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Report No. UT-21.31

EVALUATING THE IMPACT OF DETOUR MESSAGING ON ACTUAL DRIVER DETOUR BEHAVIOR

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16. Abstract

There is limited research on the effects of variable message sign (VMS) message content on revealed driver behavior. This study investigated the associations of message content with diversion rate during crash incidents using 5 years of VMS message history within a section of I-15 in the state of Utah. The diversion rate was found to be higher when the message consisted of information such as miles to crash, “crash ahead,” location of the crash, delay information, traffic ahead (i.e., is slowing or slows), and lane of the crash. However, “use caution,” speed suggestions, and “prepare to stop” content were found to be negatively associated with diversion rate. When considering message content combinations, combinations of miles to crash + “prepare to stop” had the highest diversion rate, followed by combinations of crash location + delay information, and miles to crash + “use caution” + lane of crash information. These findings could be used by agencies to make informed decisions about choosing the message content during future crash incidents. The study also revealed that a higher diversion rate is associated with a shorter distance between the crash location and VMS device location, which suggests recommending increasing the number of VMS devices, particularly in crash-prone areas. In addition, the diversion rate correlated with some roadway characteristics (e.g., occupancy in mainline) along with the temporal variations.

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UNIT CONVERSION FACTORS

SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
		NOTE: volumes greater than 1000 L shall be shown in m^3		
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact degrees)		
°F	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	°C
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
		TEMPERATURE (exact degrees)		
°C	Celsius	1.8C+32	Fahrenheit	°F
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

*SI is the symbol for the International System of Units. (Adapted from FHWA report template, Revised March 2003)

LIST OF ACRONYMS

BI	Behavioral Intention
EB	Empirical Bayes
HOV	High Occupancy Vehicle
IQ	Information Quality
MUTCD	Manual on Uniform Traffic Control Devices
MV	Mainline Volume
PeMS	Performance Measurement System
PEOU	Perceived Ease of Use
PU	Perceived Usefulness
RWIS	Road Weather Information System
TAM	Technology Acceptance Model
UDOT	Utah Department of Transportation
VMS	Variable Message Sign
WAER	Weighted Average Exit Rate

EXECUTIVE SUMMARY

Messaging via Variable Message Signs (VMS) can be presented in several ways. For example, “Crash 3 miles ahead, use caution” and “Crash ahead, prepare to stop” could both be used to inform drivers of a crash incident and suggested response/strategy. Anecdotally, there could be a noticeable difference in the behavioral response of drivers corresponding to how “startling” the message is. This study investigated the driver diversion response to different message content commonly used in Utah during crash incidents. VMS message history and associated crash data on I-15 within mileposts 285 and 342 were assembled for the period 2016 – 2020 and used for analyses. During this time period, less than 2% of VMS messages were related to crashes.

A logistic regression model of increase in diversion rate (model A) was fitted. The diversion rate – with three levels: none/low, medium, and high – was the dependent variable of the model. The independent variables of the model were: (a) message content; (b) other VMS-related variables, which include the number of frames used to display the message, the time difference between crash incident and message display, the distance between crash incident and VMS device, and message display duration; (c) roadway characteristics during message display, which include an increase in roadway occupancy, weather condition, and light condition; and (d) temporal variables, which include an hour of the day and day of the week. Next, another logistic regression model of increase in diversion rate (model B) was fitted by changing the message content-related variables of model A to a variable representing combinations of different message content with all other variables remaining the same to ascertain the drivers’ behavioral response to different message combinations.

Messages containing miles to crash, “crash ahead,” location of the crash, delay information, traffic ahead (i.e., is slowing or slows), and lane of the crash were found to be positively associated with diversion rate. However, messages containing “use caution,” speed suggestions, and “prepare to stop” were found to be negatively associated with diversion rate. Based on the estimates, the combinations of message contents associated with the greatest diversion rate were messages with miles to crash + “prepare to stop” information, followed by message combinations of crash location + delay information, and miles to crash + “use caution” + lane of crash information. In addition, the message combinations associated with reduction in diversion rate were crash location + “prepare to stop,” followed by crash location + speed suggestions, and miles to crash and speed suggestion information.

Messages with two frames had higher diversion rates than those with one frame (in model B only). The larger distance between the VMS device and the crash location was negatively associated with diversion rate. However, the time difference between crash incident and message display, and duration of message display had no significant impact on diversion rate. In terms of roadway characteristics, occupancy on the mainline was positively associated with diversion rate. A higher diversion rate was observed during rain than during clear weather conditions (in model A only). In comparison to daylight conditions, the diversion rate was found to increase during dark (lighted or unlighted) conditions and, to a lesser extent, during dawn/dusk light conditions. Both temporal variables considered in the study – peak hour and day of the week – were positively associated with diversion rate. In comparison to an off-peak hour, morning peak hours observed greater diversion rates (marginally significant), but evening peak hours observed lower diversion rates. No significant difference in diversion rate was observed between Saturdays and weekdays, but higher diversion was observed on Sundays in comparison to weekdays.

Crash incident management is a high priority for UDOT. This study found that incident management can be improved by displaying consistent message content that is known to have the greatest impact on diversion. The use of consistent message content throughout the state would decrease driver confusion and indecision. In addition, it would support traffic managers through informed decision-making and decreased ambiguity in choosing the message content during crash incidents, ideally saving time for more critical tasks. In summary, this study’s findings support the UDOT Traffic Operations Center by improving efficiency and consistency in response to future crash incidents. The research team also recommends increasing the number of VMS devices, particularly in crash-prone areas, to increase the impact of crash-related messages. Finally, the team speculates that the impacts of crash-related messages may be lessened by the oversaturation of non-critical messaging displayed to drivers on VMS devices. The research team recommends that UDOT consider policies and decision-making related to overall VMS utilization.

1.0 INTRODUCTION

1.1 Problem Statement

Variable message signs (VMS), sometimes also referred to as dynamic or changeable message signs, are traffic control devices installed on roadways that impart messages to drivers, primarily about traffic conditions. As a regulatory guideline, the Manual on Uniform Traffic Control Devices (MUTCD) has outlined 11 situations where VMS can be used, which are listed in Chapter 2 (MUTCD, 2009). VMS devices are mostly programmable and are often controlled from a central location, though they can also be controlled onsite in the cases of temporary VMS. Whenever the controller gets information about traffic incidents, the messages about the incidents may be displayed on the devices. Thus, the traffic information displayed via VMS is most often real-time.

Among the variety of VMS applications, this study particularly focuses on the messages displayed during crash incidents. Crash incidents have severe negative impacts on roadways, including congestion and the subsequent, associated safety risks. The congestion during crash incidents might be temporary depending upon the crash clearance time, but it could be severe in terms of travel time and safety risks. Informing drivers about the crash incident along with associated traffic information is important to mitigate such negative impacts, and VMS is a commonly used solution for this task. When provided with accurate and timely crash information, drivers might consider changing their route for two purposes: (a) to avoid traffic congestion and (b) to lower their personal safety risks. Alternatively, drivers might use the same route with additional necessary safety precautions (e.g., considering lower speed, higher headways, focused driving, etc.).

Although there have been a handful of past studies (summarized in the subsequent Literature Review section) that evaluated the effectiveness of displaying crash incident messages via VMS in reducing the negative effects of crashes, the following research gaps motivate this study:

- Most of the existing studies used drivers' stated preference (survey) to evaluate the performance of VMS messages, but several studies have found large discrepancies between the revealed and stated behavior. This necessitates capturing actual driver behavior during crash incident-related messages.

- None of the existing revealed behavior-related studies (either utilizing survey or loop-detector data) focused on analyzing the impact of specific message content on drivers' behavior.

Based on these gaps, this study utilized the VMS message history and detector data (loop detector and radar data) of a section of I-15 in Salt Lake City, Utah, to evaluate drivers' behavior during crash incidents and in response to related VMS messages.

1.2 Objectives

The objective of this project was to identify the association of diversion rate as a result of crash incident messages with different message content. The authors hypothesized that message content alters the diversion rate, and that diversion rate is also influenced by other factors, such as weather and congestion on the mainline.

1.3 Scope

This project accomplished the research objectives through the following major tasks:

- Reviewing the literature on driver response to VMS messages (with slightly more focus on crash-related messages) based on stated, revealed, experimental, and real-field data.
- Selecting a study site: I-15 NB and SB from milepost 285 to 342.
- Obtaining and filtering historical VMS data and crash incident data for the study site between 2016 and 2020.
- Joining VMS messages with respective crash incidents.
- Obtaining message content-related information (e.g., miles ahead information included or not, location of the crash included or not, etc., in the message) for each joined message record.
- Data analysis and modeling of the assembled data to explore the associations between message content and diversion rate.

- Providing recommendations based on study findings to improve the VMS messaging practice for crash-related incidents.

1.4 Outline of Report

This report is organized as follows:

- Chapter 1 includes the problem statement, research gaps and motivations, project objectives, project scope, and the outline/organization of the report.
- Chapter 2 includes a detailed literature review of studies investigating driver response towards different styles and graphics of VMS messages, message contents (e.g., delay and congestion information, incident information, detour information), and general safety messaging followed by behavioral acceptance to VMS technology and associated characteristics of drivers.
- Chapter 3 covers the data collection process, including details on the scope and source of data.
- Chapter 4 discusses the data evaluation and analysis process, including model development and results.
- Chapter 5 discusses the results of the data analysis, including key findings as well as limitations and challenges of the study.
- Chapter 6 includes recommendations resulting from the study and an implementation plan.

2.0 LITERATURE REVIEW

2.1 Overview

Guidelines for the installment and use of VMS are established in the MUTCD (MUTCD, 2009). In this manual, VMS is instead referred to as a changeable message sign. Changeable message sign and dynamic message sign are both used in the literature as synonyms for VMS. All of these terms are defined as having the ability to display messages that can be changed over time (short term and long term). VMS or CMS are sometimes also called dynamic message signs (DMS) in the literature. In this report, to maintain consistency with Utah Department of Transportation (UDOT) terminology, only VMS is used.

Several applications of VMS have been discussed in the existing literature. As a regulatory guideline, the MUTCD has outlined 11 situations where VMS can be used, which are (MUTCD, 2009):

- Incident management and route diversion
- Warning of adverse weather conditions
- Special events applications associated with traffic control or conditions
- Control at crossing situations
- Lane, ramp, and roadway control
- Priced or other types of managed lanes
- Travel-time information
- Warning situations
- Traffic regulations
- Speed control
- Destination guidance

VMS messaging is considered effective if drivers follow the directions as displayed. In the literature, four methodologies have been used to ascertain drivers' response behaviors as a result of VMS messaging: (1) stated preference survey, (2) revealed preference survey, (3) lab-based driving simulator experiment, and (4) quasi-experiment and analysis of real field data. In a stated preference survey, travelers are asked to show their preference and choice in different hypothetical scenarios related to VMS. The scenarios may include but are not limited to message type, wording, letter size, information content, use of abbreviation, level of incident, presence of detour strategy, travel time, speed limit, etc.

Theoretically, stated preference surveys should capture travelers' behavior, but the responses might not reflect the actual behavior in all cases. To validate the stated preference survey result, revealed preference surveys are more often preferred. In this case, travelers who have actually experienced a scenario with a VMS message are asked about the experience and their response. In one study, a revealed preference survey showed a slightly lower diversion likelihood than that of the stated preference survey (Kim et al., 2014). A difference in the stated (survey) and revealed (driving simulator) diversion rate was also observed by Banerjee et al. (2010).

During the phased installment of a number of VMS in London, UK, three methods were applied to evaluate driver response to different VMS messages (Chatterjee et al., 2002). A stated preference study was conducted, followed by a revealed preference survey and field observation of diversion rates. The results showed that the observed diversion rate was only one-fifth of the estimated diversion rate based on the stated survey. These contradictory results between the different methodologies demonstrate that there is a significant difference between stated and revealed behavior. These differences might be a result of the shortcomings of the stated preference survey in having the respondents realize a real field scenario, such as placement of VMS, the distraction created by VMS, the time needed to perceive the message, etc. One study found that only 0.07% of the respondents who stated to follow VMS information actually diverted in response to different types of VMS messages (Taisir Ratrout & F Issa, 2014).

The third method used to gauge driver response to VMS messaging is to create a virtual traffic environment using simulation technology. Here, participants are asked to drive in the simulator in various VMS scenarios and their behavior is evaluated. The fourth method is quasi-experiment and analysis of real field data. This is the most effective but unfortunately often uneconomical and uncontrollable method to evaluate VMS message effectiveness. A quasi-experiment is the installment of VMS in a controlled site to analyze travelers' responses to VMS. Here, a number of VMS scenarios can be tested, and the response of travelers assessed in a controlled, physical environment. A real field experiment uses VMS installed on in-use roads where drivers behave the most naturally, but the experiment is not completely controlled. In both cases, the driver response data can be analyzed to ascertain the effectiveness of VMS under different attributes.

This review summarizes various studies available in the VMS literature domain. The studies are divided into different sections below based on the primary objective of the studies.

2.2 Message Style and Graphics

The style and graphics are some of the most important aspects of VMS design in terms of effectiveness. The effectiveness of VMS is dependent upon its ability to deliver a message to drivers in a timely manner without creating distraction or confusion. Thus, the style and graphics should be designed and used with care. In this report, display style refers to characteristics such as message color, number of frames, flashing status, etc. Graphics refers to the use of non-words in messages.

Each of these attributes is dependent upon the position at which a VMS is placed. Thus, understanding VMS visibility and legibility distance is important. Visibility distance is the maximum distance from which the VMS unit is visible to drivers and legibility distance is the maximum distance from which the driver can read and identify the VMS message (MUTCD, 2009). Visibility and legibility are dependent upon the VMS board size, letter size, styles, colors, speed limit, lighting condition, weather condition, the visual capability of drivers, etc. The MUTCD has recommended a minimum visibility distance of 0.5 miles under both day and night conditions and a minimum legibility distance of 600 feet for nighttime conditions and 800 feet for normal daytime conditions.

Drivers' preferences of and response times to VMS display, colors, wordings, and formats were evaluated using a survey and subsequent lab-based driving simulator experiment (Yang et al., 2005). It was found that one-frame messages with specific wordings and without abbreviations were preferred over other combinations. One-line flashing messages in amber color were found to have the fastest response time when compared to all-frame flashing and other possible combinations. VMS display color preference was found to be in the order of amber, green, the combination of amber and green, and, lastly, red. Using the same study approach, other researchers (Wang et al., 2007) found the preference of VMS display color to be amber, then red, and then green. In addition, Lai (2010) determined that there was a higher performance with two-color displays over one- and three-color displays.

In terms of preference of graphics, contradictory results exist in the literature. A study using a survey followed by a video-based driving simulation experiment found higher preference and lower response time for signs that included graphics over text-only messages (Wang et al., 2007). If the combination of graphics and text needs to be used, Wang et al. (2007) suggested the use of graphics on the left side of the frame. A higher preference was found for graphical messages over character messages in VMS in a stated preference study in China (Ma et al., 2014). However, evidence from a driving simulator-based experiment by Roca et al. (2018) found that single-worded VMS messages performed better than graphic-added signs or pictograms in terms of reading distance and visual demands, with fewer glances and lower glance time for a typical VMS having a high aspect ratio. Recently, Banerjee et al. (2010) proposed a colorblind-friendly VMS message design with color-coded horizontal bars to display the level of congestion and conducted a driving simulation experiment to evaluate the effectiveness of the proposed design. The results showed that the proposed design was more effective than the existing designs, including for non-colorblind drivers.

VMS should be able to provide sufficient information to drivers without creating cognitive difficulty, distraction, and confusion via information overload. The impact of information overload on VMS was studied by Xu et al. (2020) using a driving simulator-based experiment in China. The findings supported the theory that an increase in information load decreases the legibility distance and reduces drivers’ comprehension accuracy significantly. Thus, it can be expected that an overload of VMS information could increase non-compliance with the message. To accommodate for this, MUTCD guidelines set a maximum of three lines of VMS display with no more than 20 characters per line (MUTCD, 2009).

Lai (2010) recommended the use of a two-line display based on the findings from a study coupling a driving simulator and survey. In the study, two-line displays were found to be most preferred by drivers and had the lowest response time compared to other combinations. Also, when the same safety campaign message was displayed frequently and in high concentrations throughout a simulated roadway network, drivers were found to more often ignore other VMS messages when a specific safety hazard was displayed instead of the standard safety message (Jamson, 2007). In the case of graphical VMS, Xu et al. (2020) recommended a maximum of five lines to be displayed. MUTCD (2009) has conceptualized the use of biphasic or two-frame VMS displays instead of overloading information on one frame.

In the case of biphasic displays, the MUTCD recommends a minimum display time of 2 seconds per phase with a minimum exposure time of 1 second per word and 2 seconds per unit of information. The effectiveness of this guideline was evaluated by Dutta (2003), who found that the effectiveness of VMS increases if the exposure time is reduced to 0.5 seconds per word and the phase is displayed twice (instead of displaying it with double exposure time and only once). In another driving simulator-based experiment, the effectiveness of VMS messages was found to be higher when the same message was displayed on consecutive VMS displays (Sharples et al., 2016). The authors claimed that the observed effects, in this case, were a result of the formation of trust towards the message.

A study of the legibility of bilingual VMS was carried out by Jamson (2004) in Wales, where two languages, English and Welsh, were used in the experiment using a tachistoscope. No significant difference in the response time of drivers was observed when using a one-line monolingual sign or a two-line bilingual sign. However, a significantly slower response time was observed in the case of a two-line monolingual sign compared to that of a one-line bilingual sign. In such a case, the grouping of lines by language, with the dominant language on top, was found to perform better and was recommended.

The impact of VMS on the speed of vehicles was analyzed by using a driving simulator-based experiment on I-95 in Maryland (Aka, 2017). The area in the vicinity of the VMS was divided into four regions: initial, visible, readable, and post-VMS. No significant difference in speed was observed between the initial, visible, and readable areas. However, there was a significant increase in speed when vehicles passed from the readable area to the post-VMS area. There was no significant difference in speed in the readable area when the VMS was on compared to when it was off.

2.3 Message Content and Response

Relevance and understandability of the information disseminated via VMS are important to achieve the desired response to the message. To avoid driver confusion, the MUTCD recommends against vague VMS wording (MUTCD, 2009). For example, “incident ahead” should not be used alone. It should be supplemented by other information, such as location or distance to the incident, expected travel time or delay, alternative routes, etc.

The diversion behavior or response to VMS was found to depend on several factors. Several studies have found that message content has a significant impact on diversion likelihood and rate. Shortly after the introduction of VMS in Al-Khobar City, Saudi Arabia, a stated preference survey and field observations were used to evaluate the effectiveness of VMS (Taisir Ratrout & F Issa, 2014). About one-third of the stated survey respondents were unfamiliar with VMS. Stated diversion likelihood in response to different types of messages was found to be different: crash (84%), congestion (82%), construction (82%), adverse weather (71%), and special events (65%). However, actual average diversion rates in response to different types of VMS messages were found to be only 5.9%, which accounted for only 0.07% of the respondents who stated to follow VMS information. Similar results were obtained from a survey in Norway, with a higher diversion likelihood for crash messages than for other types of messages (Hoye et al., 2011). Another stated preference study in Athens, Greece, ranked VMS message type by compliance rate (highest to lowest): crash, demonstration, construction, and congestion (Spyropoulou & Antoniou, 2014).

An evaluation of VMS benefits and effectiveness was carried out by using loop detector data from different roads in Minnesota (Huo & Levinson, 2006). A statistical analysis of the loop detector data 10 minutes before and after displaying a VMS message found that the diversion rate changed significantly, confirming the effectiveness of VMS. However, this diversion rate was found to be different for different types of messages. This study also ranked VMS message type by highest to lowest diversion rate: crash, congestion, and construction. Interestingly, the study found no evidence of network-wide travel savings or safety improvement as a result of the VMS only. In a driving simulator experiment carried out by the University of Nottingham, driver diversion in response to VMS messaging was found to be highest for crash-related messages (Sharples et al., 2016).

To improve the effectiveness of VMS by offering flexibility to drivers in choosing their route before entering the freeway, an alternative method of placement of 13 VMSs in Milwaukee, WI, was evaluated (Peng et al., 2004). In this scenario, an on-site revealed preference survey engaged drivers who had just encountered the VMS devices near expressway entrances. The diversion rate was found to depend on the number of VMS devices a given driver had encountered, and the perceived usefulness and trust of the VMS message based on past experience. In addition, among the different types of VMS messages, respondents revealed that they had the highest compliance with crash-related messages, followed by congestion messages, and lastly by environmental information. The survey showed that the two main reasons for diversion in response to VMS were reduction of travel time and avoidance of crashes. Using a number of hypothetical choice scenarios with crash and congestion information on VMS, a stated preference survey in China showed that diversion likelihood was higher for crash information than for congestion messages (Gan & Ye, 2015).

In the following subsections, the results of VMS studies focusing on specific message content and corresponding response are summarized. Three types of VMS content/information dominate the literature and are summarized below: congestion and delay, incident, and detour.

2.3.1 Delay and Congestion Information

Evidence from an on-site stated preference survey of travelers in the Borman Expressway (I-94) region in Indiana suggested that increased detail of information, such as expected delay, increased VMS message compliance (Peeta et al., 2000). Travelers in Athens, Greece, also stated that they would be more likely to detour if the incident message was supplemented by expected delay (Spyropoulou & Antoniou, 2014). Another stated preference survey in South Korea concluded that higher diversion likelihood was stated in cases of higher delay and higher volume of vehicles (Kim et al., 2014). Additionally, one study from the UK found that the diversion rate was higher when the delay was greater (Sharples et al., 2016). The results suggested that the absence of delay information created confusion for drivers, resulting in unpredictable diversion behavior. Thus, the Sharples study recommended displaying expected delay.

A sensitivity analysis of time factors and VMS contents was carried out using traffic data (loop detector and license plate reader) in Shanghai, China, to understand actual driver response to VMS messages (T.D. Xu et al., 2011). The results claimed that informing drivers about travel times for the current route was more effective in altering diversion behavior than informing drivers of the qualitative congestion level (“low”, “medium”, “high”). In addition to providing travel time on the current route, informing drivers about the travel time of alternate routes and coordinating with neighboring VMS devices were found to increase the VMS effectiveness. This study and another study (T. Xu et al., 2011) evaluated the differences in the stated and actual behavioral response to VMS messages. Time factors (peak hours, morning or evening peak, daytime, nighttime, etc.), actual visibility of congestion on the route, off-ramp condition, etc., were all found to impact the actual diversion behavior. The effects of these factors could not be captured in a stated preference survey.

An evaluation of driver response to VMS congestion messaging was conducted using a stated preference survey followed by field observational data in Paris (Yim & Ygnace, 1996). The dissemination of real-time VMS traffic information was found to help drivers choose the less congested route. When a higher level of congestion was displayed on the current route, a higher diversion rate was observed. Interestingly, message compliance was found to be higher in the morning peak than during the evening peak, which could potentially be explained by the consequence of the delay in work start time. In line with other studies, the actual diversion likelihood in response to congestion messaging was found to be lower than the stated response.

A similar approach was used in China, where the results of a stated preference survey showed varying diversion likelihood for different demographic groups of drivers and for different levels of congestion (Shen & Yang, 2020). In addition, a 10-12% increase in the diversion rate was observed in the field when the congestion message was varied from “moderate traffic congestion” to “heavy congestion”.

Instead of displaying the congestion level of the current route on VMS, the Korea Expressway Corporation carried out a pilot installment of VMS on the Seohaean and Yeongdong Expressways displaying the estimated travel time on neighboring national highways (Yang et al., 2015). The diversion rates as a result of the travel time VMS were estimated using dedicated short-range communication and vehicle detection systems. In different sections, the diversion rates observed during the pilot study were 1.9%, 9%, 17%, etc., and these values were found to vary based on the length and estimated travel time of alternative routes. As a result, the total length of congested segments on the expressways decreased by 7.8 km, and average speed increased by 5.3 km/h.

Similarly in a study in China, the diversion likelihood was found to be higher when the alternate route offered higher travel-time savings (Gan & Ye, 2015). For a new type of VMS called D-VMS, which provides travel time on the freeway and local streets, an on-site stated preference survey in Shanghai, China, found that those who were not sensitive towards travel-time savings didn't have any intention to detour and also didn't actually detour when observed (Gan & Ye, 2013).

An in-depth analysis of driver response to changes in congestion messaging (e.g., from "moving slowly" to "moving well") on 27 VMS devices was carried out using 3 years of loop detector data (2003-2005) from Highway 401 in Toronto, Canada (Foo et al., 2008). The results showed that the diversion rate was significantly different within 10 minutes of changing the VMS message. For example, when the congestion message changed from "moving slowly" to "moving well," a significant decrease in the diversion rate was observed. After 10 minutes, the diversion rate was found to stabilize gradually. In all the studied cases of changing congestion message, a statistically significant difference in the stabilized diversion rate before and after the change of message was observed, except when the message changed from "express and collector moving well" to "express moving well, collector moving slowly."

Diversion behavior from congestion messaging via VMS was studied in Japan using a survey (Kusakabe et al., 2012). When the level of congestion is displayed on VMS (with no expected delay information, which is difficult to predict under congestion), drivers assume the travel time on the alternate route and compare it with the expected travel time on the current route. This assumed difference in travel time triggers the driver's diversion behavior. This highlights the impact of the level of information provided to drivers on their diversion behavior. Similarly, a stated preference study in China (Ma et al., 2014) determined that including information related to travel time on alternate routes and expected delay on the current route increased the likelihood of diversion.

One of the few studies evaluating driver response to VMS on toll roads was carried out by Al-Deek et al. (2009). A survey was distributed to travelers on a toll road in Orlando, FL, before and after encountering VMS devices. Study findings were consistent with that of non-toll road studies, indicating higher diversion rates for higher travel-time savings, drivers familiar with alternate routes, positive past experiences with VMS messages, complimentary information (radio, TV, etc.), etc. However, travelers with a cash payment of tolls were more reluctant to detour than users with automatic tolling passes. Thus, infrequent toll road users (i.e., those without passes) might be more likely to detour in response to VMS messages than frequent toll road users (i.e., those with passes).

Using the Contingent Valuation Method on survey data of travelers on national highways in Seoul, South Korea, the average economic value of real-time traffic information via VMS was calculated for an individual driver to be $0.06 (Rhee et al., n.d.). The economic value was found to vary by socio-demographic characteristics (e.g., income) and the level of congestion on the highway.

2.3.2 Incident Information

Evidence from an on-site stated preference survey of travelers in the Borman Expressway (I-94) region in Indiana suggested information including the location of the incident was redundant to drivers (Peeta et al., 2000). The response of travelers to VMS crash messaging was evaluated by using three types of survey – on-site, mail-back, and online – in another study performed in Indiana (Peeta & Ramos, 2006). It was found that the willingness to detour in response to a VMS crash message increased with an increase in the level of crash information, which included occurrence, location, expected delay, detour strategy, etc. The same was validated by a simulator-based study by Morgan State University that suggested supplementing VMS crash messages with delay information and detour strategy (Banerjee et al., 2020).

During the phased installment of VMS in London, UK, a stated preference study concluded that the diversion rate was highly dependent on the location of the incident and the wording of the VMS message (Chatterjee et al., 2002). In field trials of VMS in 9 European cities between 1994 and 1999 (Chatterjee & McDonald, 2004), four types of messages were disseminated: incident information, route guidance information, continuous information, and travel-time information. Higher diversion rates were observed when the incident location and possible detour information were included in the VMS message along with incident type and severity.

Commuters on the Deerfoot Trail in Calgary, Canada, where 12 VMS signs were present, were interviewed to ascertain their response to VMS crash messages (Kattan et al., 2010). Among 500 respondents, 63.3% stated that they wanted to alter their trips in response to VMS crash messaging either by diverting to alternate routes or by modifying their trip time, trip destination, etc. Compliance with VMS messaging was found to be influenced by driver experience, driver familiarity with alternate routes, trip time, trip length, trip purpose, and complimentary information provided by radio, TV, etc. If complimentary traffic information by radio and TV was available, allowing commuters more time to alter their planned trips, the overall compliance with VMS messaging was increased (Kattan et al., 2011).

A study of the effectiveness of VMS installed in the urban road network of Southampton, UK, was done using a revealed preference survey and travel diary form (Richards & McDonald, 2007). Only 1% of the respondents were found to alter their route based on the VMS incident message. However, 53% of the respondents stated that they intended to detour. Moreover, VMS compliance was found to be higher when the incident information was supplemented by radio.

The actual effect of VMS incident information in California was evaluated using one year of loop detector data from freeways and offramps (Xuan & Kanafani, 2014). At the time of the incidents, only incident type and location were displayed on the VMS. After the in-depth analysis of empirical data, the authors concluded that VMS messages were not able to significantly increase the diversion rate but that the increase in diversion rate was ultimately as a result of visible congestion. The authors also claimed that most of the other studies suggesting a significant relationship between diversion rate and VMS messaging followed the wrong methodologies or made incorrect interpretations.

In another study, a network-wide simulation was carried out to understand the impact of VMS messaging on diversion rates (Hoye et al., 2011). The results showed that diverting due to VMS crash incident messages slightly reduced the overall travel time but increased the number of crashes. However, slight environmental efficiency benefits were observed. Based on the simulation results, the study also claimed that VMS travel time and congestion information do not have any significant effect on diversion behavior as long as there are no incidents.

2.3.3 Detour Information

Evidence from an on-site stated preference survey of travelers in the Borman Expressway (I-94) region in Indiana suggested that increased detail of information, such as best detour strategy, increased VMS message compliance (Peeta et al., 2000). Travelers in Athens, Greece, stated that they would be more likely to detour if the incident message was supplemented by the best detour strategy (Spyropoulou & Antoniou, 2014). A stated preference survey in South Korea concluded that a higher diversion likelihood was observed in cases where the directed detour exit was nearby (Kim et al., 2014). One state preference survey found that the diversion likelihood was higher when the alternate route had a smaller number of traffic signals (Gan & Ye, 2015).

Similarly in another study, the motivator for diverting was found to be fewer traffic lights on the local streets (Gan & Ye, 2013). Similar results were obtained by Gan (2013).

2.4 General Safety Messaging

A driving simulator-based experiment was carried out in Auckland, New Zealand, to understand the effects of VMS messages unrelated to driving conditions on compliance with detour messages (Thomas & Charlton, 2020). Messages such as "wear seat belt," "drive to the conditions," etc., were found to create inattentional blindness and, hence, lower compliance with the detour message. The study suggested that VMS devices should not be used for disseminating advertisements, safety slogans, or other messages unrelated to driving conditions. Another driving simulation-based study in the UK also found similar results when displaying VMS safety messages such as "watch your speed" and "keep your distance" (Jamson, 2007). The safety messages were found to increase the overall attentiveness of drivers but their effect on individual driving behavior (e.g., in speed reduction) was not significant. This result also highlights the limited benefits of using VMS for safety messages.

Use of VMS safety messages to manipulate drivers' risk perception and driving behavior was explored by Fallah et al. (2017). The study evaluated individual vehicle behavior on the Tehran-Saven Freeway in Iran in response to different safety messages. The rear-end crash risk calculated for the previous 5 minutes' traffic conditions was used to determine and disseminate safety risk messages by VMS, using a scale of low, medium, and high risk. No consistent effects of the "low" and "medium" safety risk messages were observed in terms of reducing the actual risk of rear-end crashes. However, significant safety improvement was observed for "high" risk safety messages in both day and night times. Conversely, more risky driving behavior was observed when "low" and "medium" risk safety messages were displayed compared to no message at all.

The impact of VMS on reducing vehicle speeds and increasing vehicle headway was studied for icy road conditions in Finland (Rama & Kulmala, 2000). With real-time monitoring of the road condition, two VMS messages (slippery road condition and minimum headway recommendation) were displayed. The mean speed of vehicles dropped by 1-2% about 500-1000 m after encountering a slippery-road-condition VMS message. Speed reduction was found to be insignificant 9-14 km after the sign. There was a significant drop in the proportion of vehicles having shorter headways (less than 1.5 seconds) when the minimum headway recommendation message was displayed. This study also compared the effects of VMS messages between the first and second year of available data, showing a lower positive effect of the messages in the second year. This study was extended by Luoma et al. (2000) to include a survey of the drivers who had encountered VMS messages warning about slippery road conditions and recommending minimum headway. In addition to a reduction in average speed and proportion of vehicles with shorter headways, the two messages were found to increase driver attention towards potential hazards, influence safer passing behavior, etc.

An evaluation of safety after the installment of VMS coupled with a road weather information system (RWIS) in six locations was conducted in British Columbia, Canada (El Esawey et al., 2019). The RWIS sensors were used to monitor the roadway condition and the corresponding information was disseminated via VMS. After analyzing 8 years of crash data (4 years before and after VMS installation) using the Empirical Bayes (EB) method, a reduction of 32.7% was found for all winter serious crashes after the installment of VMS coupled with RWIS.

The effect of VMS in improving the safety and operational efficiency of railroad crossings near I-10 was studied in San Antonio, TX (Sivanandan et al., 2003). Network microsimulation was conducted to evaluate the effectiveness of the proposed VMS suggesting the use of nearby exits to avoid the exit with the railroad crossing and associated congestion. The results showed a slight improvement in total travel time when VMS compliance was set to 40%. However, diminishing returns were observed when the compliance exceeded 40% due to the induced congestion on other routes. In addition, this use of VMS was found to increase overall fuel consumption and emission.

2.5 Behavioral Acceptance

The behavioral acceptance of VMS was modeled by extending the Technology Acceptance Model (TAM) with a structural equation modeling approach (Diop et al., 2020). The predictors of behavioral intention (BI) to use VMS were found to be perceived ease of use (PEOU), perceived usefulness (PU), and information quality (IQ). PU and PEOU had positive direct effects on BI. The effect of IQ on BI was found to be positive in direction but indirect through PU and PEOU. Thus, three methods could be applied to improve BI: (1) improving VMS message quality by increasing the accuracy, timeliness, and completeness of information, (2) using the color, display, type of information, length of information, etc., to improve understanding, and (3) improving the usefulness of VMS by increasing the reliability of messages such that it could reduce the travel time of users and develop positive experiences. The results of a hybrid choice model validated the paths of relationships between the predictors and BI and choice in complying with VMS.

The service quality of VMS refers to its ability to deliver accurate, reliable, and easily understandable traffic information to drivers. Diversion behavior resulting from VMS messaging is assumed to be dependent upon VMS service quality (Diop et al., 2020). Using an on-site survey, with data collected in 6 districts of Beijing, China, the perceived service quality of VMS and its predictors was assessed using a structural equation modeling framework (Ma et al., 2020). The predictors of service quality of VMS were found to be the attitude towards the contents of the VMS, attitude towards the format of the VMS, the effectiveness of the VMS, driving frequency, and driver's decision making. These predictors had different relationships with the perceived service quality of VMS. Some predictors had direct relationships while others were indirect. Moreover, these relationships depended on whether the person was driving a private car, company car, or taxi. In addition, the perceived service quality of VMS was found to vary by age, gender, and driver experience.

2.6 Driver Characteristics

In reviewing the literature related to VMS, differences in compliance with VMS messaging were found between the drivers of different socio-demographic groups, driving characteristics, and trip-related characteristics. However, the differences are inconsistent across different studies. For example, younger drivers were found to have a higher diversion likelihood than other age groups in Indiana (Peeta et al., 2000). However, an opposing result was obtained from a stated preference survey in China, which found higher diversion rates for older drivers (Ma et al., 2014). Another study in China found lower compliance for both young and old drivers compared to middle-aged drivers (Gan & Ye, 2013). Similar inconsistency was observed in the case of driver gender. One study (Peeta et al., 2000) found males to have higher compliance with

VMS messages than females. However, another study (Ma et al., 2014) found the opposite relationship.

Other driver characteristics found to be associated with higher compliance rates include higher educational backgrounds (Peeta et al., 2000), lower number of daily trips (Shen & Yang, 2020), calmness (Ma et al., 2014), regular commuting (Ma et al., 2014), lower familiarity with the current route (Gan & Ye, 2013), higher familiarity with the alternate route (Ma et al., 2014), longer driving experience (Gan & Ye, 2013), more experience with VMS (Spyropoulou & Antoniou, 2014), positive attitude towards VMS (Spyropoulou & Antoniou, 2014), higher use of radio/TV for traffic information (Spyropoulou & Antoniou, 2014), etc.

The varying results across different studies regarding VMS compliance of drivers with different characteristics might be related to the specific characteristics of the scope end environment of those studies (availability of main and alternate routes, populace experience with VMS, service quality of information, etc.). Also, differences between the study methodologies, such as survey question wording, can have a significant impact on the different results. Private car drivers were found to be more reluctant to detour than government car and taxi drivers (Ma et al., 2014). Similarly, more resistance towards diverting was observed for truck drivers than for non-truck drivers (Peeta et al., 2000). Diversion likelihood was also lower for two-wheeled vehicles than for four-wheeled vehicles (Spyropoulou & Antoniou, 2014).

2.7 Summary

This chapter summarized the key studies available in the literature regarding driver response to VMS. Different methodologies have been used for analysis and are categorized into four groups: (1) stated preference survey, (2) revealed preference survey, (3) lab-based driving simulator experiment, and (4) quasi-experiment and analysis of real field data. Stated preference surveys are relatively easy to conduct but the results may be somewhat ambiguous and different than that of revealed and actual behavior-based studies. Therefore, stated preference surveys are the least preferred method for analysis of driver behavior. Revealed preference surveys and analyses of real field data offer limited ability to control the testing environment. Results of driving simulator-based studies may not exactly capture drivers' natural responses because the experiments are conducted in a non-physical environment and respondents are aware of the experiment. The most accurate, but often uneconomical method is the quasi-experiment, which uses a controlled, physical environment.

VMS message compliance studies were categorized into five groups based on their objectives:

1. Message style and graphics,
2. Message content and response,
3. General safety messaging,
4. Behavioral acceptance, and
5. Traveler characteristics.

The studies found that compliance varied based on the style, color, length of the message, use of pictograms, number of lines (single line or multi-line), flashing status, type of message, traveler characteristics, etc. For example, most of the studies found higher compliance for green-colored displays over other colors. In terms of VMS message type, the highest compliance rates were found for crash or incident messages. The studies also agreed that the message content should be as short as possible to avoid information overload, but it also should not be vague or incomplete. For example, the message content “crash ahead” should be supplemented by the location of the crash, expected delay, and suggested detour.

The use of general safety messages such as “wear seat belt” was found to reduce overall VMS message compliance. However, displaying safety messages with real-time weather information was found to improve safety. Diversion behavior was found to follow acceptance theories of human behavior (e.g., TAM) and to vary based on socio-demographic and trip-related characteristics of the travelers. However, there were some inconsistencies in the findings of different studies regarding the association of traveler characteristics and VMS compliance.

3.0 DATA COLLECTION

3.1 Overview

To achieve the project objective of identifying the association between VMS message content and driver response, this research considered crash-related messages displayed on VMS devices in Utah. The potential factors affecting driver response to crash-related VMS messages were identified from the literature review. Then, the research team assessed the message content and other potential confounding factors from the historical VMS database, crash database, and UDOT's Performance Measurement System (PeMS).

This chapter covers the sources and procedures adopted to collect and assemble the data. First, the site selection procedure and general characteristics of the selected site are described. Second, the procedure used to collect, filter, and assemble/join VMS data and crash data is presented. Third, the procedure used to measure/calculate the diversion rate (a measure of drivers' response to crash-related VMS messages) is described. Fourth, the procedure adopted to obtain VMS message content information and other potential confounding factors affecting driver response to crash-related VMS messages is described. Each subsection includes the summary statistics of the data collected/assembled.

3.2 Study Site

This project aimed to analyze driver response to crash-related VMS messages in Utah. The research team first hypothesized that driver response to crash-related VMS messages could be assessed by measuring the vehicle diversion. Availability of alternate routes, VMS devices, and crash data were the primary factors considered by the research team in choosing the section of I-15 from milepost 285 to 342 as the study site, using 5 years of data (2016-2020). As this section runs through an urban area (Salt Lake City metro area), the research team assumed the adequate availability of alternative routes (if drivers want to divert after encountering the crash-related VMS messages), though in-depth consideration of alternative routes was not made in the study. A sample study section showing VMS devices, on-ramps, off-ramps (exit points for diversion), and detector stations (used to measure diversion and congestion; to be described later) is presented in Figure 3.1.

3.3 VMS History and Crash Data

UDOT provided the VMS history and crash data required for this study (UDOT, 2021). First, the history of VMS messages displayed on all the VMS devices across Utah was archived. The messages were updated frequently, at the discretion of the controller, based on real-time traffic conditions available to the controller without a formal algorithm or a set of guidelines. In the study site and study period, there were a total of 21 VMS devices (similar to that shown in the sample section in Figure 3.1), 12 in the northbound direction and 9 in the southbound direction. Only messages related to crash incidents were used in this study. As a result, 9896 VMS message records were obtained. It is important to note that less than 2% of VMS messages were crash related (Figure 3.2). This may have resulted in crash-related messages having less impact on driver behavior due to oversaturation of non-crash-related messaging. The presence of several repeated messages required further filtration. Second, the crash database obtained from UDOT was filtered for the study site and location. As a result, 26262 crash records were obtained.

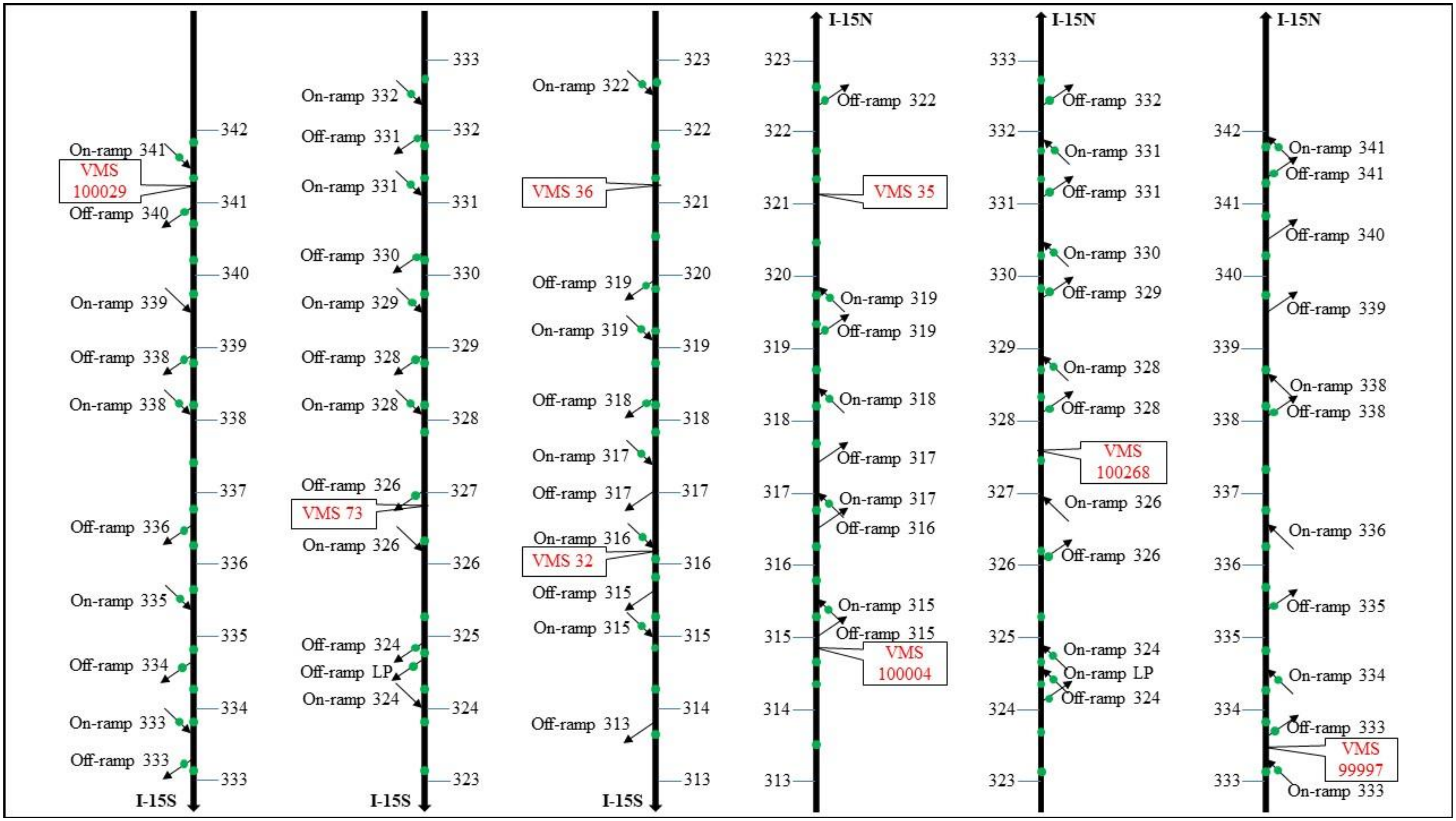

Figure 3.1 Study site sample section (I-15 between mileposts 313 and 342)

Note: green dots indicate the mainline and on/off-ramp detector stations

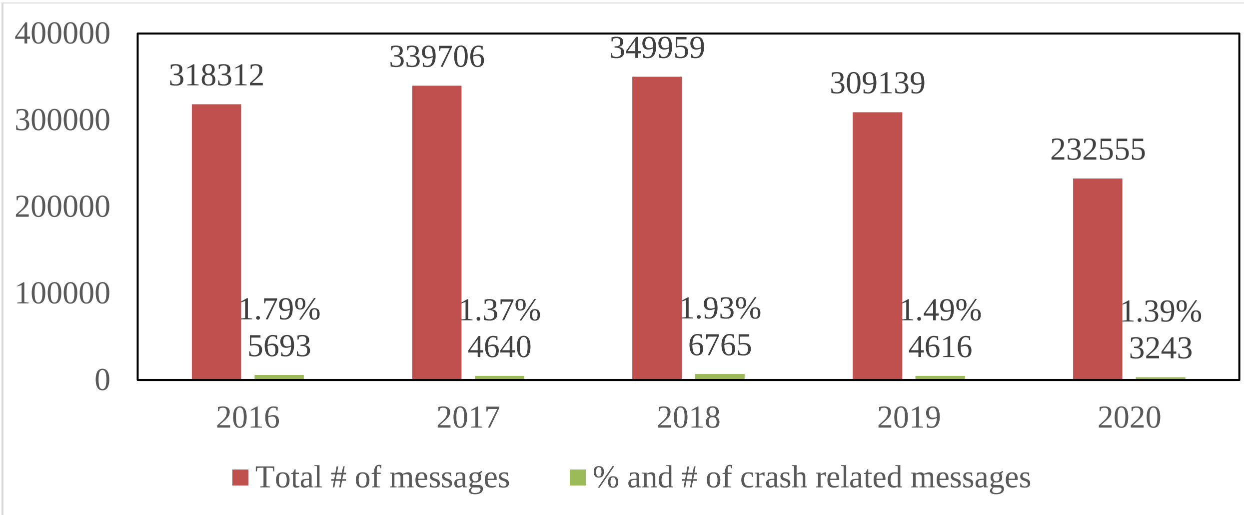

Figure 3.2 Number of VMS records by year

Third, the two databases – VMS records and crash records – were joined together using multiple criteria due to the lack of a common identifier in the UDOT record keeping. The criteria used were: (a) matching time of message display and crash incident (the display time should follow the crash incident), and (b) matching the locations of the crash and VMS device, information about crash message should be displayed on the upstream VMS devices. The joined records were further filtered by excluding the different/multiple message displays for the same crash incident to ease further analysis. In addition, the records associated with VMS message display time less than 5 minutes were also excluded (because the granularity of flow data was 5 minutes; to be described later). Finally, the joined crash and VMS history records were checked manually to confirm that they made sense intuitively. This manual check resulted in 595 joined records for further analysis. The proportions of crash severity levels represented in these 595 records are shown in Figure 3.3.

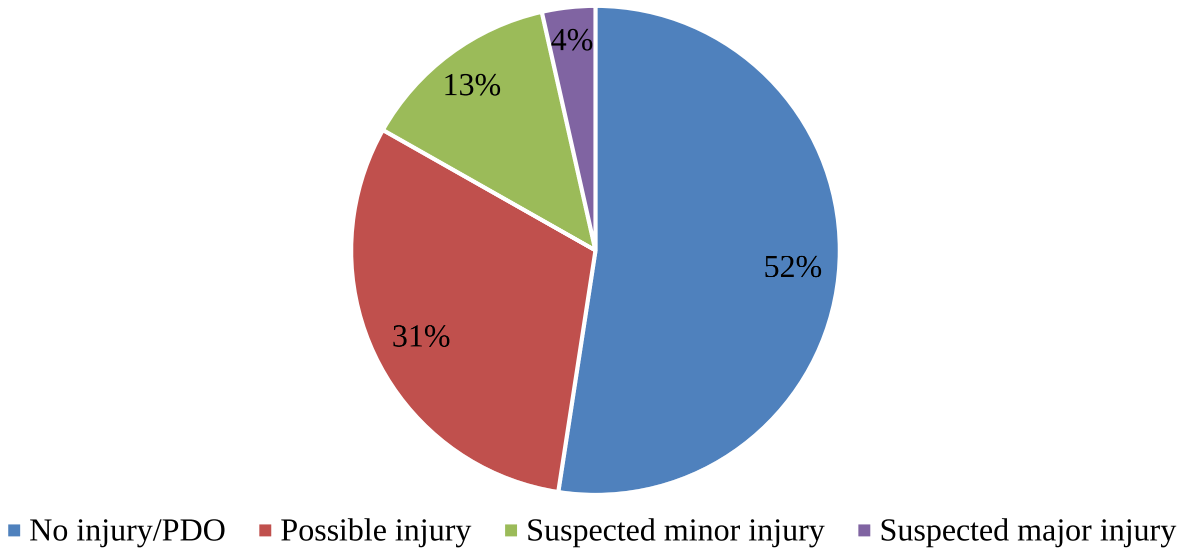

Figure 3.3 Proportion of different levels of crash severity

3.4 Diversion Rate

Diversion rate calculation begins with the calculation of exit rate. Exit is defined as the proportion of vehicles exiting from a point on a highway, which is calculated as the ratio of off-ramp volume to the mainline volume at the diversion point. The flow data required to calculate the exit rate was obtained from UDOT’s PeMS (PeMS-UDOT, 2021). The data were available in an aggregated granularity of 5 minutes.

The research team calculated the diversion rate after the display of a crash-related message as a measure of change in exit rate (i.e., change in driver response). First, the start and end times of each crash-related message were obtained. Second, the number of off-ramps (i.e., exits or points of diversion) between the VMS device and respective crash incident location was obtained. Third, the exit rate of an off-ramp for a point in time was calculated using Equation 3.1. The exit rates for all off-ramps (between the VMS device and crash incident location) for each 5-minute timestamp during the message display period were calculated.

$$ER = OR / (MV + OR) \quad \text{eq. 3.1}$$

where,

ER = exit rate at an off-ramp location at a timestamp

OR = off-ramp volume at a timestamp

MV = mainline volume after off-ramp at a timestamp

Fourth, for each timestamp of the display period, averaging of exit rates of all off-ramps was done using Equation 3.2. Weighted average exit rate (WAER) was used in this equation to account for the differences in mainline volumes of different off-ramps during averaging (Foo et al., 2008). Fifth, from a list of WAER values for each timestamp during the display period, the highest value was selected as the maximum exit rate. Sixth, the stable exit rate was calculated as the average exit rate of two time periods for the same section: start of message display and 10 minutes after the end of the display of the message. The calculation of exit rates of the before-and-after periods followed the same procedure used to calculate WAER for a timestamp. Finally, the difference between maximum and stable exit rate gives the diversion rate resulting from the message display. Since the units for the exit rates are in percent, the unit for diversion rate is also in percent.

$$WAER = \sum (ER * MV) / \sum MV \quad \text{eq. 3.2}$$

where,

WAER = weighted average exit rate of all off-ramps between VMS device and crash location at a timestamp

Off-ramp volume for a timestamp represents either the flow observed from a sensor on the off-ramp or is calculated as the difference between mainline sensors before and after the off-ramp. The mainline volume represents the traffic flow of the roadway just after the off-ramp. If a higher occupancy vehicle (HOV) lane is present at the location, the mainline volume is the sum of an HOV lane sensor and regular lane sensors. Since there could be a varying number of off-ramps between the location of a VMS device and a crash, arithmetic averaging with weighting based on mainline volume was done to find WAER. Also, since the duration of display varied for different crash/VMS incidents (presumably because of varying crash clearance time), a consistent point of time was necessary to calculate the diversion rate across multiple incidents. For this purpose, the start and end time of the message displays were converted to the nearest 5 minutes (as per the available granularity of traffic flow data) and the exit rate of each off-ramp between the VMS device and the crash location was calculated for each 5-minute interval within the message display period.

The selection of 10 minutes after the end of the display of the message for the stable exit rate calculation was made based on two criteria: (a) it takes some time for the drivers who have seen the message on VMS to pass through the crash location, and (b) using a longer time period might distort the data because of temporal variations in traffic and exiting behavior. The selection of 10 minutes is supported by past studies (e.g., Foo et al., 2008). To calculate the exit rate before the display of the message, the research team considered the timestamp at which the message display began. Though past studies considered 10 minutes before the display of message for the before period, the authors didn’t find this conceptually intuitive because none of the drivers change their behavior before the message is displayed. The diversion rate was calculated as the difference between the maximum and stable exit rates for each crash-related VMS message. In short, diversion rate is the additional traffic (in percent increase) leaving the mainline via an exit during the display of a crash-related VMS message.

For the joined records, the mean diversion rate was 5.42% during the message display period, with a standard deviation of 7.36%. There were 47 observations with a negative or zero diversion rate. Note that a negative value diversion rate indicates a decrease in exit rates during the message display period. A diversion rate of zero indicates no change in exit rates as a result of message display. For analysis (to be described in Chapter 4), the authors classified the diversion rate into three bins: (a) low/none, where the diversion rate is less than 5%; (b) medium, where the diversion rate is within 5-10%; and (c) high, where the diversion rate is more than 10%. The distribution of these categories of diversion rate is presented in Figure 3.4.

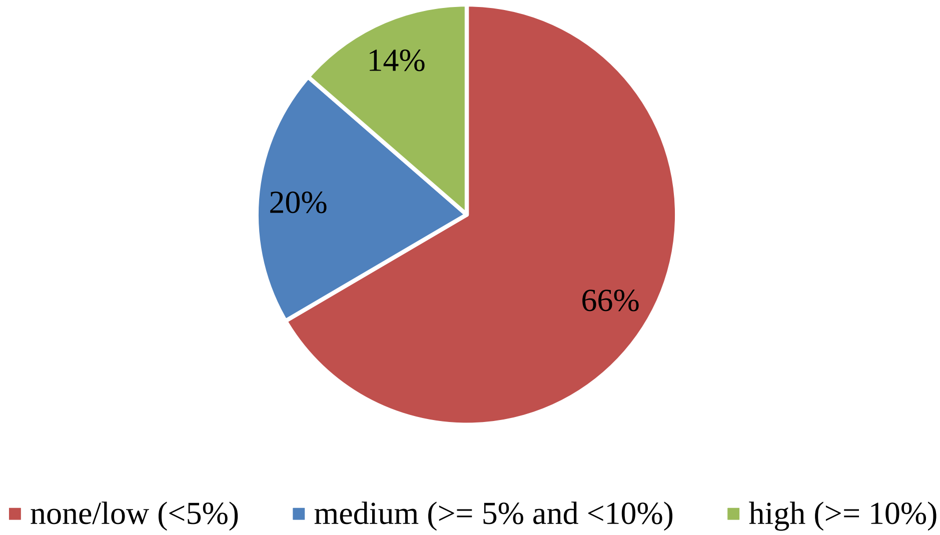

Figure 3.4 Categories of diversion rate

3.5 Message Content

The variables associated with message content were necessary to ascertain the relationship between VMS message content and diversion rate after the display of the message. Based on the content of selected message records, the following 11 variables were created:

- Miles to crash
- “Crash ahead”
- Crash location
- Delay information
- “Use caution”
- Traffic slows/stopping
- Speed suggestion (e.g., “reduce speed”)
- “Keep left/right”
- “Prepare to stop”
- Lane of crash
- Lane blocked

These variables signify whether the specific content was included in the displayed message or not. Thus, each of them was binary in nature, with "yes" and "no" categories. For example, if the information about miles to crash is included in the message, the variable "miles to crash" was assigned "yes," otherwise "no." The proportion of observations with different message content in the data (N = 595) is shown in Figure 3.5.

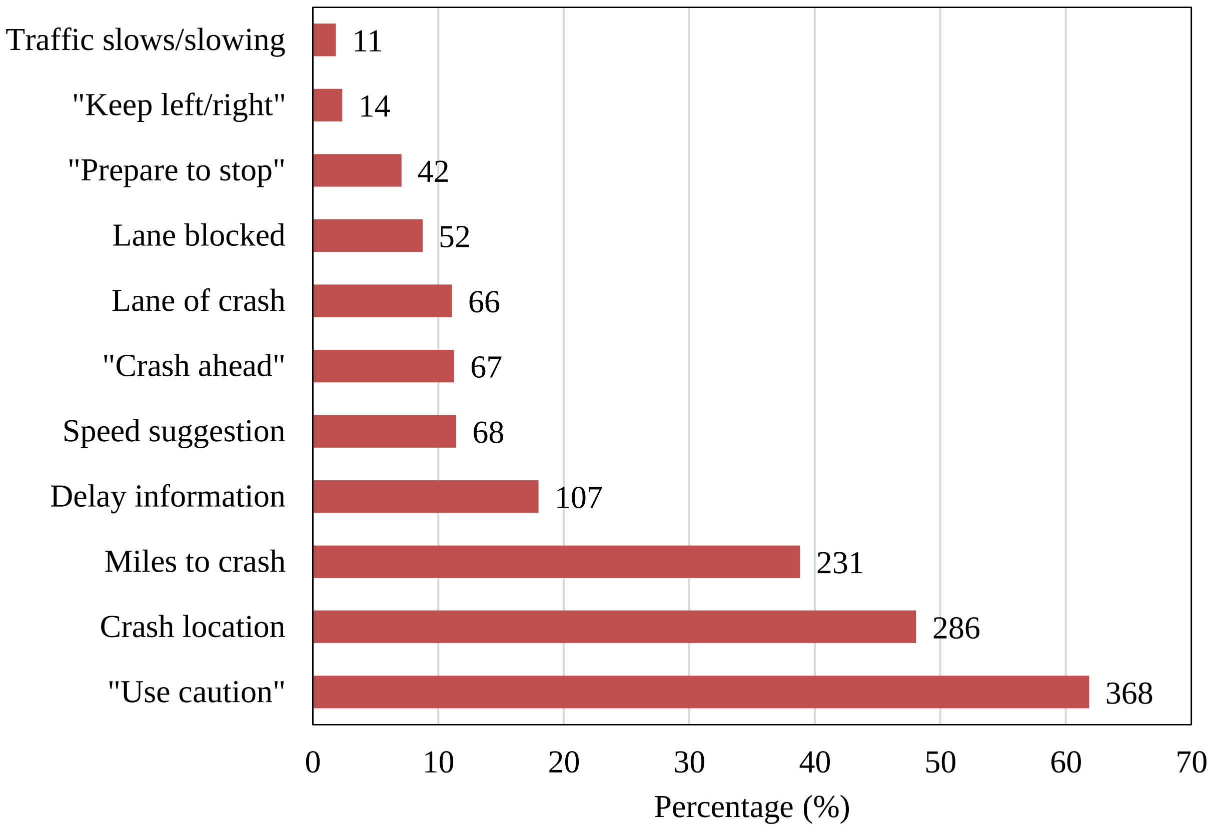

Figure 3.5 Proportion of VMS messages by contents

A VMS message often consists of a combination of the content items presented above. For example, a VMS message "Crash 2 miles ahead, expect delay" consists of two pieces of information: miles to crash and delay information. Thus, to investigate driver response to different VMS messages with different combinations of information, we ascertained the combinations of content in the data. As a result, we found 68 unique combinations. Thirteen combinations with high frequencies of use were considered in this study. The frequency of each combination considered in this study is presented in Figure 3.6.

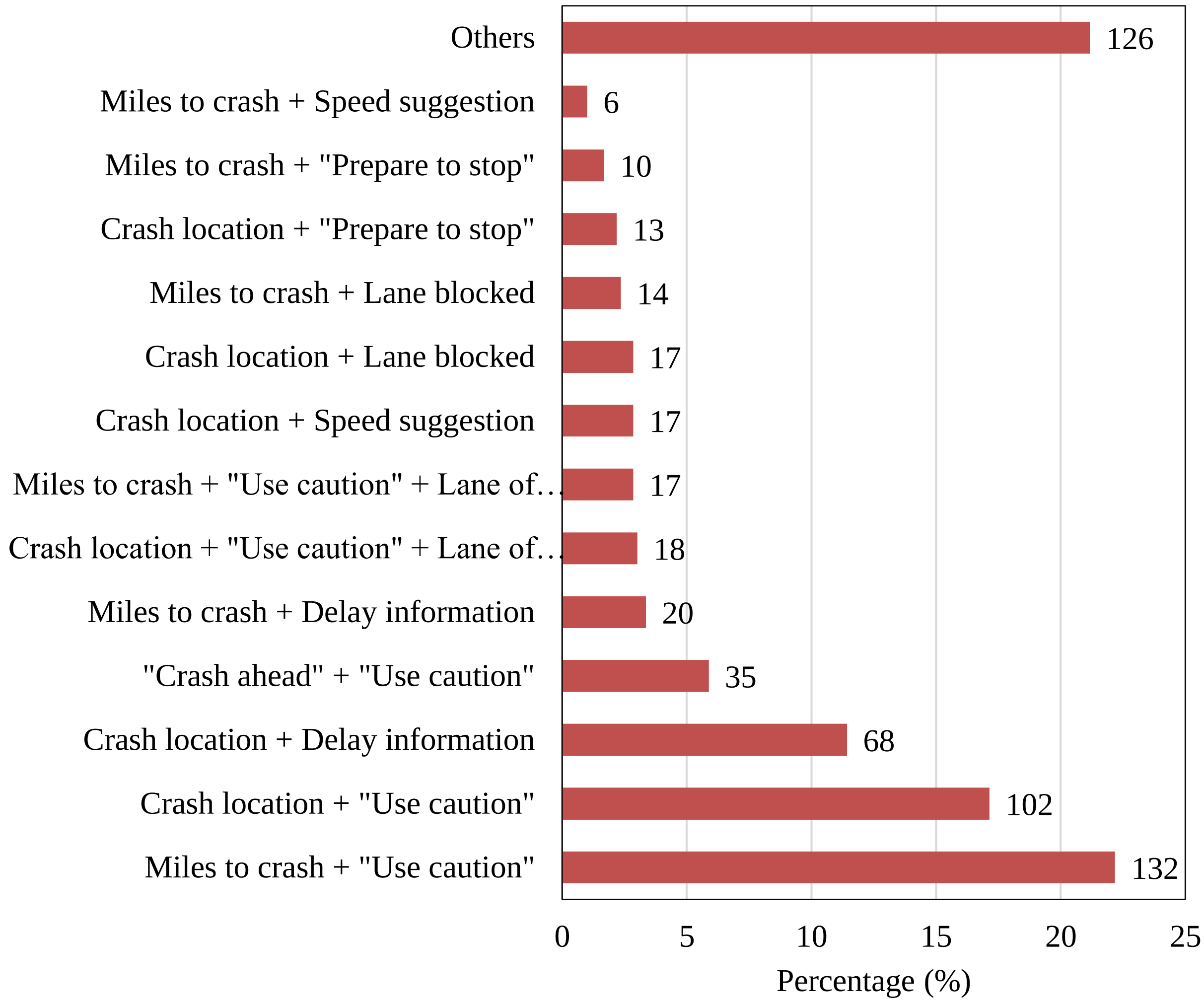

Figure 3.6 Proportion of VMS messages by different content combinations

3.6 Occupancy

In this report, occupancy is defined as the percentage of time the sensor is occupied by a vehicle, which typically has a direct relationship to density thus can be used as a measure of highway congestion. To account for the impact of possible crash-related congestion (or reduction in capacity) on diversion rate, increase in occupancy in the mainline at the time of message display was considered in the study. The calculation of increase in occupancy during the message display period was similar to that of diversion rate. First, the start and end times of the message display period were obtained for each crash-related message. Second, the number of off-ramps between the VMS device and the respective crash incident location was obtained.

Third, the occupancies of all the mainline points just after each off-ramp (between VMS device and crash incident location) for all 5-minute timestamps during the message display period were calculated. Fourth, for each timestamp of the display period, arithmetic averaging of occupancies of all mainline points was done. Fifth, from the list of average occupancy for each timestamp during the display period, the highest value of average occupancy was selected and classified as maximum occupancy. Sixth, the stable occupancy was calculated as the average occupancy of two time periods for the same section: message start time and 10 minutes after the display of the message. The calculation of occupancy of the before-and-after periods followed the same procedure used to calculate average occupancy for a timestamp. Finally, the difference between maximum and stable occupancy gave the value of the increase in occupancy during the display of the message. The increase in occupancy was calculated for each crash-related VMS message.

The mean increase in occupancy during the message display period was found to be 4.53% with a standard deviation of 5.55% for the 595 joined records. There were 47 observations with a negative or zero increase in occupancy. A negative value of increase in occupancy indicates a decrease in occupancy during the message display period. A zero increase in occupancy indicates no change during the message display period.

3.7 Other Factors

Other potential confounding factors affecting diversion rate during the message display period considered in this study were:

- time difference between the crash incident and the start of display of a VMS message.
- distance between VMS device and crash incident.
- duration of display of the message.
- hour of the day during message display (morning peak hour: 7 – 9 AM, evening peak hour: 4 – 6 PM, off-peak hour: otherwise).
- day of week during message display (Saturday, Sunday, and weekdays).
- weather conditions during the message display period (clear, cloudy, rain, and snow).
- light condition during the message display period (daylight, dark, dawn, and dusk).

3.8 Summary

The data from three sources – the historical VMS database, crash database, and PeMS – were assembled into one complete dataset. Each observation in the dataset consisted of a crash-related message displayed in VMS, the message content, the combination of content, diversion rate during the message display period, increase in occupancy during the message display period, and other potential confounding factors affecting the diversion rate during the message display period. The final dataset included 595 observations. The descriptive statistics and characteristics of the final dataset are summarized in Table 3.1.

Table 3.1 Explanation of the variables and descriptive statistics

Variable	Explanation	Categorical #	Categorical %	Continuous Mean	Continuous S.D.
Diversion rate	Difference of maximum and stable exit rate in percent.			7.65	7.45
Message contents (Whether the following information is included in the message or not; all are binary variables with "yes" and "no" responses; given statistics are for "yes")					
Miles to crash	Miles to crash from the device.	231	38.82		
"Crash ahead"	Distance to crash not included but crash ahead only mentioned.	67	11.26		
Crash location	The exact location of the crash.	286	48.07		
Delay information	Information about the delay as a result of the crash; usually displayed as expected/possible delay ahead.	107	17.98		
"Use caution"	Suggestion to use caution ahead.	368	61.85		
Traffic slows/slowing	Traffic ahead is slowing/stopping.	11	1.85		
Speed suggestion	Suggestion to reduce speed.	68	11.43		
"Keep left/right"	Suggestion about merging to left/right lane.	14	2.35		
"Prepare to stop"	A suggestion to prepare to stop ahead.	42	7.06		
Lane of crash	In which lane did crash happen? Left/center/right lane.	66	11.09		

Lane blocked	Closure of left/center/right lane as a result of the crash.	52	8.74		
Combination of message content	Which combination of message content is present? (categorical variable)				
“Crash ahead” + “Use caution”		35	22.18		
Miles to crash + Lane blocked		14	17.14		
Miles to crash + Delay information		20	11.43		
Miles to crash + “Use caution” + Lane of crash		17	5.88		
Miles to crash + Speed suggestion		6	3.36		
Miles to crash + “Prepare to stop”		10	3.03		
Miles to crash + “Use caution”		132	2.86		
Crash location + “Prepare to stop”		13	2.86		
Crash location + Speed suggestion		17	2.86		
Crash location + “Use caution” + Lane of crash		18	2.35		
Crash location + “Use caution”		102	2.18		
Crash location + Delay information		68	1.68		
Crash location + Lane blocked		17	1.01		
Others		126	21.18		
Other control variables					
Frames	The number of frames used to display a message.				
One		499	83.87		
Two		96	16.13		
Time difference	Time difference between the occurrence of crash and start of message display in minutes.			6.51	4.11
Distance	Distance between VMS device and the crash incident in miles.			4.24	3.10
Duration	Duration of display of the message in minutes.			40.43	34.34
Hour	Whether the message display started during peak or off-peak hours.				
Morning peak	7 – 9 AM	364	61.18		
Evening peak	4 – 6 PM	79	13.28		
Off-peak hour	Others	152	25.55		
Day of week	On which day of the week did incident happen?				
Weekday		467	78.49		
Saturday		72	12.10		
Sunday		56	9.41		
Increase in occupancy	Percent difference of maximum and stable occupancy of mainline.			4.53	5.55

Weather condition	Weather condition during the display of the message.		
Clear		410	68.91
Cloudy		113	18.99
Rain		40	6.72
Snowing		32	5.38
Light condition	Light condition during the display of the message.		
Daylight		426	71.60
Dark – lighted		79	13.28
Dark – not lighted/unknown		84	14.12
Dawn/dusk		6	1.01

4.0 DATA EVALUATION

4.1 Overview

To better understand the associations of VMS message content and diversion rate, 595 combinations of crash-related VMS messages and related crash data were analyzed. This chapter contains information about how the collected data were analyzed, and what results were obtained from the analysis. It starts with the descriptive statistics of some key characteristics of the VMS messages followed by the analysis of the data collected.

4.2 Ordinal Logistic Regression

Ordinal logistic regression is an extension of logistic regression (binary with "yes" and "no" categories), which is suitable to model a dependent variable having multiple categories with some form of continuous nature. In this study, three categories of diversion rate – low/none, medium, and high – have an ordered nature such that the "medium" category has a higher diversion rate than that of the "low/none" category but lower than that of the "high" category.

Ordinal logistic regression assumes that there is some form of an unobserved continuous dependent variable, called a latent variable, that represents the observed ordinal categorical variable. This latent variable is discretized into the observed variable with some threshold values that are associated with the beginning and end of the categories. If $\boldsymbol{Y}$ is the ordered dependent variable, $\boldsymbol{Y^*}$ is the latent variable, and $\boldsymbol{t_i}$ are the thresholds, then the following relationships hold:

$\boldsymbol{Y}$ = 1st category if $\boldsymbol{Y^* \leq t_1}$
$\boldsymbol{Y}$ = 2nd category if $\boldsymbol{t_1 \leq Y^* \leq t_2}$
$\boldsymbol{Y}$ = ith category if $\boldsymbol{t_{i-1} \leq Y^* \leq t_i}$
$\boldsymbol{Y}$ = nth category if $\boldsymbol{t_n \leq Y^*}$

With this discretization, the model assumes the linear relationship between the latent variable and independent variables such that the relationship can be represented by Equation 4-1.

$$Y^* = \beta_i X_i + \varepsilon \quad \text{eq. 4-1}$$

where β_i is an estimate that defines the relationship between the dependent variable (X_i) and latent variable (Y^*), and ε is the error associated with the model, which is assumed to follow a standard logistic distribution.

The dependent variable – diversion rate – was initially collected as a continuous variable. Generally, a parsimonious linear regression model is preferred for a continuous dependent variable. However, in the process of developing a linear regression model, violations of several assumptions of linear regression models and poor modeling results occurred. Thus, the research team opted to categorize the diversion rate into three bins – low/none, medium, and high – and carried out ordered logistic regression. This strategy was found to be effective with a good model fit. The values used to classify bins of diversion rate were selected based on authors' intuition and a trial/error approach to achieve a good model fit.

4.2.1 Model A: Considering Message Content

An ordinal logistic regression model of diversion rate was fitted and the results are presented in Table 4.1. The categorized diversion rate was the dependent variable of the model. The independent variables of the model were: (a) variables describing message content; (b) other VMS-related variables, which include the number of frames used to display the message, the time difference between crash incident and message display, the distance between crash incident and VMS device, and duration of display of message; (c) variables related to roadway characteristics during message display, which include the increase in occupancy, weather condition, and light condition; and (d) temporal variables, including the hour of the day and day of the week. The intercept values are called thresholds. They are similar to the intercept of a linear regression model, but because of the three categories of dependent variables in this model, two thresholds are obtained between the categories.

Table 4.1 Results of ordered logit model of diversion rate (model A)

Variable	***B***	***SE***	***p***
Intercepts			
None/low | Medium	1.537	0.151	<0.001*
Medium | High	3.154	0.204	<0.001*
Message content-related variables			
Miles to crash: Yes	0.508	0.161	0.002*
“Crash ahead”: Yes	0.493	0.195	0.012*
Crash location: Yes	0.308	0.162	0.057~
Delay information: Yes	0.451	0.195	0.021*
“Use caution”: Yes	-0.574	0.166	0.001*
Traffic slows/slowing: Yes	1.052	0.038	< 0.001*
Speed suggestion: Yes	-0.656	0.120	<0.001*
“Keep left/right”: Yes	-0.606	0.052	< 0.001*
“Prepare to stop”: Yes	-0.537	0.068	<0.001*
Lane of crash: Yes	0.560	0.163	0.001*
Lane blocked: Yes	0.150	0.151	0.323
Other VMS message-related characteristics			
# of frames: Two	0.263	0.185	0.155
Time difference	0.000	0.000	0.642
Distance to crash	-0.212	0.045	<0.001*
Duration of display	0.000	0.000	0.165
Roadway characteristics			
Increase in occupancy	0.206	0.019	<0.001*
Weather condition (base: Clear)			
Cloudy	-0.203	0.236	0.390
Rain	0.359	0.104	0.001*
Snow	0.053	0.052	0.309
Light condition (base: Daylight)			
Dark – Lighted	0.713	0.186	<0.001*
Dark – Not lighted/Unknown	0.379	0.194	0.052~
Dawn/Dusk	-0.122	0.014	<0.001*
Temporal variables			
Peak hour (base: Off-peak hour)			
Morning peak	0.273	0.162	0.094~
Evening peak	-0.576	0.221	0.010*
Day of week (base: Weekday)			
Saturday	0.233	0.206	0.259
Sunday	0.862	0.158	<0.001*
Model fit statistics (N = 595)			
McFadden’s pseudo-R^2	0.205		
Log likelihood (null model)	-513.66		
Log likelihood (full model)	-408.17		
AIC (null model)	1031.33		
AIC (full model)	872.34		

Notes: *statistically significant at 95% confidence interval, ~statistically significant at 90% confidence interval

The fitted ordered logit model of diversion rate (model A) was more significant than the null model and has an acceptable goodness of fit with a pseudo-R-squared of 0.205. Most of the message content-related variables were found to be significantly associated with diversion rate. The diversion rate significantly increased with the presence of miles to crash, "crash ahead" only (without location and miles to crash), location of crash (marginally significant), delay information, traffic ahead (is slowing or slows), and lane of crash (left, center, right) information in the message. However, the presence of "use caution," speed suggestion, and "prepare to stop" were found to be negatively associated with diversion rate. The only message content-related variable considered in the study with no significant association with diversion rate was lane-blocked information.

In addition, the larger distance between VMS devices and crash incidents was negatively associated with diversion rate. However, the time difference between crash incident and message display, duration of message display, and the number of frames of message display had no significant impact on the diversion rate. In terms of roadway characteristics, occupancy on the mainline was positively associated with diversion rate. Though no significant association between roadway weather conditions and diversion rate was observed, the light condition was found to impact the diversion rate significantly. In comparison to daylight conditions, the diversion rate was found to increase more during dark (lighted or unlighted) conditions and to a lesser extent during dawn/dusk light conditions. Both temporal variables considered in the study – peak hour and day of the week – were significantly associated with diversion rate. In comparison to off-peak hours, morning peak hours observed higher diversion (marginally significant), but evening peak hours observed less diversion. No significant difference in diversion rate was observed between Saturdays and weekdays, but higher diversion was observed on Sundays in comparison to weekdays.

4.2.2 Model B: Considering Combination of Message Contents

Another ordinal logistic regression model of diversion rate (model B) was fitted to assess which combination of message content was associated with higher diversion rates. The results are presented in Table 4.2. The independent and dependent variables for this model are the same as for model A, except that instead of a variable describing message content, a variable representing different message combinations (as described in Section 3.5) was used.

The fitted ordered logit model of diversion rate (model B) was more significant than the null model and had acceptable goodness of fit with pseudo-R-squared of 0.206. The variable associated with the combinations of different content was found to be significantly associated with diversion rate. Figure 4.2 shows how specific message combinations correlated to increased and decreased diversion rates. Based on the estimate coefficients, the combination of message contents with the highest diversion rates was miles to crash + “prepare to stop,” followed by crash location + delay information, and miles to crash + “use caution” + lane of the crash. The content combination that had the greatest reduction of diversion rate was crash location + “prepare to stop,” followed by crash location + speed suggestion, and miles to crash + speed suggestion.

Table 4.2 Results of ordered logit model of diversion rate (model B)

Variable	B	SE	p
Intercepts			
None/low | Medium	1.604	0.164	<0.001*
Medium | High	3.220	0.216	<0.001*
Message content-related variables			
Message content combination (base: Crash ahead + Use caution)			
Miles to crash + Lane blocked	0.533	0.021	<0.001*
Miles to crash + Delay information	0.375	0.008	<0.001*
Miles to crash + "Use caution" + Lane of crash	0.567	0.043	<0.001*
Miles to crash + Speed suggestion	-0.314	0.005	<0.001*
Miles to crash + "Prepare to stop"	1.825	0.013	<0.001*
Miles to crash + "Use caution"	-0.041	0.188	0.829
Crash location + "Prepare to stop"	-0.784	0.007	<0.001*
Crash location + Speed suggestion	-0.380	0.019	<0.001*
Crash location + "Use caution" + Lane of crash	0.267	0.021	<0.001*
Crash location + "Use caution"	-0.115	0.208	0.582
Crash location + Delay information	0.914	0.179	<0.001*
Crash location + Lane blocked	0.098	0.020	<0.001*
Others	-0.158	0.123	0.198
Other VMS message-related characteristics			
# of frames: Two	0.463	0.116	<0.001*
Time difference	0.000	0.000	0.582
Distance to crash	-0.201	0.041	<0.001*
Duration of display	0.000	0.000	0.170
Roadway characteristics			
Increase in occupancy	0.210	0.019	<0.001*
Weather condition (base: Clear)			
Cloudy	-0.297	0.239	0.213
Rain	0.313	0.116	0.007*
Snow	-0.103	0.055	0.061~
Light condition (base: Daylight)			
Dark – Lighted	0.758	0.186	<0.001*
Dark – Not lighted/Unknown	0.389	0.203	0.055~
Dawn/Dusk	-0.107	0.010	<0.001*
Temporal variables			
Peak hour (base: Off-peak hour)			
Morning peak	0.311	0.186	0.095~
Evening peak	-0.572	0.229	0.013*
Day of week (base: Weekday)			
Saturday	0.079	0.160	0.623
Sunday	0.849	0.186	<0.001*
Model fit statistics (N = 595)			
McFadden's pseudo-R^2	0.206		
Log-likelihood (null model)	-513.66		
Log-likelihood (full model)	-407.82		
AIC (null model)	1031.33		
AIC (full model)	875.65		

Notes: *statistically significant at 95% confidence interval, ~statistically significant at 90% confidence interval

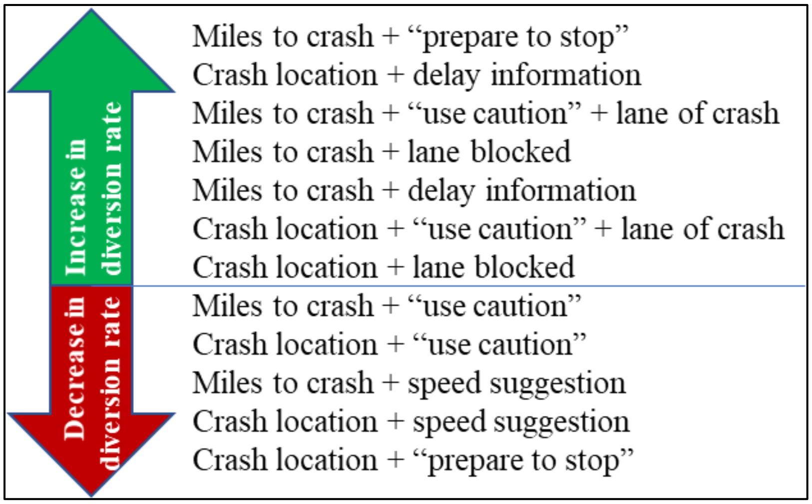

Figure 4.1 Ranked message combinations (compared to "crash ahead" + "use caution") by impact on diversion rate

In addition, messages with two frames had higher diversion than messages with one frame. Larger distance between VMS device and crash incident was negatively associated with diversion rate. However, the time difference between crash incident and message display, and duration of message display had no significant impact on diversion rate. In terms of roadway characteristics, occupancy on the mainline was positively associated with diversion rate. Higher diversion was observed during rainy conditions than during clear weather conditions. In comparison to daylight conditions, the diversion rate was found to increase more during the dark (lighted or unlighted) conditions and to a lesser extent during dawn/dusk light conditions. Both temporal variables considered in the study – peak hour and day of the week – were significantly associated with diversion rate. In comparison to off-peak hours, morning peak hours observed more diversion (marginally significant). Evening peak hours observed a lesser increase in diversion than morning peak hours. No significant difference in diversion rate was observed between Saturdays and weekdays, but higher diversion was observed on Sundays in comparison to weekdays.

4.3 Summary

This chapter presented the model estimation approach and results of this study. A logistic regression modeling approach was used to fit two models. Both models were estimated for the diversion rate during crash-related message display in VMS with message content, other VMS message characteristics, roadway characteristics, and temporal characteristics as independent variables. The difference between the two models – model A and model B – was the message content-related variable. The presence of different contents in the message was used to account for message content in model A whereas the combination of different contents was used to account for message content in model B.

The estimation results of the ordered logistic regression models showed a significant relationship between the diversion rate and message content when controlling for other VMS device/message-related characteristics, roadway characteristics, and other characteristics. Of the 11 most often used crash message content, 7 were positively associated with diversion rate. “Traffic ahead is slowing” had the highest positive association, followed by lane of crash information, and miles to crash information. Of the 13 most common message combinations, messages with miles to crash + “prepare to stop” had the highest positive association with diversion rate, followed by crash location + delay information, and miles to crash + “use caution” + lane of crash information, etc. The message content combination associated with a reduction in diversion rate was crash location + “prepare to stop” information, followed by crash location + speed suggestion, and miles to crash + speed suggestion information. These results suggest that the content of messages displayed in the VMS devices during crash incidents impacts driver diversion decision-making.

5.0 CONCLUSIONS

5.1 Summary

The overall goal of this project was to investigate the behavioral response of drivers to different message content displayed in VMS devices during crash incidents. In particular, this study analyzed diversion behavior in response to different VMS messaging. With this primary goal, this study explored the relationship between increase in diversion rate during the message display period during crash incidents and the content of the message along with other potential confounding factors. The models revealed that the content of message is important in driver response to crash-related VMS messages.

Chapter 1 introduced the project by providing the problem statement, objectives, and scope of the project. Chapter 2 provided the background of the project by summarizing the findings of key past studies related to VMS. Chapter 3 summarized data collection efforts. Chapter 4 presented the analysis methodology and estimation results. This chapter provides study conclusions. Chapter 6 provides recommendations for the implementation of the study findings.

5.2 Key Findings

This study investigated the association between the diversion rate during the message display period during crash incidents and the content of the message. Message content consisting of miles to crash, “crash ahead” only (without location and miles to crash), location of crash, delay information, traffic ahead (i.e., is slowing or slows), and lane of crash (left, center, right) information were found to be positively associated with diversion rate. However, “use caution,” speed suggestion, and “prepare to stop” were found to be negatively associated with diversion rate. Based on the estimates, the combination of message contents with the greatest diversion rates was miles to crash + “prepare to stop” information, followed by crash location + delay information, and miles to crash + “use caution” + lane of crash information. The message content combination with the lowest diversion rate was crash location + “prepare to stop” information, followed by crash location + speed suggestion, and miles to crash + speed suggestion information.

Messages with two frames had higher diversion rates than messages with one frame (in model B only). A larger distance between VMS devices and crash incidents was negatively associated with diversion rate. However, the time difference between crash incident and message display, and duration of message display had no significant impact on diversion rate. In terms of roadway characteristics, occupancy on the mainline was positively associated with diversion rate. A higher diversion was observed during rain and a marginally lower diversion during snow (in model B only) than that of clear weather conditions. In comparison to daylight conditions, the diversion rate was found to increase more during the dark (lighted or unlighted) and to a lesser extent during dawn/dusk light conditions. Both temporal variables considered in the study – peak hour and day of the week – were significantly associated with diversion rate. In comparison to off-peak hours, morning peak hours observed greater diversion (marginally significant), but evening peak hours observed less diversion. No significant difference in diversion rate was observed between Saturdays and weekdays, but higher diversion was observed on Sundays in comparison to weekdays.

5.3 Limitations and Challenges

This study has some limitations that can be addressed through future study. First, the dataset used came from real field data of limited spatial and temporal scope. The dataset might not have enough variability in message content and thus this study’s results might not be generalizable outside of Utah. This study investigated driver behavior in response to commonly used crash-related message content in Utah. Only one section of I-15 with a sufficient number of VMS devices and crash incidents was studied. More sites could have strengthened the generalizability of the findings, but no other freeways in Utah had adequate data. Second, the flow and occupancy data used in the study were of 5-minute granularity, but finer data of 1-minute or 30-second granularity could produce more accurate results. Third, there were no comparisons between crash incidents followed by VMS messages and “control” incidents with no VMS message displayed.

Another challenge the authors encountered while carrying out this work was related to incident identification across data sources. The analyses in this study required the joining of crash data and VMS history, but the record-keeping system in the UDOT database didn't have any common identifiers to join those two datasets. Thus, authors had to join them by using a number of approximate criteria as discussed in Section 3.3. As such, there may have been errors in matching messages to incidents. The authors recommend that UDOT incorporate a common identifier in their record-keeping system.

The choice of a good model of diversion rate during the crash message display period was the greatest challenge the research team encountered. The original aim of the research team was to be able to make rough predictions of diversion rate in real-time during incidents. A parsimonious linear regression model could be a good choice in such cases. However, the linear regression model couldn't be fitted for the data because of the number of violations of the assumptions of the model, which led the research team to create the ordinal categories of increase in diversion rate. As a result, ordered logistic regression models were chosen to assess the increase in diversion rate.

6.0 RECOMMENDATIONS AND IMPLEMENTATION

6.1 Recommendations

This project investigated the associations of message content displayed during crash incidents with drivers' behavioral responses to such messages. Crash incident management is a high priority for UDOT, and this study's findings can support the incident management process. Improvement in incident management could be achieved through the display of consistent message content that is known to have the greatest impact on diversion rates. The use of consistent message content throughout the state would decrease driver confusion and indecision. It would also support traffic managers in making informed decisions and decreasing ambiguity in choosing the message content during crash incidents, ideally saving time for more critical tasks. The recommended message content can be implemented primarily within the Traffic Operations Center of UDOT. The following are the recommendations made based on this study's findings:

- **Standardize choice of content for a VMS message:** Standard message content should be selected based on the overall goal of the message, such as to implicitly encourage diversion or reduce diversion. Miles to crash, "crash ahead" only, location of the crash, delay information, "traffic ahead," and lane-of-crash contents had significantly higher diversion rates. However, the messages consisting of "use caution," speed suggestion, and "prepare to stop" information had significantly lower diversion rates.

- **Standardize the combination of message contents:** Standard message content combinations should be selected based on the overall goal of the message, such as to implicitly encourage diversion or reduce diversion. The combination of miles to crash + "prepare to stop" information had the highest diversion rate, followed by combinations of crash location + delay information, and miles to crash + "use caution" + lane of crash information. The combination of crash location + "prepare to stop" information had the lowest diversion rate, followed by combinations of crash location + speed suggestion, and miles to crash + speed suggestion.

- **Increase number of VMS devices:** The diversion rate was found to be greater when the distance between the VMS device (where the message was displayed) and the crash incident was smaller. This finding suggests that agencies should strive to shorten distances between VMS devices, particularly in crash-prone areas, in order to increase diversion rates.

- **Consider reducing the use/display frequency of non-crash-related messages:** As shown in Figure 3-2, less than 2% of VMS messages are crash-related each year. Oversaturation of non-specific safety messaging or non-safety messaging may be impacting driver behavior (i.e., drivers may be "tuning out" VMS messages). Further study is recommended on this issue.

6.2 Implementation Plan

This study identified several factors that UDOT should consider for crash incident management. First, the effectiveness of displaying crash-related messages to influence driver diversion was verified. UDOT should consider increasing the number of VMS devices in the state, particularly in crash-prone locations with adequate diversion routes available. Consistent messaging practices should be adopted for crash incidents to shift time spent on VMS programming to more critical activities, thus improving the incident management process. For example, the Traffic Operations Center could provide messaging guidance, such as in Figure 6.1, to operators for quick reference during incidents. Providing consistent messaging will save valuable operator time during incidents and decrease driver confusion and indecision.

Goal: Inform drivers of incident and increase diversion off the freeway

Use the following message contents (greatest impact message listed first):

- “X miles to crash, prepare to stop”
- “Crash at X, expect delays”
- “X miles to crash in [left, right, center] lane, use caution”
- “X miles to crash”
- “Crash ahead”
- “Crash at X”
- “Expect delays”
- “Traffic [slowed, stopped] ahead”
- “Crash in [left, right, center] lane”

Goal: Inform drivers of incident and decrease diversion off the freeway

Use the following message contents (greatest impact contents listed first):

- “Crash at X, prepare to stop”
- “Crash at X, slow down [to Y MPH]”
- “X miles to crash, slow down [to Y MPH]”
- “Use caution”
- “Slow down [to Y MPH]”
- “Prepare to stop”

Figure 6.1 Possible VMS message “cheat sheet” for UDOT TOC operators

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