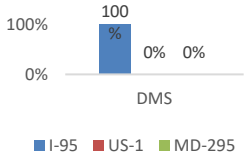
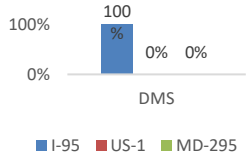
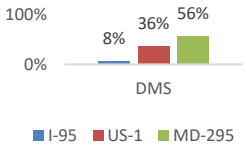
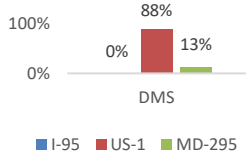
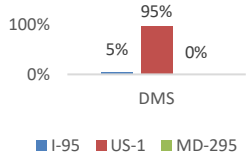
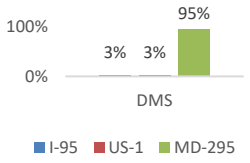
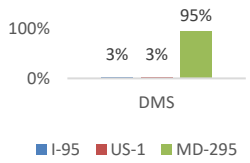
As the relative travel times for "Destination time" messages with alternate routes in scenario 1 and "Destination time" messages without alternative routes in scenario 2 were very small (within 5 – 7 minutes), the difference in route choice behavior seemed trivial. This meant that participants stayed on the same route they were on.

Route Choice – Scenarios 3 & 4

Scenarios 3 and 4 were related to lane closure DMS, with or without advice as shown in Figure 25. The route chosen by the participants after passing each DMS in scenarios 3 and 4 are shown in Figure 40. More than 90% of the participants avoided I-95 after passing the initial crash on I-95 related DMS. Incident-related messages (DMS3) on all routes in scenario 3 showed very low compliance possibly due to the vague advice of 'consider alternate route'. DMS3 without advice in scenario 4 showed that majority of the participants stuck to their current route possibly due to lack of advice. Lane closure DMS with advice (DMS2) in scenario 3 had 100% and 86% compliance based on route choice for routes I-95 and MD-295 and only 23% compliance on US-1.

	DMS1	DMS2	DMS3
I-95		 Lane closure with Advice	 Crash with vague Advice
US-1	 Crash with Avoid Advice	 Lane closure with Advice	 Crash with vague Advice
MD-295		 Lane closure with Advice	 Crash with vague Advice

Scenario 3 Route Choice

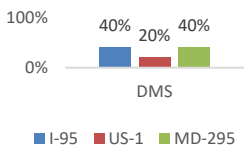
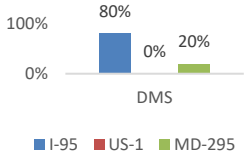
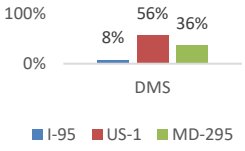
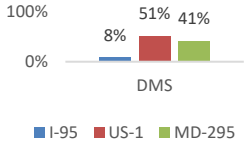
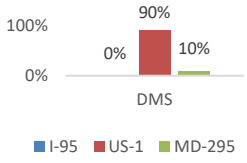
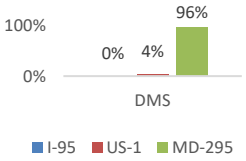
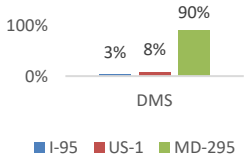
	DMS1	DMS2	DMS3
I-95		 Incident messages with Advice	 Incident messages without Advice
US-1	 Lane closure without Advice	 Incident messages with Advice	 Incident messages without Advice
MD-295		 Incident messages with Advice	 Incident messages without Advice

Scenario 4 Route Choice

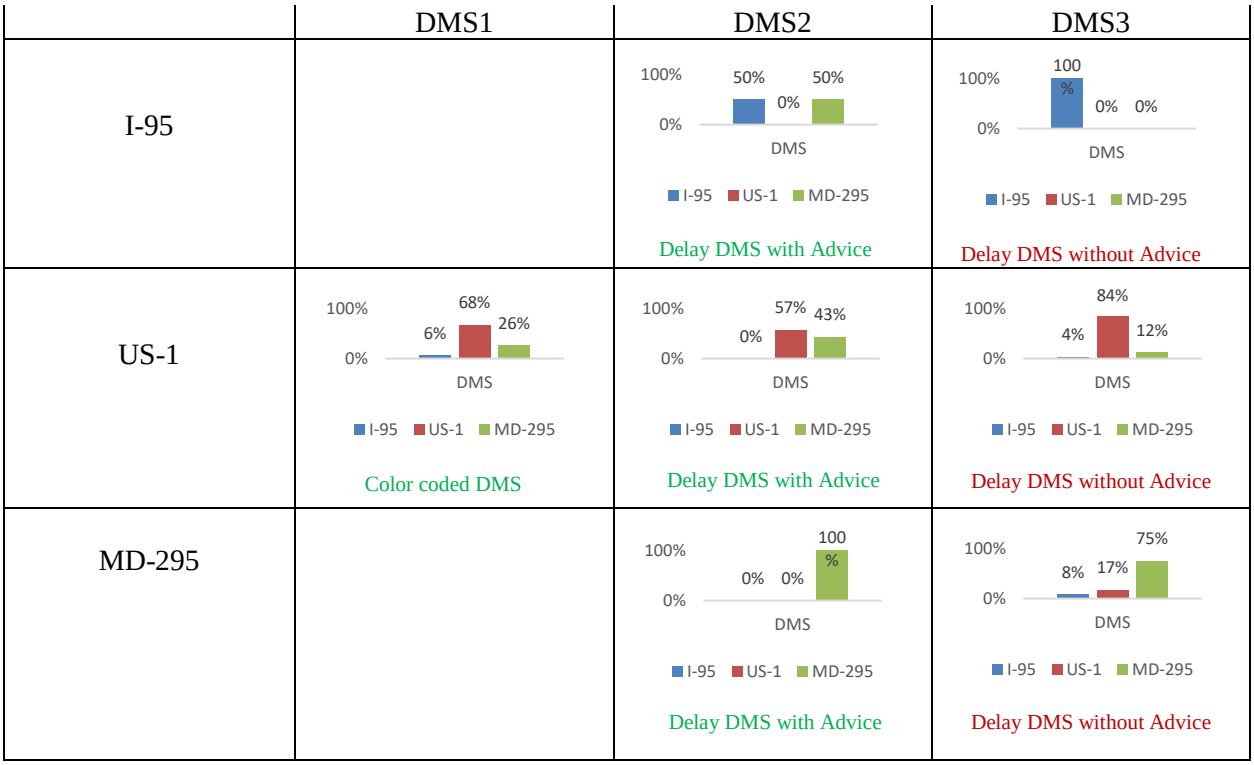
Figure 40. Route Choice Post DMS Passage (Scenarios 3 & 4)

Route Choice – Scenarios 5 & 6

Scenarios 5 and 6 were related to delay DMS, with or without advice as shown in Figure 26. The route chosen by the participants after passing each DMS in scenarios 5 and 6 are shown in Figure 41. DMS1 in scenario 6 or Design II had a 12% greater compliance than DMS1 or Design I in scenario 5.

	DMS1	DMS2	DMS3
I-95		 DMS with Save Time Advice	 Delay DMS with Advice
US-1	 Color coded DMS	 DMS with Save Time Advice	 Delay DMS with Advice
MD-295		 DMS with Save Time Advice	 Delay DMS with Advice

Scenario 5 Route Choice



Scenario 6 Route Choice

Figure 41. Route Choice Post DMS Passage (Scenarios 5 & 6)

DMS with save time and delay time messages in scenarios 5 and 6 had almost similar compliance but delay time messages had a slightly higher compliance. Participants chose to stick to their route when they came across DMS with delay messages without advice.

Route Choice Model

For this model, the first sign participants encountered in the network was selected to determine route choice behavior. The socio-demographic and survey data in Table 54 and the sign categories in Table 39 were used for this behavioral analysis.

Table 54. Descriptive Statistics of Route Choice Dataset

Variables	Description	Percentage
DMS Messages	Distance Time with Alternate Routes	17%
	Distance Time	17%
	Crash Related DMS with Advice	33%
	Color Coded DMS	33%
Route Choice	MD-295	44%
	US-1	47%
	I-95	9%

Figure 42 shows the MDG score for all the variables used for route choice analysis. The results show that three variables (color-coded DMS, crash-related DMS and when DMS/GPS conflict – I follow GPS) stand out and were selected as the important variables.

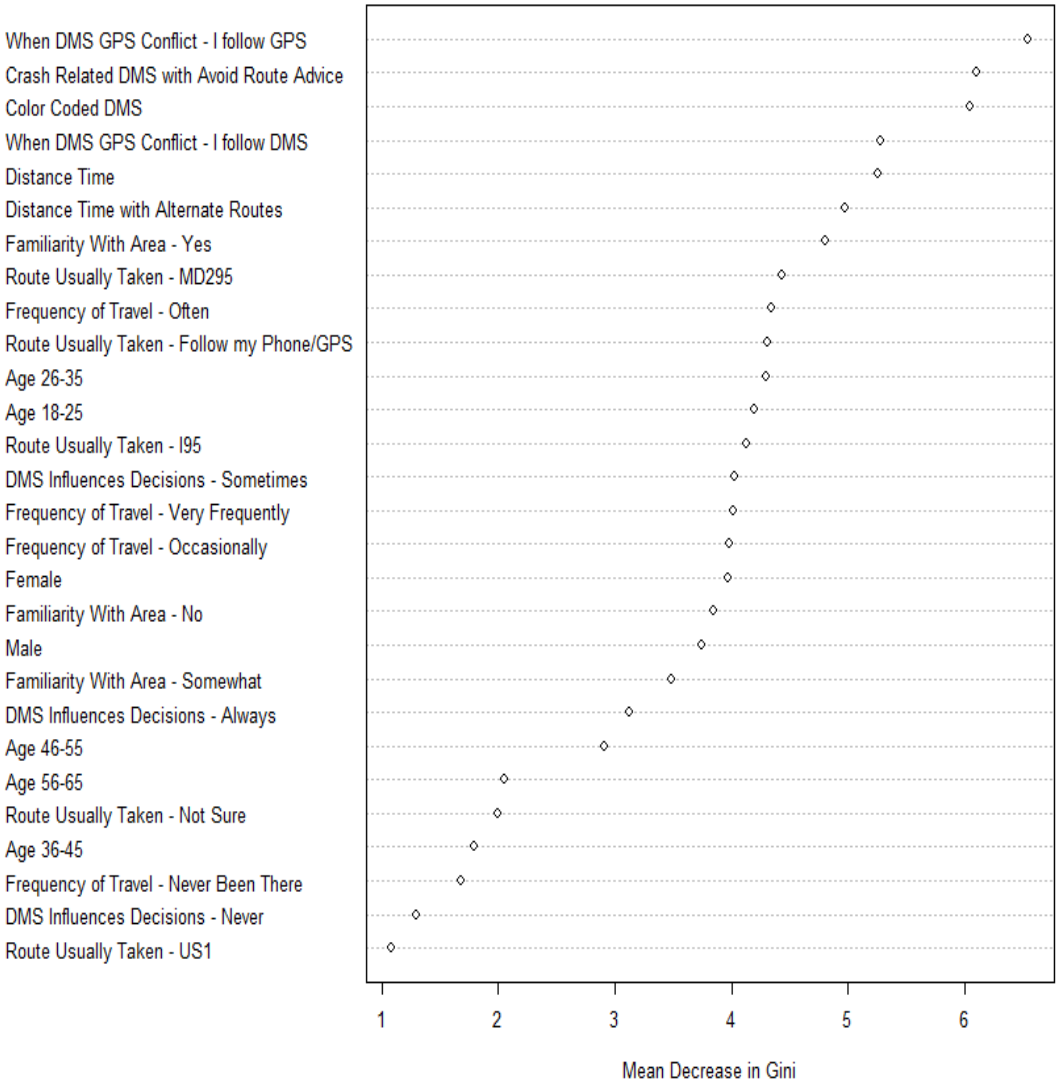


Figure 42. Plot of Variable Importance for Route Choice by MDG Score

To determine the trend of influence these variables have on route choice, PDPs were drawn for each class and shown in Figure 43. The binary outcomes for each route are shown for the selected important variables.

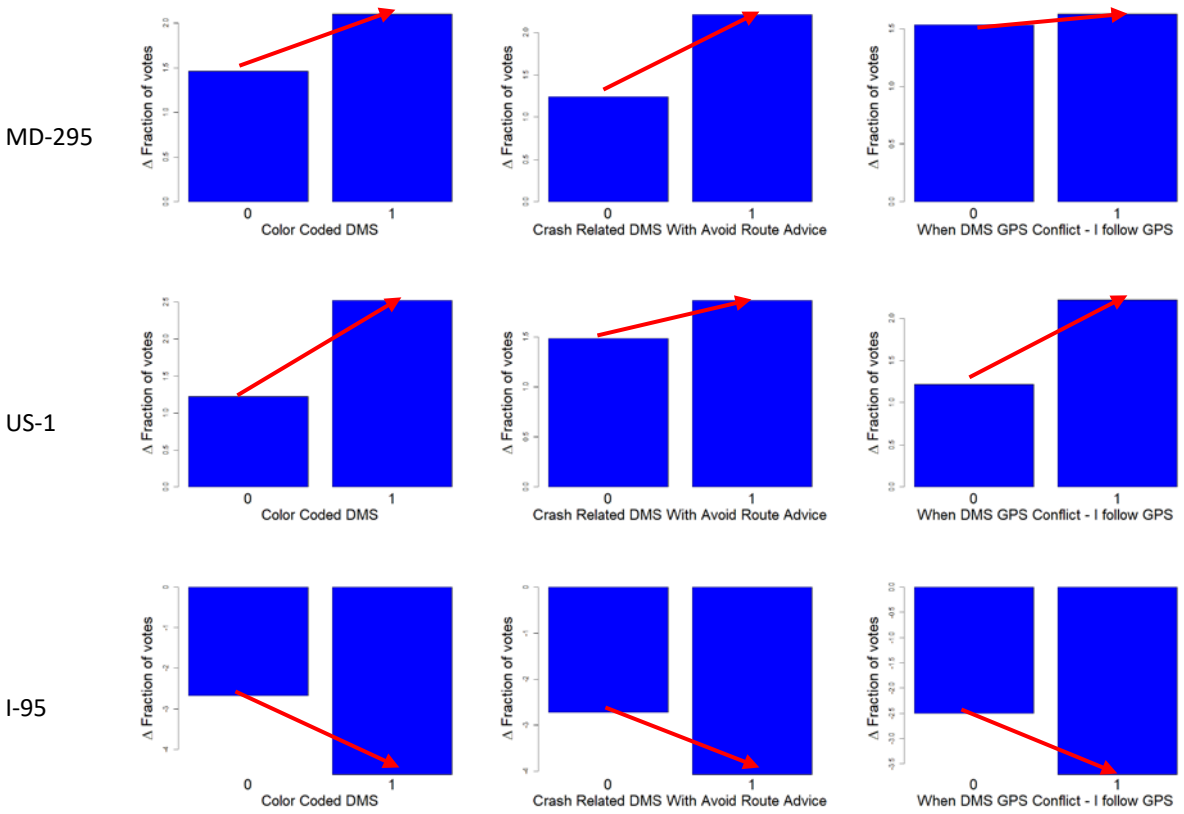


Figure 43. PDPs of Important Variables Impacting Route Choice[4]

The color-coded DMS was found to be the most important variable and, as can be seen in Figure 43, participants have a higher likelihood of picking US-1 over other routes if the DMS showed heavy traffic on I-95, medium traffic on MD-295 and light traffic on US-1. Similarly, the crash-related DMS with avoid route advice gave information about a crash on I-95 and advised participants to avoid it. Participants responded to the DMS by using either MD-295 or US-1. Participants, who answered that they would follow GPS in case of conflicting DMS route suggestions, showed less likelihood of picking I-95 in the absence of a GPS, as advised by the DMS to avoid that route.

Conclusion

A comprehensive literature review and compilation of DMS best practices was completed in this study. The impact of content, structure and type of DMS messages on driver behavior was also investigated using a full-scale high-fidelity driving simulator. Both SP surveys and driving simulator techniques were used to evaluate the effects of different DMS on driver behavior. A before and after DMS sign encounter speed analysis was conducted, and the speeding behavior of the participants following certain trends was shown. A route diversion model, a route choice model and a DMS compliance model were developed considering participant socio-demographic

[4] The direction of the trend is shown by the red arrows.

and survey answers, using a random forest algorithm to gauge how people react to different signs and how it impacts their decision making.

Approximately 7.5% (~11 million) of the population in the United States cannot distinguish between red and/or green colors. As they have become familiar with traffic lights, the authors designed the color-coded DMS messages to be color-blind people-friendly. Although the red and yellow colors on the DMS sign were to show heavy traffic and medium traffic, they were in the shape of horizontal bars (Design II). The length of the bars would show traffic congestion levels, making them color-blind people-friendly based on the input received. Although there weren't any color-blind participants, the overall compliance of color-coded DMS, and its effectiveness in determining route choice, make it a valuable means of signage and MDOT SHA could benefit from better visuals and graphics which can grab drivers' attention. Based on the findings of this study, use of color-coded DMS should be considered in Maryland. Pilot studies can be performed to corroborate the findings of this study.

The number of units of information on a DMS should be very concise, i.e. the fewer units of information, the less time it will take for drivers to process the information. If drivers must reduce the speed to read the information on a DMS, in case of higher units of information (6-7), it could lead to a gradual slowdown causing congestion. Therefore, the authors recommend that the number of units be kept to a minimum. If needed, the information could be split up into two phases.

Prior research on the study corridor showed that people have a tendency to choose I-95 as their default route, since it is wider, has a higher speed limit and is faster under normal traffic conditions (Jeihani et al., 2014). This driving behavior is altered under non-recurrent situations like roadwork or crashes. In this study, the DMS messages have stated throughout the six scenarios that I-95 had heavy traffic. The results indicate that the participants tend to better comply with crash-related DMS with advice, especially advice that mentions "avoid," lane closure with alternate route advice and delay-related DMS with advice. Most drivers depend on their GPS/smartphones for turn-by-turn guidance to reach their destination. Some 98% of the participants in this study stated that they use GPS/smartphone for navigation at least sometimes. In such scenarios, drivers pay less attention to travel time-related DMS messages. Smartphone navigation informs the driver of a delay before leaving their point of origin. But incidents like crashes can happen at any time or a phone battery can die, and appropriate DMS messages are useful in such situations, since they can prevent delay and congestion. Lane closure, delay DMS with specific route diversion and avoid route information will likely be useful in such situations once drivers start experiencing a slowdown on their choice of route. Although these DMS messages are used intermittently, as incidents occur, they should be employed more often based on the study findings. This will possibly reduce congestion through compliance with DMS messages. The authors strongly recommend that DMS should display messages that give specific instructions or advice to drivers in case of an incident rather than vague messages like "Expect Delays" or "Consider Alternate Routes."

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Appendix A: Survey Questionnaire 1 (Socio-demographic Survey)

Dear Participant,

We are excited and highly appreciative of your interest in our ongoing study aimed at evaluating the potential effects of Dynamic Message Signs (DMS) on driver behavior.

Please fill in the appropriate choice for each question and kindly ensure that the subject number assigned to you (as stated in the subject of the email sent to you) is selected.

Thank you once again for your invaluable contribution.

Please select your subject number *

1) What is your gender? *

- Female
- Male

2) What is your age group? *

- 18 to 25
- 26 to 35
- 36 to 45
- 46 to 55
- 56 to 65
- > 65

3) What is your present educational status? *

- High School or less
- Associate degree
- Undergraduate Student
- Undergraduate degree (completed)
- Post graduate Student
- Post graduate Degree (completed)

4) Are you currently employed?

- No
- Part Time
- Work full time

5) What type of driving license do you have? *

- Permanent license for regular vehicles (class C)
- Permanent license for all types of vehicles (class A)
- Learner's Permit

- Don’t have a license

6) What is your household annual income? (Optional)

- < $20, 000
- $20,000 - $29,999
- $30,000 - $49,999
- $50,000 - $74,999
- $75,000 - $99,999
- > $100,000

7) What is your household size? (If you live away from family/dorm, check '1')*

- 1
- 2
- 3
- 4 or more

8) How many cars does your household own? *

- 1
- 2
- 3 or more
- None

9) Do you drive a car? *

- Less than 8,000
- 8,001 to 15,000
- 15,001 to 30,000
- More than 30,000

10) What is the average annual driving mileage on your own car (in miles)? *

- <8,000 miles
- 8,001 - 15,000 miles
- 15,001 -30,000miles
- > 30,000
- Not applicable

10) Are you familiar with any type of Dynamic Message Signs (DMS), such as this image: *

- Yes
- No

Please read the following before answering the next set of questions if you are not familiar with DMS:

/Dynamic Message Sign (DMS) is an electronic device providing qualitative and/or quantitative information on traffic conditions and events to travelers. Traffic congestion, accidents, work zones, alternative routes, and expected delay represent such information.

11) How often do you see a DMS on your travel? *

- Never
- Sometimes
- Everyday commute

12) To what extent do you pay attention to a DMS? *

- I don't pay attention
- Usually don't get a chance to read it
- Only in a few situations (such as an accident)
- Always read and sometimes follow
- Always read and follow

13) When you go to work/home, do you follow DMS messages? *

- I dont pay attention
- Only in a few situations (such as an accident)
- Read to see when I get there
- Always read and follow
- Not applicable for me

14) Do you feel that VMS is a useful device for providing traffic information for travelers? *

- Absolutely
- Potentially
- I don't think so

15) Do you usually use GPS/smartphone for route guidance when you drive? *

- Never
- Sometimes
- Always

16) If you use GPS, would you change your route if you see a DMS sign with traffic/roadwork information on your selected route? *

- Yes
- No
- Maybe
- Not applicable to me

17) Do you usually listen to the radio traffic information when you commute? *

- All the time
- Most of the time
- Sometimes
- Never
- Not applicable to me

Appendix B: Survey Questionnaire 2 (Pre-Simulation Survey)

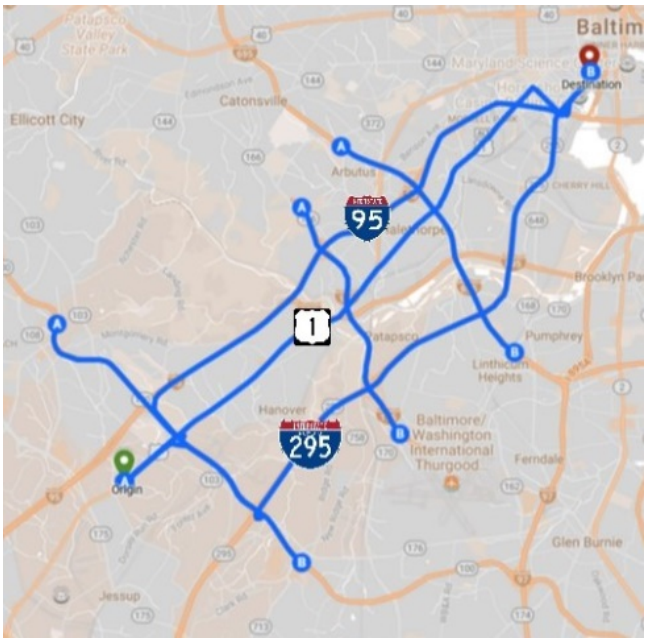
Dear Participant,

We remain grateful for your input in our ongoing study and kindly request that you fill this form; the second part of our survey. Please, while filling this form, assume that you are driving on US-1 in the Northbound direction with Baltimore stadium as your destination.

Please select your subject number *

1) Are you familiar with the area? *

- No
- Somewhat
- Completely familiar



2) How often do you travel in this area? *

- Very frequently (At least once a week)
- Often (Once a month)
- Occasionally (less than 5 times per year)
- Never been there

3) Which route would you usually take to reach the destination from the origin point? *

- I-95
- US-1 (Washington Blvd)
- MD-295
- I use my GPS/ smartphone
- I am not sure

4) Do you understand the abbreviations that you see on DMS? *

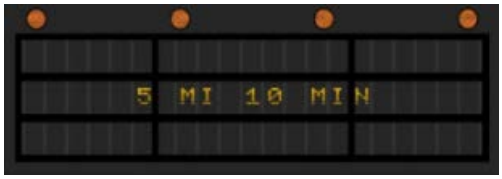
- Full text

- Abbreviated text

- Do not care

5) Which of the following ranks high on your priority list of messages that you would like to see on a DMS? (1, 2, 3, 4…. 1 being the highest)

- Travel Time DMS



- Crash DMS

- Delay DMS

- Weather Information DMS

- Alerts (Amber, Silver…) DMS

- Construction DMS

- Speed DMS

- Public Service DMS

6) What kind of crash information would you like to see on a DMS? *

Option 1

Option 2

Option 3

Appendix C: Survey Questionnaire 3 (Post Scenario 1 Survey)

Dear Participant,

Thank you for completing the first simulation of the study. Please fill out this short questionnaire to enable us to know your experience in the just completed simulation.

Please select your subject number *

1) Did you understand the DMS's that you observed in the scenario that you just drove in? *

- Yes
- No

2) How many DMS's did you follow? *

- 1
- 2
- 3
- All
- None

If you selected "None" in the previous question, please explain why?

Appendix D: Survey Questionnaire 4 (Post Scenario 2 Survey)

Dear Participant,

Thank you for completing the first simulation of the study. Please fill out this short questionnaire to enable us to know your experience in the just completed simulation.

Please select your subject number *

1) Did you understand the DMS's that you observed in the scenario that you just drove in? *

- Yes
- No

2) How many DMS's did you follow? *

- 1
- 2
- 3
- All
- None

If you selected "None" in the previous question, please explain why?

Appendix E: Survey Questionnaire 5 (Post Scenario 3 Survey)

Dear Participant,

Thank you for completing the first simulation of the study. Please fill out this short questionnaire to enable us to know your experience in the just completed simulation.

Please select your subject number *

1) Did you understand the DMS's that you observed in the scenario that you just drove in? *

- Yes
- No

2) How many DMS's did you follow? *

- 1
- 2
- 3
- All
- None

If you selected "None" in the previous question, please explain why?

Appendix F: Survey Questionnaire 6 (Post Scenario 4 Survey)

Dear Participant,

Thank you for completing the first simulation of the study. Please fill out this short questionnaire to enable us to know your experience in the just completed simulation.

Please select your subject number *

1) Did you understand the DMS's that you observed in the scenario that you just drove in? *

- Yes
- No

2) How many DMS's did you follow? *

- 1
- 2
- 3
- All
- None

If you selected "None" in the previous question, please explain why?

Appendix G: Survey Questionnaire 7 (Post Scenario 5 Survey)

Dear Participant,

Thank you for completing the first simulation of the study. Please fill out this short questionnaire to enable us to know your experience in the just completed simulation.

Please select your subject number *

1) Did you understand the DMS's that you observed in the scenario that you just drove in? *

- Yes
- No

2) How many DMS's did you follow? *

- 1
- 2
- 3
- All
- None

If you selected "None" in the previous question, please explain why?

Appendix H: Survey Questionnaire 8 (Post Scenario 6 Survey)

Dear Participant,

Thank you for completing the first simulation of the study. Please fill out this short questionnaire to enable us to know your experience in the just completed simulation.

Please select your subject number *

1) Did you understand the DMS's that you observed in the scenario that you just drove in? *

- Yes
- No

2) How many DMS's did you follow? *

- 1
- 2
- 3
- All
- None

If you selected "None" in the previous question, please explain why?

Appendix I: Survey Questionnaire 9 (Final Post-Simulation Survey)

Dear Participant,

Congratulations! We have come to the end of the simulation session. We sincerely hope you had fun! Please, kindly share your driving simulation experience with us by filling the survey below. As with the previous surveys, please ensure that the subject number assigned to you is selected. If in doubt, kindly ask the observer.

Please select your subject number *

1) **What is your reaction on seeing a DMS?** *

- It is distracting
- Happy to get directions to save time
- Crosscheck with GPS/smartphone
- Ignore it

If you Crosscheck the DMS information with a GPS/smartphone, and the information conflicts, would you go with the DMS sign or your GPS/smartphone?

- GPS/smartphone
- DMS
- Not applicable

2) **Please rank your preference in case of a delay? (1, 2, 3, 4…. 1 being the highest)** *

- DMS with advice
- DMS without advice
- Color coded DMS
- Don't care

3) **Please rank your preference for travel time information that would you like on the DMS? (1, 2, 3, 4…. 1 being the highest)** *

- Travel time information with alternate routes (M&T stadium: Via US-1 20 minutes, Via I-95 25 minutes)
- Travel time information without alternate routes (M&T stadium 25 minutes)
- Distance-time with alternate routes (NXT 5 MI: Via US-1 8 MIN, Via I-95 12 MIN)
- Distance-time without alternate routes (NXT 5 MI 8 minutes)
- Don't care

4) **Please rank your preference in case of lane closures? (1, 2, 3, 4…. 1 being the highest)** *

- Lane closure information on same routes (RDWK Ahead 3 MI, Left Lane Closed)
- Lane closure information on neighboring routes (Maj Accident at I-95, 2 LFT LNS Closed)
- Lane closure information with advice (Crash past I-95, Right Ln closed. Use MD-295)
- Lane closure information without advice (RDWK Ahead, LFT LN Closed)
- Don't care

5) **What kind of text do you prefer on a DMS?** *

- Full text
- Abbreviated text
- Don't care

6) **Does the DMS make you change your route?** *

- Always
- Sometimes
- Never

7) **Please check the intensity of any symptom which applies to you now.** *

	None	Slight	Moderate	Severe
General discomfort				
Fatigue				
Headache				
Eyestrain				
Blurred Vision				
Salivation increase/decrease				
Sweating				
Dizziness				
Nausea				

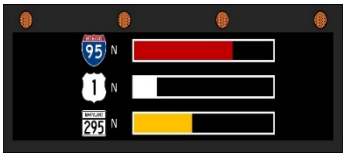
8) **Do you think DMS is a useful device in providing information for travelers?** *

- Yes
- No

9) **Which color coded DMS message do you prefer?** *

- Option 1

- Option 2



10) **Will you return for another simulation run using the driving simulator?** *

- Yes
- No

Appendix J: Consent Form

You are invited to participate in a study of the effect of dynamic message sign on drivers' behavior. We hope to learn how effective these systems are and how we can make them more effective for travelers. The study is being conducted by Dr. Mansoureh Jeihani of Morgan State University. You were selected as a possible participant in this study because you kindly responded to our invitation and accepted to participate.

If you decide to participate, we will ask you to fill out three survey questionnaire forms. You will be trained how to drive the simulator. Then you will drive the simulator several times in different traffic and driving conditions. It will take no more than 2 hours in each visit. You may participate in different days. You will be paid $15 per hour of driving the simulator. When you drive the simulator, you may feel dizzy in the first few experiments until you get used to it. There is no risk of driving the simulator, you just may feel dizzy or fatigue or get headache. You may find it fun to drive the simulator and have some experiences such as crashes that are dangerous in the real world.

Your decision whether or not to participate will not prejudice your future relation with the Morgan State University. If you decide to participate, you are free to discontinue participation at any time without prejudice.

Any information that is obtained in connection with this study and that can be identified with you will remain confidential and will be disclosed only with your permission.

If you have any questions, please do not hesitate to contact us. If you have any additional questions later about the study, please contact Dr. Mansoureh Jeihani at 443-885-1873 who will be happy to answer them. If you have further administrative questions, you may contact the MSU IRB Administrator, Dr. Edet Isuk, at 443-885-3447.

You will be offered a copy of this form to keep.
You are deciding whether or not to participate. Your signature indicates that you have read the information provided above and have decided to participate. You may withdraw at any time without penalty or loss of any benefits to which you may be entitled after signing this form should you choose to discontinue participation in this study.

_____	_____
Signature	**Date**
_____	_____
Signature of Parent/Legal Guardian (If necessary)	**Date**
_____	_____
Signature of Witness (If appropriate)	**Signature of Investigator**