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STUDYING THE BOTTLENECK ISSUE AT WORK ZONES AND ASSESSING THE EFFECTIVENESS OF A PORTABLE DYNAMIC LANE MERGING SYSTEM IN PROMOTING ZIP MERGE BEHAVIOR

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BY

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ABSTRACT

In this research study, drivers' preferences of and responses to text and graphic road sign messages at work zones were analyzed in an attempt to reduce the bottleneck conditions at lane-reduced work zones. A particular emphasis was placed on zip merging, an application of alternate vehicle merging already successfully employed in the Czech Republic and other nations, that eliminates the perceived right-of-way held by drivers in the open lane(s) at merge points. Both experimental and currently existing advisory messages were evaluated and compared for effectiveness in this study. These advisory messages, associated with three driving advisory conditions (DACs), "Merge to the Right Lane," "Zip Merge" (vehicles take turns), and "Continue Travel Normally," were assessed through a questionnaire survey, driving simulation and traffic study to seek the best messages in advising drivers in different traffic conditions when approaching work zones.

A questionnaire survey was first deployed to identify participants' preferences towards a series of messages posted on variable message signs (VMSs). Participants rated each message from one to five as to their effectiveness in advising drivers in different conditions. By comparing the highest rated text and graphic messages under each DAC, participants then gave their preference toward either text or graphic messages. A total of 81 subjects participated in the survey. Survey results indicated that text messages were preferred at a 4:1 ratio over graphic messages, where the Zip Merge text sign messages were the least preferred of any combination of DAC and message type.

The effectiveness of several top rated messages identified in the survey was further assessed through a driving simulation. Various text and graphic messages were posted on portable VMSs along a straight freeway in a fixed-base driving simulator. Subjects were asked to verbally respond with a number when they identified a message, denoting the DAC associated with that message. It was found that graphic messages were most effective in all three DACs in terms of response time and accuracy, while the Zip Merge graphic messages elicited the fastest and most accurate responses.

Through regression and analysis of variance models, the questionnaire and driving simulation results show a bias of the public towards text sign messages, especially those which are currently being used in lane-reduced work zone setups, that is not supported through drivers' responses to messages. While the survey offered the conclusion that drivers prefer to be advised by text sign messages using wording familiar to them, the driving simulation displayed the power of graphic messages to elicit more quick and accurate responses when compared with text. The combination of drivers' not in favor of Zip Merge text sign messages and their positive response to Zip Merge graphics shows a clear recommendation to use graphic messages in any future field test at work zones. A field study was planned but not carried out in this study due to constant mechanical setbacks with a portable Dynamic Lane Merge System (DLMS) unit obtained from the Czech Republic.

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TABLE OF CONTENTS

ABSTRACT .... **ii**

ACKNOWLEDGMENTS .... **iv**

TABLE OF CONTENTS .... **v**

LIST OF TABLES .... **vii**

LIST OF FIGURES .... **viii**

CHAPTER 1 .... **1**

INTRODUCTION **1**

CHAPTER 2 .... **4**

RESEARCH OBJECTIVES **4**

CHAPTER 3 .... **7**

REVIEW OF LITERATURE **7**

Bottleneck Issue at Work Zones 7

Variable Message Sign 8

Effectiveness of Graphic and Text Sign Messages 10

Strategies for Lane Merging at Work Zones 12

Portable DLMS Unit 15

Driving Simulation in Research 16

CHAPTER 4 .... **18**

METHODOLOGY **18**

4.1 Questionnaire Survey 19

4.1.1 Designing the Questionnaire Survey 19

4.1.2 Conducting the Questionnaire Survey 23

4.2 Driving Simulation Experiment 25

4.2.1 Design of the Driving Simulation Experiment 25

4.2.2 Conducting the Driving Simulation Experiment 30

4.3 Field Study 33

4.3.1 Design and Setup of the Field Study 34

4.3.2 Conducting the Field Study 39

CHAPTER 5 .... **40**
RESULTS AND DISCUSSION **40**
5.1 Questionnaire Survey 41
5.1.1 Ratings for Messages 41
5.1.2 Message Type Preference 46
5.2 Driving Simulation Experiment 49
5.2.1 Mean Response Time 49
5.2.2 Message Identification Accuracy 54
5.3 Field Study 60
5.4 Discussion of Findings 63
CHAPTER 6 .... **65**
CONCLUSION **65**
APPENDICES **68**
Appendix A. Complete Set of Questionnaire Survey PowerPoint Slides for use with VisualBasic Macros 68
Appendix B. Modules (Message Sets) used for Randomization in the Driving Simulation Experiment 75
Appendix C. Sign Libraries for Portable DLMS Message Display 76
Appendix D. Module Order Randomization for Subjects in the Driving Simulation Experiment 77
BIBLIOGRAPHY **78**

LIST OF TABLES

TABLE PAGE

Table 1. Messages Used in Questionnaire Survey 21

Table 2. Messages Used in Driving Simulation Experiment 26

Table 3. Basic Setup for 2-Day Field Study 35

Table 4. ANOVA Table for Ratings 43

Table 5. Ordinal Logistic Regression Output for Questionnaire Survey: Message Ratings 45

Table 6. Text Message Preferences by Gender, Age, and Driving Advisory Condition 47

Table 7. Binary Logistic Regression Output for Questionnaire Survey: Message Type Preference 48

Table 8. ANOVA Table for Driving Simulation: Mean Response Time 50

Table 9. Regression Analysis Output on Possible Learning Curve for Mean Response Time 54

Table 10. ANOVA Table for Response Accuracy 56

Table 11. Binary Logistic Regression Output for Driving Simulation: Response Accuracy 58

Table 12. Average Vehicle Flows by Lane, I-95 Traffic Study 61

Table 13. Observation of Vehicles Merging from Closed Lane, I-95 Traffic Study (Work Zone) 61

LIST OF FIGURES

FIGURE PAGE

Figure 1. Variable Message Sign (VMS) with 50 x 24 Pixilated Board 9

Figure 2. TA-34 MUTCD Design for a One Lane Closure at a Freeway Work 11

Figure 3. MUTCD Static Merge Signs, W4-2 and W4-1 14

Figure 4. Portable DLMS, 2-Panel LED Display (Congman) 16

Figure 5. Initial Merge Messages Discussed at RIDOT, Providence, RI 20

Figure 6. Progression of PowerPoint Slide in Questionnaire Survey 22

Figure 7. VisualBasic Macros OnClick Command Flow Chart 23

Figure 8. ScenarioBuilder Program Screenshots 27

Figure 9. Dummy Messages used in Driving Simulation Experiment 28

Figure 10. Driving Simulator Views 29

Figure 11. Driving Simulation Experiment: Motorcycle in front of driver 30

Figure 12. Driving Simulation Experiment: Subject Study Sheet 31

Figure 13. Driving Simulation Experiment Setup at URI 33

Figure 14. Drawing of Proposed DLMS Setup 36

Figure 15. Recommended Messages for use in Applicable Merge Applications 37

Figure 16. Initial Corel Drawing of Graphic to be used in Field Study 38

Figure 17. Questionnaire Survey: Main Effects and Interaction for Mean Rating 43

Figure 18. Main Effects and Interaction Plots for Driving Simulation: Mean Response Time 50

Figure 19. Fitted Line Plot for Possible Presence of Learning Curve in Driving Simulation Experiment: Mean Response Time by Experiment Sequence.................. 53

Figure 20. Main Effects and Interactions for Mean Response Accuracy 56

CHAPTER 1

INTRODUCTION

As the roadway transportation system of the United States has matured, roadway construction under varied traffic conditions has become the rule rather than the exception, and successful management of these scenarios has become an important challenge. Traffic flow management at work zones has become a top priority among the various traffic management issues. At work zones, natural traffic flow is disrupted when lane closures occur. Due to the capacity diminution, heavy congestion, or "bottlenecks," resulting from lane merging occur in the midst of high traffic demand.

It has been observed that dangerous vehicle maneuvers exist at freeway work zones where traffic merging occurs. Such maneuvers include quick braking and speeding up, as well as vehicles in the open lane not allowing vehicles in the closed lane to merge sufficiently because of a perceived right of way. Messaging at lane-reduced work zones, through the use of variable message signs (VMSs), is in high regard for the state of Rhode Island's Intelligent Transportation System. To help better manage traffic flow and eliminate bottlenecks at work zones, this study seeks to improve the message display on portable variable message signs (PVMS) to advise drivers approaching work zones.

This study was conducted to help transportation authorities improve their management of freeway traffic flow and eliminate dangerous driving maneuvers at lane-reduced work zones. To accomplish this, efforts were made to understand the effectiveness of certain advisory messages in promoting the desired driving behavior and to improve the message design and displays at work zones.

Three approaches were carried out in this study: a questionnaire survey, a driving simulation experiment and a field study. The questionnaire survey was conducted to examine drivers' preferences towards the design and display of VMS messages as they would apply to certain work zone driving advisory conditions. The survey was developed as a series of PowerPoint slides, where the messages were presented through three driving advisory conditions (DACs). The driving simulation experiment aimed to determine the effectiveness of these messages, specifically how accurately and quickly drivers responded to their intended meanings. The field study aimed to pilot test the messages identified in the first two parts of study using a portable Dynamic Lane Merging System (DLMS) and compare its effectiveness with that of a conventional Manual of Uniform Traffic Control Devices (MUTCD) setup at lane-reduced work zones. Data and observations gathered in the field study were limited to an observational traffic study due to inabilities to operate the portable DLMS.

This report gives a review of related past studies, a description of the methods in conducting the current study, and presents the findings and recommendations through the three parts of the study. Chapter 2 defines the research objectives set forth at the onset of the study and notes goals associated with these main objectives. Chapter 3 summarizes various past studies in a literature review on similar study topics. Chapter 4 describes, in detail, the methods used in conducting all three parts of the study. Chapter 5 provides results from the three parts of the study and a discussion of the implication of these results, and Chapter 6 summarizes the findings of the study in a conclusion, with relation to study objectives. In addition, appendices and references follow the conclusion.

CHAPTER 2

RESEARCH OBJECTIVES

The goal of this research was to examine the effectiveness of a portable Dynamic Lane Merging System (DLMS) on mitigating bottlenecks at lane-reduced work zones with both existing and experimental text and graphic messages, and to compare it with the traditional MUTCD setups.

The objectives of this research are:

- Obtain insights on work zone congestion and bottleneck issues through literature review and evaluate the design of the portable DLMS and its feasibility to be deployed at work zones.

This objective was achieved with a comprehensive literature review on existing research and publications related to bottleneck issues at work zones, strategies for lane merging, Variable Message Signs, and text and graphic messages. Further literature review can gain insight into similar studies in the field and also successful application of similar strategies around the world, especially in the Czech Republic.

- Develop text sign messages and pictograms to be posted on the portable DLMS system at work zones to promote zip merging behavior.

To accomplish this objective, a series of text and graphic messages were developed for the study through collaboration with transportation authorities. A questionnaire survey was conducted first to gain insights into drivers' preferences on these messages, on both their content and type. A driving simulation experiment was conducted next to evaluate drivers' responses to these messages in a simulated driving environment. The results of the questionnaire survey and driving simulation experiment led to a set of recommendations for the best messages to be used on the portable DLMS display.

- Design and conduct a field study at identified locations and collect traffic data to compare the portable DLMS with conventional MUTCD lane merge configurations.

The fulfillment of this objective required an initial recommendation of messages on different driving advisory conditions (DACs) and a field test of those messages. One location for the field study was identified on Interstate-95 in Providence, RI. The completion of the field study relied on maintaining a fully functional portable DLMS to display sign messages and collect traffic data to compare with the traditional MUTCD lane merge configuration data at the same site. Additionally, driving behaviors at the field study locations were observed.

- Design and conduct a drive-through study to understand driver behavior at work zones.

During the same time period and location as the field study, a drive-through study is planned for the inclusion of 12 subjects to be carefully examined while driving through the work zone area, including vehicle behavior, surrounding vehicle behaviors, and driver eye movement tracking. Subjects are needed for consecutive days during the field study time period as to provide data for both the proposed DLMS and the MUTCD setup.

- Analyze the study results and prepare an implementation plan for the effective deployment of a recommended lane merge control system.

From the questionnaire survey and the driving simulation, recommendations were made regarding the best messages for particular conditions. The field study results will determine the advantages and disadvantages of the merge configurations evaluated. Specific recommendations will be given regarding the effectiveness of the 2-panel LED board in the portable DLMS setup and messages used.

CHAPTER 3

REVIEW OF LITERATURE

A comprehensive literature review was conducted to gain insight into the various aspects of the current study. The bottleneck issue at work zones was further investigated to identify the current issues, noting significant statistics at lane-reduced work zones and putting a focus on safety. The characteristics, capabilities and common uses of variable messages signs were also investigated. Past studies were then referenced to understand the effectiveness of different messages, both in use and experimental, in lane-reduced work zones. These studies included the testing of text messages, graphic messages and combination text and graphic messages. The lane merge strategies that currently exist were identified and the conditions of their successful application were noted. Finally, the use of driving simulation in research, both its positive and negative attributes, was examined to understand possible sources of gain and error experienced during the second part of this research.

Bottleneck Issue at Work Zones

Traffic congestion is often observed at work zones with temporary capacity reduction (*1).* Increased travel time, queue length, aggressive behaviors, and roadway accidents are commonly seen *(2).* Between 1982 and 2005, the percentage of the major road system classified as congestion grew from 29% to 48% in the United States *(3)*. Approximately 10% of travel time delays occur at roadway work zones *(4)*. Work zones on freeways are estimated to account for nearly 24% of non-recurring delay *(5)*. In 2000, the Federal Highway Administration conducted a survey in which 32% of people were dissatisfied with the areas of construction, placing work zone dissatisfaction as the second highest cause of user dissatisfaction on major highways, with the highest dissatisfaction rate belonging to traffic flow. In the same survey, people were asked what percentage of time they were delayed during highway travels, and their level of dissatisfaction with the delays they experience. The delay time and dissatisfaction percentages showed a positive correlation, including a sharp spike in dissatisfaction percentage when the perceived delay time was greater than 30% of the total travel time *(6)*.

Despite all conventional efforts, work zones remain hazardous places *(7)*. Research has shown that drivers are slow to recognize that they have entered a work zone, causing crashes and subsequent decreases in roadway capacity. According to the Fatality Analysis Reporting System (FARS), there were 720 work zone fatalities in the United States in 2008; this figure represents 2% of all roadway fatalities for that year. There was one work zone fatality every 10 hours and one work zone injury every 13 minutes *(8)*. Undoubtedly, it is a critical challenge for traffic management and safety engineers to maintain a satisfactory level of efficiency and safety at work zones without sacrificing roadway functions.

Variable Message Sign

As a critical component in the Intelligent Transportation System, a Variable Message Sign (VMS) is a useful tool for managing traffic in real time at work zones.

By giving drivers clear and direct instructions, a well-designed VMS could help effectively reduce congestion, while maintaining safety at lane-reduced work zones.

VMSs used at lane-reduced work zones typically display two to three lines of amber colored text with no line being more than eight characters long. The typical VMS is a 50x24 pixilated board, with each character a maximum of 7x5 pixels, and one pixel between characters on the same line. The VMS warning message should be placed 800 to 1600 m (2625 to 5250 ft) upstream of the lane closure taper (*9*). Figure 1 shows an image of a typical VMS with the dimensions described above.

Figure 1. Variable Message Sign (VMS) with 50 x 24 Pixilated Board

VMS messages should not only be recognizable to drivers, but also be coherent and legible from a distance. Therefore, installation and message operations considering drivers' legibility performance are very important. Drivers' legibility distances are dependent on various factors, such as geometric conditions, travel speed and driver characteristics, etc. (*10*). There have been a variety of relevant research studies and experiments on legibility performance for VMS. In 1994, Armstrong and

Upchurch emphasized reflecting ergonomic factors into designing a VMS, and suggested legibility distance models through experiments that compare legibility of fiber-optic and Light-Emitting Diode (LED) characters (*10*). In 2005, Wang and Cao (*11*) developed a VMS information legibility model with number of lanes and number of lines of messages as the main variables, and age and gender as the other variables, using a driving simulator (*12*).

Effectiveness of Graphic and Text Sign Messages

The messages displayed on a VMS, in terms of level of detail, could significantly affect the reaction time of a motorist, as well as their willingness to make a maneuver, and therefore affect the safety of the roadways. Thus, the more specific and clearer a message is, the more persuasive and influencing it becomes *(13).* Plummer et al. investigated the effectiveness of text versus graphics in conveying a desired message. Graphics were found to be more effective in conveying the intended message, whereas the difference in comprehension speed between text and graphic messages could not be determined *(14).* Wang et al. (*15*) conducted a study on the use of graphics on VMSs and found that most test subjects both preferred and responded faster to graphic-aided text messages than to text-alone messages. It is also recommended by the Conference of European Directors of Roads (C.E.D.R.) report and Lucas et al.'s study that graphics and symbols should be used as much as possible to avoid the problem of disseminating information to drivers who speak and use different languages (*16,17*).

Symbols and graphics displayed on VMS offer potential advantages because drivers can read and understand symbols and graphics quicker and farther upstream of the sign in comparison to word messages *(18)*. Field and laboratory results have indicated that efficient graphic sign messages have several advantages over text sign messages such as enhanced legibility for a given size and at shorter exposure durations, recognition when the information is degraded due to poor environmental conditions, quicker extraction of information, and improved comprehension for drivers with difficulty understanding text sign messages *(19)*.

Figure 2 shows the MUTCD designed configuration for a single lane closure in a freeway work zone, including sign types and particular locations if and when they are implemented at the work zone.

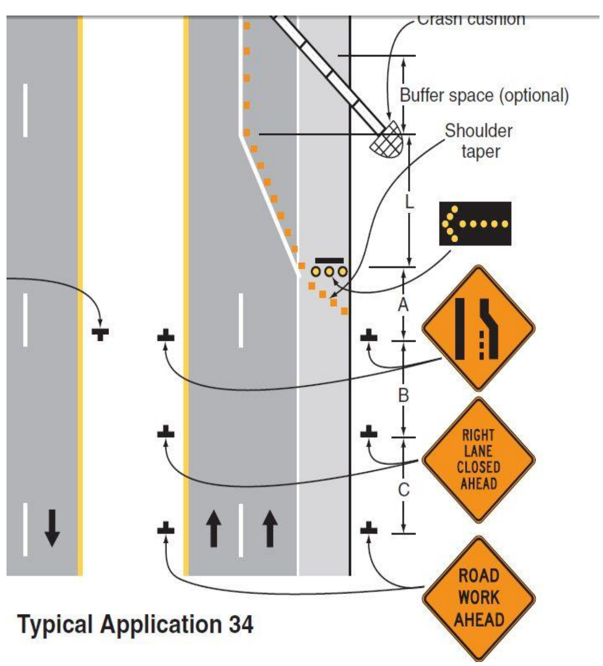


Figure 2. TA-34 MUTCD Design for a One Lane Closure at a Freeway Work Zone

Strategies for Lane Merging at Work Zones

To increase the efficiency and safety of traffic flow in lane-reduced transition areas, engineers around the world have been exploring innovative techniques to facilitate traffic flow through these bottleneck areas. Among them, traffic control devices and merging strategies play an important role in managing the flow of vehicles.

Based on the conventional Manual of Uniform Traffic Control Devices (MUTCD) lane merge control strategy, alternative strategies have been found to enhance the safety and efficiency of transition areas and deal with traffic flow control issues. Among them are the "Early Merge (EM)", "Late Merge (LM)", "Dynamic Early Merge (DEM), and "Dynamic Late Merge (DLM)" (*20,21,22,23*). Normally, EM and DEM work well as long as congestion does not develop. When the traffic demand exceeds the capacity of the work zone, queues may extend back beyond the advance warning signs, often surprising approaching traffic and increasing the accident potential. LM addresses many of these problems, because it maximizes the traffic capacity of the work zone. When there is no congestion and speeds are high, potential confusion among drivers at the merge point becomes a concern, and the DLM concept is proposed in the interest of providing the safest and most efficient merging operations at all times.

The Minnesota Department of Transportation developed a dynamic traffic control strategy, the DLM system, and deployed it on a section of US 10 in 2003. In addition to the standard signs, this system consists of three VMSs and a Remote Traffic Microwave Sensor (RTMS) detector. When congestion begins to form, the signs are activated to provide lane use instruction to drivers. It was found that the percentage of drivers utilizing the discontinuous lane increased dramatically (almost 60% during the heaviest demand) when the VMSs were activated, which indicated that the queue length decreased and traffic capacity increased (*24*).

The Michigan Department of Transportation has deployed an early merge strategy known as the Dynamic Early Lane Merge Traffic Control System (DELMTCS), in an attempt to increase vehicle throughput and overall safety near construction lane closures. This strategy employed EM by setting up a dynamic no passing zone. The DELMTCS helped Michigan DOT achieved its goals of reducing aggressive driving behavior, improving overall safety, and reducing lane closure related delay (*23*).

Zip merge is a strategy that can be applied in conjunction with the strategies previously mentioned. Since both lanes are used in zip merging, people take turns causing a reduction of stress and erratic merging behavior. This operation requires motorists to follow a "zipper rule," in which drivers in a continuing lane permit adjacent vehicles to merge in an alternating pattern. In this instance, right-of-way assignment is suspended until the congested period ends (*25*). It is considered an effective tactic for merging traffic from several to fewer lanes with the least road rage. Zip merge operations provide an easy and efficient solution for traffic flow management when lane closures occur. However, operational difficulties are often experienced by transportation authorities. Most motorists in open lanes do not give up their right-of-way at the merge point. They commonly try to prevent drivers in the closed lane from passing them by straddling the centerline or traveling slowly in tandem with another vehicle in the closed lane. As a result, heavy congestion is formed in closed lanes, and orderly merging operations are lost when impatient drivers remaining in the closed lane attempt to squeeze into the open lane. These maneuvers tend to reduce the capacity of the merging operation and increase the accident potential and road rage among drivers (*26*).

A Connecticut study (*28*), looking to test an experimental sign to replace the traditional MUTCD static sign at merge points near intersections, found an improvement in the merging behavior at two separate locations when trying to facilitate zip merge behavior. An experimental sign was developed and tested against the traditional MUTCD sign (MUTCD sign in Figure 3, left). The experimental sign was preferred through surveying and also performed better in the field. Specifically, there was a noticeable increase in the number of successfully merging vehicles, especially in situations where two vehicles approached the merge side by side. The study cites an increase in “desirable” merges from 56% to 66% and a decrease in “undesirable” merges from 9% to 5%.

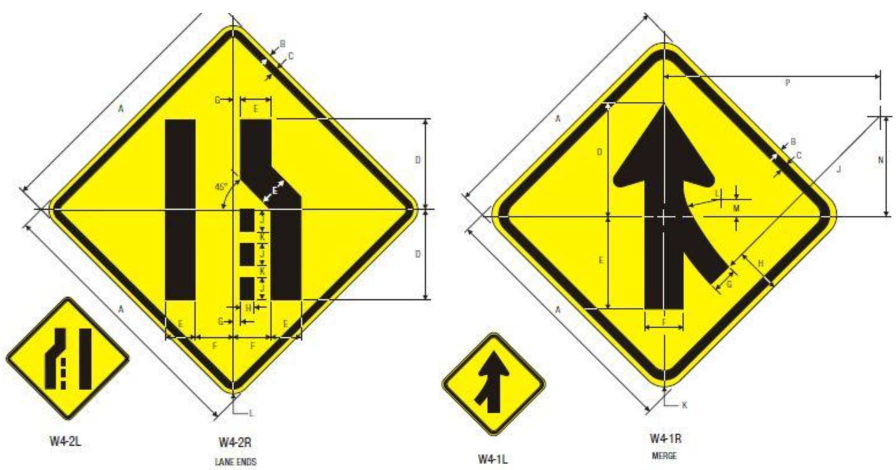


Figure 3. MUTCD Static Merge Signs, W4-2 and W4-1

A study evaluating different traffic control devices on rural high-speed maintenance work zones notes the effectiveness of a speed trailer in reducing speeds of vehicles entering the work zone. A 24” LED speed limit was used with an estimated visual sight distance of 800-1000 feet. The device produced a decrease in vehicle speed upstream of its placement, within the visual sight range. However, vehicle speeds increased thereafter, noting that drivers responded to speed limit directions at the point of warning, but did not continue to follow the desired speed while entering the work zone *(7)*. If speed limit warnings are not successful in entering the work zone, especially lane-reduced work zones, their use is highly questionable. An alternative use of the top panel display could be an indication that a work zone is ahead, by text or graphic message.

Portable DLMS Unit

To make sure that zip merge is enforced and followed by all motorists at work zones, a research team in the Czech Republic (organized by the Czech Transport Research Center) developed a portable Dynamic Lane Merging System (DLMS, Figure 4). It consists of two mutually communicating telematic units - a mobile display system with an evaluation unit (MDSE) and a mobile telematic station (MTS). The MDSE unit is equipped with traffic information display, portable variable message sign, and radar traffic detector. It can display both text and graphic messages to assist motorists with lane merging at work zones. The modular MTS is equipped with a surveillance camera, a weather station, and a radar traffic detector. Traffic data collected by the MTS are subsequently interpreted and used to display short messages or pictograms on the MDSE to help manage traffic flow at the work zone by facilitating zip merge behavior (*27*). The DLMS is to be used for field testing with light or medium traffic at stable traffic speeds.

Figure 4. Portable DLMS, 2-Panel LED Display (Congman)

Driving Simulation in Research

The use of driving simulation in a controlled environment has been shown to be an adequate indicator of real driving conditions. The use of a driving simulator in research studies allows many subjects to be involved in the data collection process without subjecting them to possible danger associated with driving on roadways. The design of driving simulators may allow the change of setting, road and weather conditions, among other factors. An advantage in using driving simulators for experimenting is the ability to recreate ideal, real world conditions. Because it has been shown that a majority of crashes in real world driving are due to driver error or dysfunction, a recreation of the external stimuli for drivers can elicit very accurate comparisons between driving simulation and the real world (*29*).

The downsides of using driving simulators for predicting real world conditions are largely based on the effectiveness of the particular driving simulator being used. The display of different types of images may not translate to drivers' perceptions on roadways. A University of Iowa study from 2005 points out the importance of how well the driving simulator screen(s) translate to real world driving (*30*). Often times, the real life condition cannot be accurately portrayed because of the presence of complex materials. These complex materials may include lighting phenomenon (such as interreflections or masking effects) and different road and roadside materials (such as asphalt and vegetation). An important detail to consider for this study is that complex light interactions for a graphic board display cannot be simulated in most commercial driving simulators, such as the VMS used in this study.

CHAPTER 4

METHODOLOGY

Three parts were developed for this research study with the Chapter 2 goals in mind. The first part of the study involved the creation of a questionnaire survey (4.1). The survey aimed to reach a significant amount of subjects, so it was kept short and focused on subjects' perceptions of the different messages that were chosen. The survey focused mainly on the differences between the two genders, age, text and graphic messages and messages in different driving advisory conditions (hence force DACs). The driving simulation experiment (4.2) focused on the reaction of motorists to the different messages and drawing conclusions on the messages' effectiveness in a simulated driving situation. The motorists' reactions to messages were classified by response accuracy and response time. In both the questionnaire survey and the driving simulation experiment, the DACs used were classified as 1) Merge to the right lane, 2) Zip merge, and 3) Continue travel normally. The decision to include these three DACs was initiated during the development of the questionnaire survey and can be found in that section (4.1). Finally, a field study plan (4.3) was developed to test the portable DLMS to compare with the traditional MUTCD setup for lane-reduced work zones.

For each part of the study, beginning with the survey, analyzed results from the previous parts played a role in deciding or recommending signs for the proceeding step. The driving simulation experiment was conducted with the absence of the least preferred messages from the survey. Similarly, results from the driving simulation experiment and survey allowed recommendations to be made for the field study portion.

4.1 Questionnaire Survey

4.1.1 Designing the Questionnaire Survey

The survey was created with the intention of gaining insight into motorists' preferences towards different messages commonly used in merge situations, and also towards experimental messages not yet implemented in the U.S. The survey needed to be of a certain length not too long as to discourage a volunteer from completing it. Therefore, the survey would aim to gain the maximum amount of information on message preference given a window of about five minutes of focus for subjects. Upon the selection of different messages to be included, the questionnaire survey would be the first evaluation of some of the experimental messages. Therefore, the wording of questions would focus on asking subjects how well a message would facilitate the desired driving behavior in a particular driving advisory condition (hence forth DAC).

Meetings with RIDOT in Providence, RI served to reiterate the main goals of the study and suggest different message types to test. Choosing and developing the messages were of paramount importance to the study, especially because they would appear in the driving simulation experiment and field study for a source of comparison. The zip merge messages were discussed at length, most notably on their contents and their ability to promote zip merging behavior. Figure 5 shows one of the first set of text messages discussed.

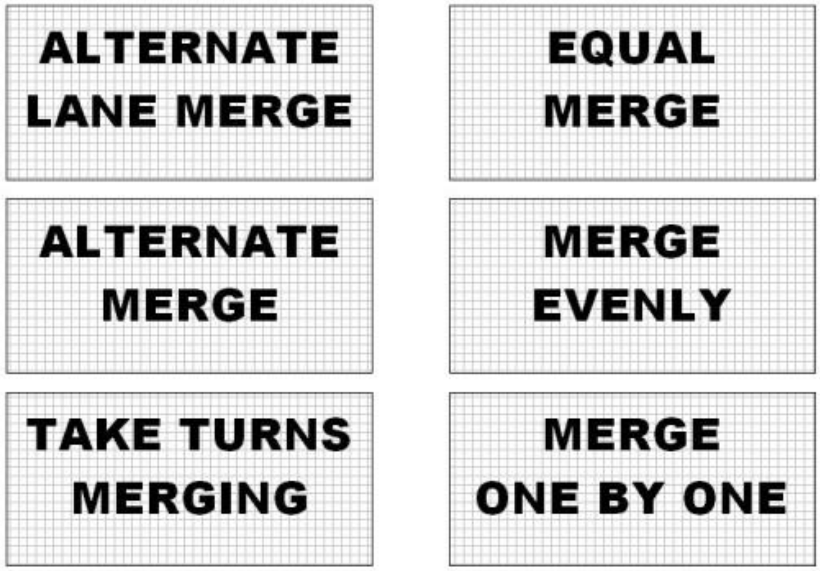
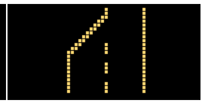
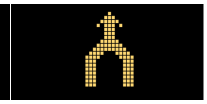
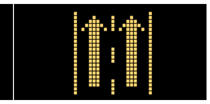
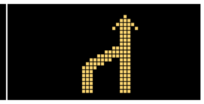
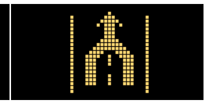
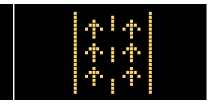
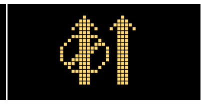
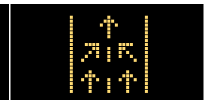
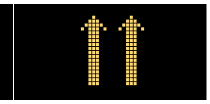


Figure 5. Initial Merge Messages Discussed at RIDOT, Providence, RI

In addition to zip merge, other driving conditions were considered, based on recommendations attained from these meetings at RIDOT in Providence, RI. These driving conditions were noted as situations pertaining to desired driving behavior in or surrounding merging conditions. Hence, the three chosen conditions were referred to as “driving advisory conditions” (DACs). The three DACs are 1) Merge to the right lane, 2) Zip merge, and 3) Continue travel normally. The complete set of messages chosen for inclusion in the questionnaire survey can be seen in Table 1.

Table 1. Messages Used in Questionnaire Survey

DACM	Merge to the Right Lane		Zip Merge		Continue Travel Normally	
	Text	Graphic	Text	Graphic	Text	Graphic
	MERGE RIGHT		TAKE TURNS MERGING		USE BOTH LANES	
	LEFT LANE ENDS		LANES MERGING		STAY IN YOUR LANE	
	LEFT LANE CLOSED		ZIPPER MERGING		TWO LANE TRAFFIC	

To increase participation and completion of the survey, both the number of questions and ease of understanding of the questions were deemed important. Considering this and the study objectives, a nine question survey template was developed that allowed comparison of individual messages with a message type and also the preference towards either text or graphic messages. Three roadway scenarios were written for each DAC and displayed identical for any question pertaining to the same DAC.

The survey was created in Microsoft PowerPoint using a series of slides displaying different combinations of messages. The sequence of questions displayed to participants was 1) Rating three text messages using a 1-5 scale, 2) Rating three graphic messages using a 1-5 scale, and 3) Choosing between the highest rated text and graphic message (Figure 6). This sequence of three questions was repeated for each of the three DACs for a total of nine questions. The complete set of survey slides can be viewed in Appendix A.

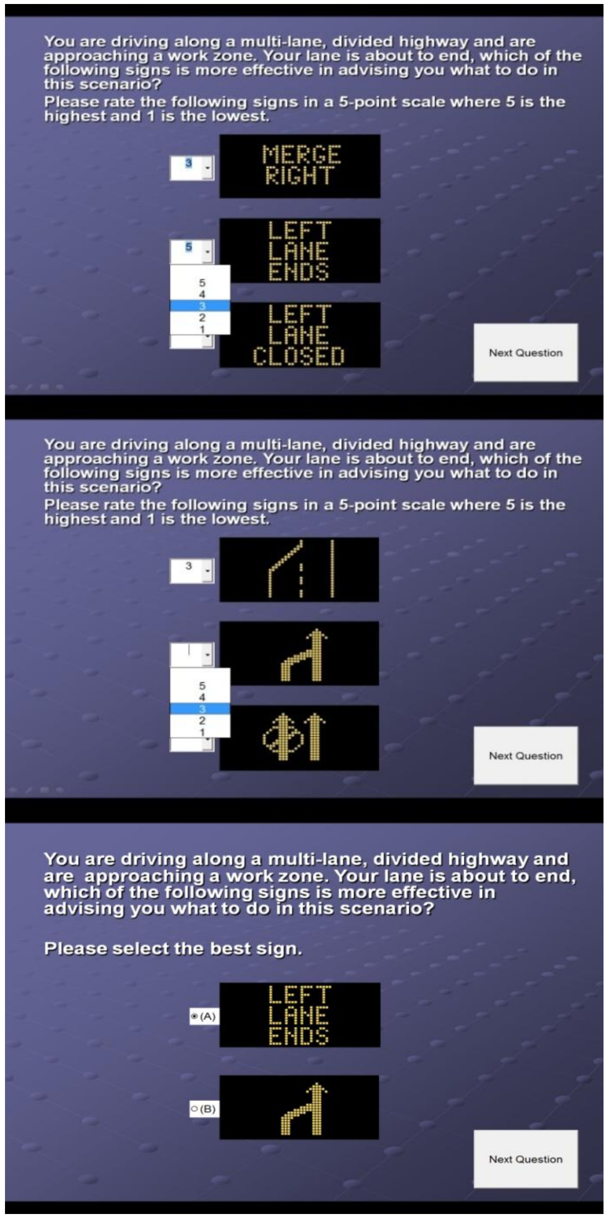


Figure 6. Progression of PowerPoint Slide in Questionnaire Survey

In order for participants to choose between their highest rated text and graphic sign, they would need to be taken to a slide that included their individual selections. With multiple possibilities, Visual Basic macros were enabled as a PowerPoint aid to allow for proper flow from question to question, still maintaining the three questions x three DAC setup. Therefore, a participant was directed to a specific slide based on their particular responses. In PowerPoint, 13 slides were created for each DAC, where participants start on slide 1 and move to one of the slides 2-4 based on their ratings of text messages, then move to one of the slides 5-13 based on their ratings of graphic messages. For a visual depiction of this, see Figure 7.

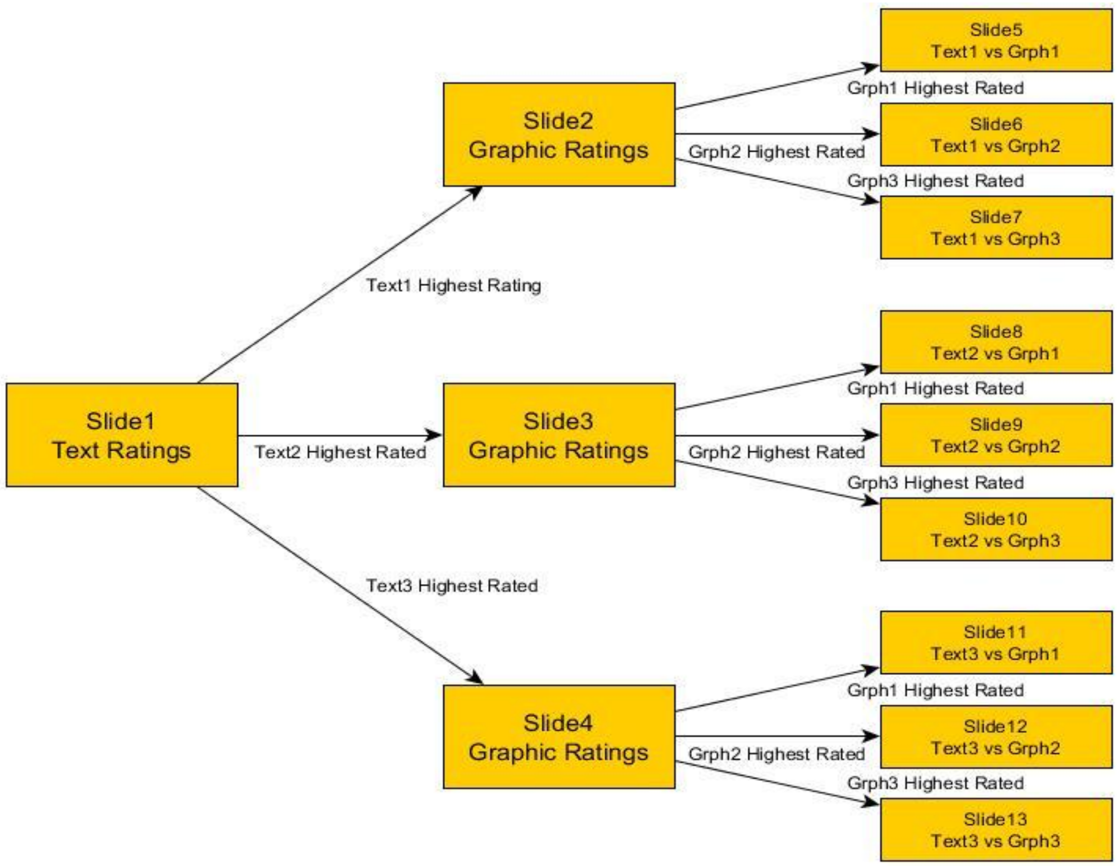


Figure 7. VisualBasic Macros OnClick Command Flow Chart

4.1.2 Conducting the Questionnaire Survey

The electronic questionnaire survey was stored on several laptop computers and taken to a reserved area in the Warwick Mall in Warwick, RI over the course of several days. Participants completed the survey, usually took less than 10 minutes, and would be given a small gift as a token of appreciation. Two to three assistants were present to aid participants. Questions pertaining to the survey were commonly regarding how to give responses or how to operate the system. Because of the wide age range of participants, help was often provided for some older participants who were unfamiliar with using a laptop computer, in which case assistants would be more hands-on with participants. Participants were informed that the survey was completely voluntary and that they were not obligated to finish. This was also included in the introductory PowerPoint slides prior to the questions, as was an acceptance of consent in the form of an electronic signature (approved by the University's Institutional Review Board). As per the IRB application submission, the survey questions were limited to about 5 minutes barring the subject's willingness to complete the survey. Several participants started but did not complete the survey, while others did not utilize click commands as instructed, which caused viewing wrong slides. In these cases, data was removed from the final analysis. Upon completion of the questionnaire survey, subjects were prompted to provide some additional information for organized data storage. Through Visual Basic macros in PowerPoint, subjects' responses were stored in individual notepad files on the laptop. As per the IRB application submission, the following statements were upheld in the data storage procedure. "None of their personal data other than basic demographics will be asked. Responses collected will be kept in a secure computer." Notepad response files were periodically moved to the base desktop computer for safe storing. In addition, when filling out demographic information, subjects were encouraged to use initials or nicknames to replace their actual names if they felt more comfortable doing so.

Although the process of gathering subjects for the survey called for anyone willing to participate, some age range and gender groups were targeted to attain a more even distribution of the basic demographics that were essential to the analysis. Subjects were recruited around the University of Rhode Island Kinston campus to further aid in a more balanced mix of age and gender groups. A total of 81 subjects were included in the final analysis for the questionnaire survey (omitting the insufficient data). Of these 81 subjects, 37 females and 44 males participated in the survey, while 35 were between 18 and 25 years old, 20 between 26 and 40 years old, and 26 were 41 years and older.

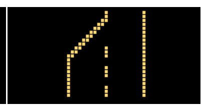
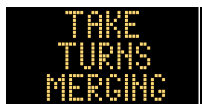
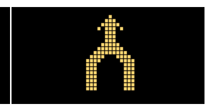
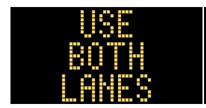
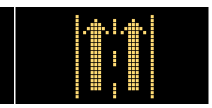
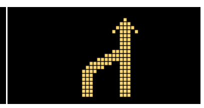
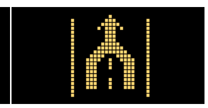
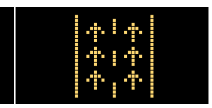
4.2 Driving Simulation Experiment

The driving simulation experiment was developed and conducted after the questionnaire survey. Based on findings from the questionnaire survey and limitations of the driving simulator, certain messages were not included in this part of the study. The driving simulation experiment focused on gaining knowledge on how quickly and accurately different messages can be identified in a simulated driving environment by test drivers. The results of the driving simulation experiment weighed most heavily in making decisions for messages used in the field study.

4.2.1 Design of the Driving Simulation Experiment

The driving simulation experiment was designed to assess the text and graphic messages used in the survey portion of the study, under the same three DACs. Due to time considerations, the lowest rated text and graphic messages from each DAC were not included in the driving simulation. Thus, only two text and two graphic messages were tested for each DAC (Table 2). The driving simulation experiment was designed to test the significance of four factors in two separate analyses. The four factors included DAC and message type (text or graphic), as well as subject age and gender. The two response variables were response time and accuracy of response.

Table 2. Messages Used in Driving Simulation Experiment

DAC	Merge to the Right Lane		Zip Merge		Continue Travel Normally	
M	Text	Graphic	Text	Graphic	Text	Graphic
						
						

The TranSim VS IV Simulator was used in the driving simulation experiment. This is a fixed-base simulator which consists of a regular driving module and three channel plasma monitors in an immersive driving environment that combines the look and feel of a real vehicle. Participants interacted with the simulator using the sedan's steering wheel and pedals that provide real-time feedback. A separate program called "ScenarioBuilder" was used to create desired conditions of the experimenter and delivers sharp visuals and crisp images (Figure 8). All the experiments were completed in the Driving Simulation Laboratory at the University of Rhode Island.

For the driving simulation experiment, there was a more flexible time window per subject than in the survey. Two main reasons for this were the need for fewer subjects in longer experiment duration and the ability to give participants more enticing gifts.

Some participants, students or employees of the university, received the same gifts as those from the survey. Participants recruited from outside of the university received a $20 Walmart gift card.

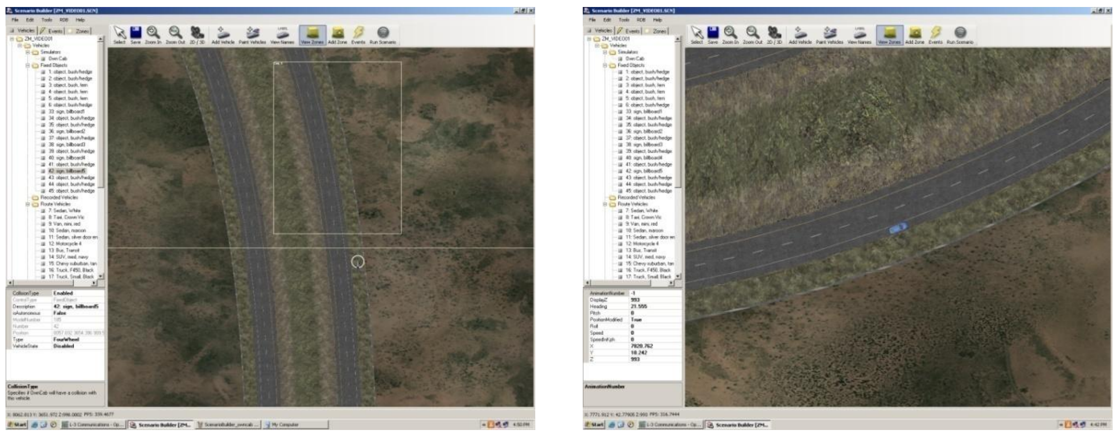


Figure 8. ScenarioBuilder Program Screenshots

The experiment design included both replicated graphic and text messages with one less sign message of each type (lowest rated) for each DAC. This was the due to the consideration that the replication in the experiment was more important than including all the messages assessed in the survey. The design of the simulation experiment was also limited by the driving simulator constraint where only five VMS messages were allowed at each simulation run. This means that after one run is complete, the computer message files must be updated before the next run. To keep a balance in the experiment design, the number of total VMS messages viewed would be a multiple of five. Used as an experimental control, three additional messages (or "dummy" messages) were included (Figure 9) that did not fit any of the three DACs. This totaled 15 VMS messages in the experiment. Each of the VMS messages would be viewed twice in the experiment, making a total of 30 VMS messages to be viewed over the course of six separate runs in the scenario.

A set of six module folders were created to represent the six runs of the experiment, each with five VMS messages (Appendix B). The selection of messages into modules was done randomly, but adjusted if a module was overloaded with a certain message type or DAC. The randomization would lessen the significance of the experiment sequence, especially factoring in the possible presence of a learning effect associated with responding to message signs. For each participant, the six modules were presented in a predetermined, random order.

Figure 9. Dummy Messages used in Driving Simulation Experiment

To minimize possible sources of error in the experiment runs, a straight section of freeway was chosen to display the five consecutive VMS messages in each module. This was chosen to promote focus on the identification and understanding of these messages. Subjects need not merge after reading the sign as it could complicate the analysis of the results by the presence of additional noise factors.

Markers were placed upstream from each VMS position. The first marker was placed at the visual sight distance of the VMS, or where the VMS first came into view, at a distance 2,124 virtual feet. The second marker was placed 1,600 virtual feet before the VMS. The markers were placed to allow the recording of participants' response times during video playback as the duration from reaching the marker to giving a response (Figure 10). Subject responses would be verbal in the form of a number to represent their identification of a particular message (details on subject responses in 4.2.3). Whether the response was correct or incorrect was tied into the analysis for response accuracy and recorded by pencil and paper method, whereas the elapsed time from a start marker to the response was used for the response time analysis and obtained through video capture.

A motorcycle was placed on the right lane in the scenario to pace the speed of the participants' vehicle. Participants were advised to stay on the right lane and travel at a constant speed, not passing the motorcycle. The motorcycle was chosen because it was short enough to not obstruct the participants' view of the VMS messages (Figure 11). Route vehicles were placed on both lanes as well as on the opposite lanes to mimic real driving on a highway.

Figure 10. Driving Simulator Views, left: Driver approaches marker, right: VMS message in view

Figure 11. Driving Simulation Experiment: Motorcycle in front of driver with message sign in view

4.2.2 Conducting the Driving Simulation Experiment

While driving along a freeway in a driving simulator scenario, designed by the ScenarioBuilder program, subjects were asked to verbally respond when identifying a VMS message on the side of the road. Prior to beginning, subjects were provided with a study sheet that closely resembled Table 2, but also gave number designations (1-3) to the different DACs, from left to right in Table 2. The “dummy” messages, not included on the study sheet as physical messages, were given the designation number 4 and described as any messages that don’t apply to the three DACs provided (Figure 12).

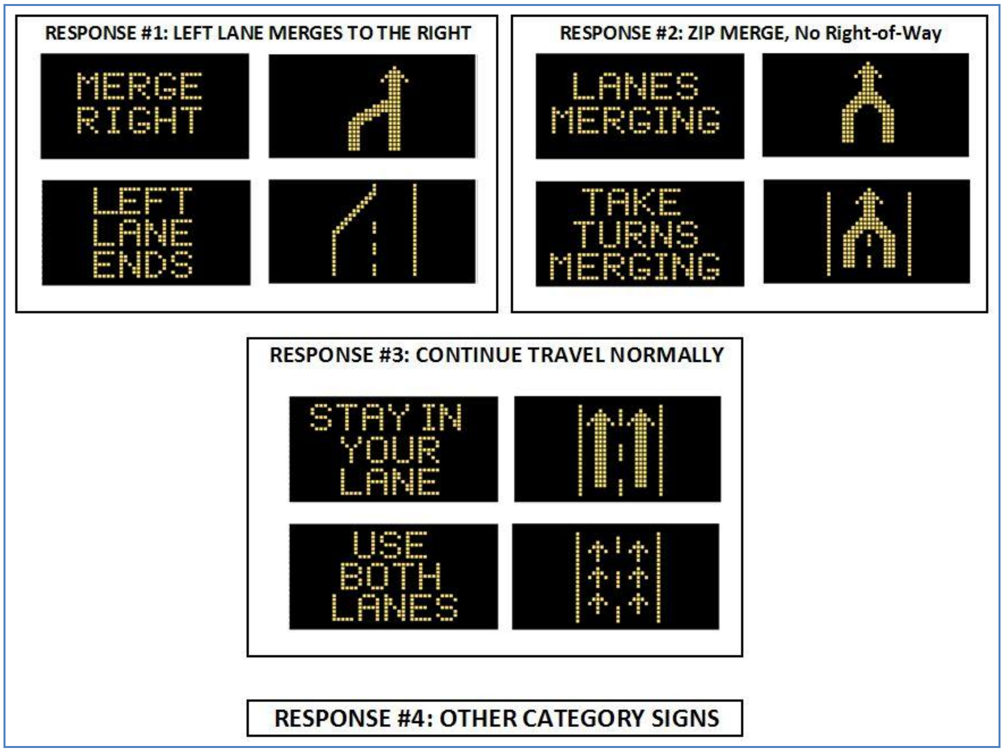


Figure 12. Driving Simulation Experiment: Subject Study Sheet

The study sheet was provided before beginning the driving simulation experiment, and subjects were told they could study the messages until they felt comfortable. Subjects were able to refer to the study sheet at any time except during experiment runs. This reference time included the time between runs (about one minute) needed to update computer files.

Prior to the beginning, a practice scenario was created to get subjects familiar with approaching a VMS message and giving a response. The practice scenario included only one VMS message, representing a "dummy" message with a desired response of "4." The particular message used in the practice scenario was not duplicated in the experiment to ensure no learning effect. Another purpose for the practice scenario was to get subjects familiar with the operation of the driving simulator.

While driving along in the simulator, subjects began parked on the right side of the highway and were prompted to start at their convenience. For each VMS message and the associated recorded response, subjects reached the bush markers and then the VMS. This occurred along the straight section of freeway a total of five times until the five responses were given and recorded. In the time following the fifth response, the scenario was stopped and the time to reference the study sheet began. This process repeated itself until the last VMS message was viewed in the sixth and final module.

To respond to the VMS message appeared in the simulation, subjects were asked to call the number associated with the message verbally at the moment they recognized it. For example, when subjects identified a message representing “merging to the right”, they would verbally call “1.”

Subjects’ responses to messages would be analyzed for time and accuracy to gain insights into drivers’ understanding of the messages. As participants drove in the simulator seat, their response time and accuracy to VMS messages were recorded using a video camera and also pencil and paper for a backup for the actual participant responses. A microphone was used during experiments to minimize the chances of inaudible responses. The video camera was positioned over the left shoulder of subjects sitting in the simulator seat, angled to have all three panels of the driving simulator screen in view. The full setup in the driving simulation lab can be viewed in Figure 13. The divide between the middle and right screen served as the starting point for the timed responses when the roadside marker just came into view of the right side panel. This starting point can be seen in the image to the left in Figure 9.

Figure 13. Driving Simulation Experiment Setup in Driving Performance Lab at URI

4.3 Field Study

As a precursor to the proposed field study, a traffic study was carried out to further investigate the bottleneck issue at lane-reduced work zones and to gain insight into vehicle behavior at merge points. The same roadway section at Interstate-95 near Branch Avenue in Providence, Rhode Island was observed, in the way of video recording from an overpass, on two different days during the same time of day to compare work zone versus non-work zone traffic. Once this was completed, traffic flow and merging vehicles data was counted using one minute time intervals. This traffic study was conducted in preparation for the main portion of the field study, which would compare the conventional MUTCD merge and the proposed portable DLMS configurations.

Recommended messages from the previous two parts of the study were considered in developing the field study aimed to gain insight into traffic flows at merge points in lane-reduced, highway work zones. The field study was to be conducted at the same location on two periods of comparable traffic volume, such as a Tuesday-Thursday combination, as advised by transportation officials aiding in the study. The two periods would provide a comparison of the traditional MUTCD lane-reduced work zone setup against the proposed dynamic lane merging system (DLMS). This comparison would be achieved by analyzing multiple 5-minute samples of video to obtain traffic volume, individual lane volume, merge percentage, while taking into account individual lane maneuvers depending on the number of lanes for a particular location. The DLMS would include the use of a 2-panel LED display board obtained from the Czech Republic. During the time of the field study, a drive through study would be conducted. The drive through study would ask willing motorists to drive through the lane-reduced work zone and comment on their experience afterwards. Additionally, the motorists' eye movements, driving behavior, and the behavior of vehicles in their vicinity would be tracked.

4.3.1 Design and Setup of the Field Study

The field study will be setup over a 2-day span at the same work zone, using the dynamic lane merging system and MUTCD setup on different days. The time frame for each day will be from 7:00-11:00am to gather traffic data for rush hour and non-rush hour times, while also complying with limitations due to third parties. Both the nature of the study and the work involved at the site would provide safety measures and small time windows to conduct the field study. A basic plan for the field study is summarized in Table 3.

Table 3. Basic Setup for 2-Day Field Study

Day	Configuration	Time of Day*
1	MUTCD	Rush Hour (7-9am)
1	MUTCD	Non-Rush Hour (9-11am)
2	DLMS	Rush Hour (7-9am)
2	DLMS	Non-Rush Hour (9-11am)
*The time 7-9am was designated for "Rush Hour" in this study, and is not meant to reflect other definitions of this term.		

The Dynamic Lane Merge System (DLMS) configuration utilizes a 2-panel LED board from the Czech Republic to replace a static MUTCD message, located at 500 feet upstream from the shoulder taper (Figure 14). The traditional MUTCD warning message currently used in Rhode Island is W4-2 (Figure 3), and is shown horizontal to the DLMS in Figure 14. With the exception of other elements of the DLMS (i.e. Truck mounted attenuator) other standards from the MUTCD setup would be unchanged in the proposed DLMS setup.

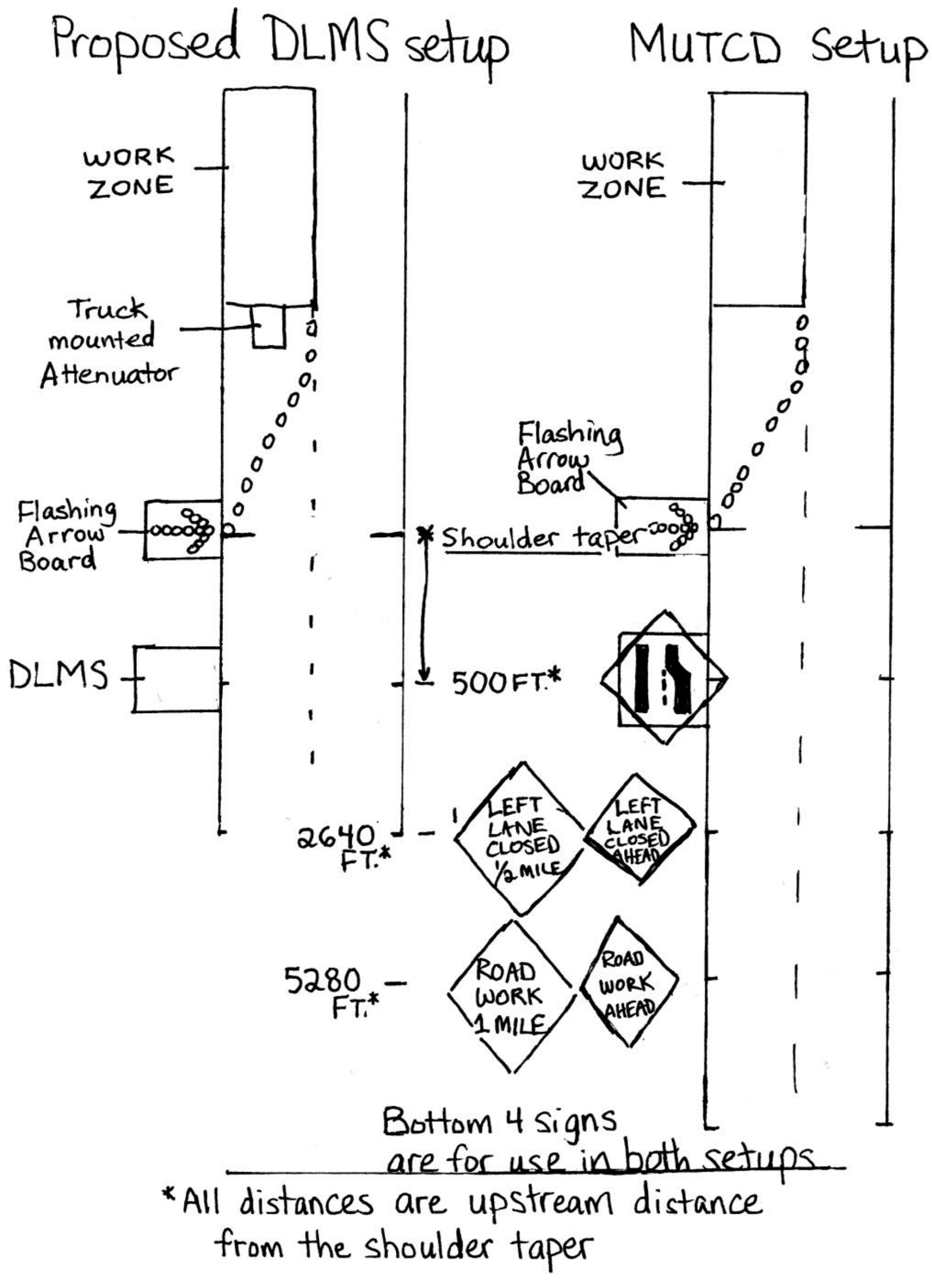


Figure 14. Drawing of Proposed DLMS and Traditional MUTCD Setups

Based on the findings of the questionnaire survey and driving simulation experiment, certain recommendations would be made regarding text and graphic messages and the differences between messages in different DACs. The findings in the

Results section for the survey and simulation led to a clear conclusion regarding the effectiveness of certain graphic messages in merge conditions. From the messages evaluated in previous parts of the study, graphic messages were created in CorelDraw, a program used and suggested by transportation officials at the RIDOT facility at Lincoln Avenue in Warwick, RI, where much of the work on the portable DLMS took place. Figure 15 shows the graphics recommended from the "Merge to the Right Lane" and "Zip Merge" DACs based on the findings of the questionnaire survey and driving simulation. These simple, bold-faced graphics were shown to be effectively understood and easily recognizable.

Figure 16 depicts the graphics created in CorelDraw for the field study, taking into account multiple lane roads and left or right lane closures possible at possible work zone locations. Based on input from transportation officials, a traditional work zone graphic would be used on the upper, and smaller, panel of the 2-panel display. A complete set of messages created for the DLMS unit, in preparation for the field study and future studies, can be seen in Appendix C.

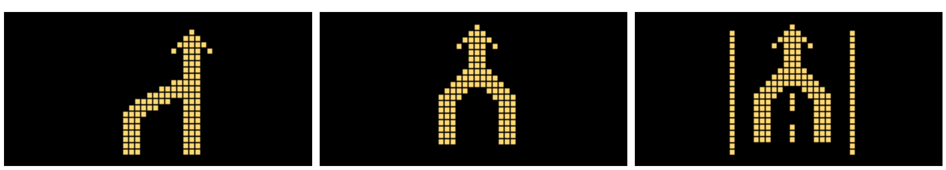
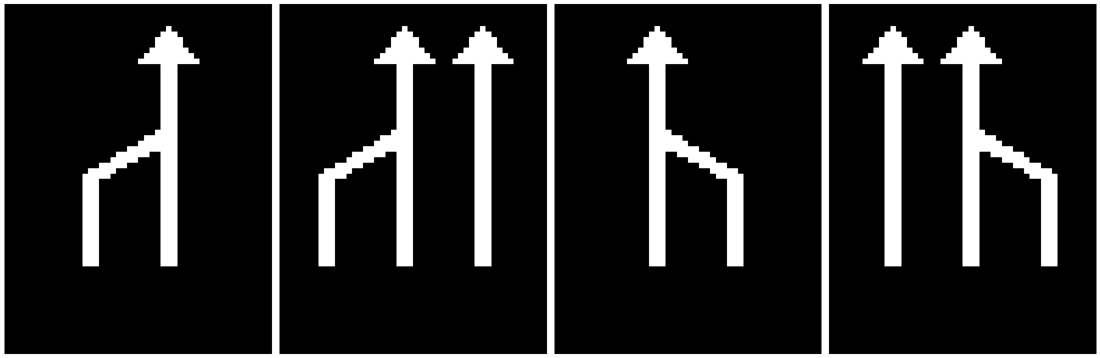
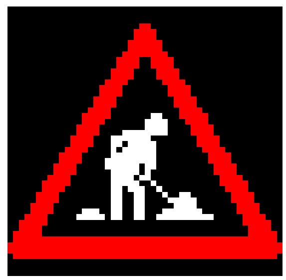


Figure 15. Recommended Messages for use in Applicable Merging Applications



Upper Panel Display



Lower Panel Display

Figure 16. Corel Drawings of Graphic to be used in Field Study

The drive through study aimed to gather 3-4 motorists per hour, and a minimum of 12 for the 4-hour block, to volunteer for participation. Motorists would be gathered prior to entering the work zone at a central location and briefed about the study. A video camera would be setup inside the vehicle to capture eye movements; meanwhile the time of day was recorded to reference easily during video playback. After passing through the work zone, subjects were to return to the central location to provide comments on different aspects of the work zone, focused around the differences between the two different setups. An effort was made to avoid duplication of subjects between the two days, or one subject participating in both work zone setups. This would eliminate any possible bias formed towards one setup or the other among subjects, which is important given that the experiment order could not be randomized (all data on one setup follows all data on the other setup day).

4.3.2 Conducting the Field Study

In conducting the field study, the biggest challenge will be to successfully setup the portable DLMS to be operational during the desired time frame. The setup needs to be done well prior to the beginning of the observational period which would begin at 7:00am. Once setup, the system would need to be activated but not raised. Before the board is raised, it faces upward and is not viewable to oncoming traffic. Dependant on the number of lanes in the freeway and the position of the lane closure, the appropriate graphic would be selected for use on the lower panel (Figure 16). The system would be raised just before 7:00am while a video camera would begin filming at an overpass to capture downstream traffic. The position of the camera and time of video would be consistent on both days of the field study to adequately compare the two setups. The portable DLMS would continue until the four hour duration was complete, at which time the board would be replaced by the MUTCD static sign according to direction by superior officials who were helping with the logistics of the field study.

CHAPTER 5

RESULTS AND DISCUSSION

Three approaches were outlined in the previous chapter as the methodology for this study but only two were completed. The completed parts of this study include the questionnaire survey, which sought out subjects' preferences towards different messages signs, and the driving simulation experiment, which gathered multiple responses towards these messages in a controlled environment. The field study and the drive through study, due to problems with the portable DLMS system, were not completed.

The results and discussion largely focuses on the findings of the questionnaire survey and the driving simulation experiment. The questionnaire survey (5.1) analyzes the ratings of messages based on several factors including subject demographics. The survey also provides an analysis of subjects' preferences towards either text or graphic messages. The driving simulation experiment (5.2) analyzes the responses given by subjects towards VMS messages viewed while driving the simulator. Separate analyses were conducted to analyze the response accuracy and response time of responses. The response accuracy analysis evaluates the amount of correct and incorrect responses by several factors. The response time analysis evaluates how quickly subjects identified the message using the same factors as the response accuracy analysis.

5.1 Questionnaire Survey

Nine questions were presented to participants with six of the questions designed to gather ratings for the individual messages. For each DAC in the questionnaire survey, there were a total of three questions. The first and second questions asked participants to give ratings for text-versus-text and graphic-versus-graphic messages, respectively. The third prompted participants to choose between their highest rated text and graphic signs. The collected data was used in two separate analyses, one for the text-versus-text and graphic-versus graphic ratings of messages, and the second for the text-versus-graphic selection. Appropriate regression analyses were selected and carried out for each of the two data sets.

5.1.1 Ratings for Messages

Participants rated messages on a 1-5 scale in how well they communicated the associated DAC, with 5 being the best. Text messages and graphic messages were presented in separate questions to participants, but message ratings were ultimately independent for each individual message. For both text and graphic message questions pertaining to message ratings, the descriptions of the DAC were kept identical to avoid unwanted error in message ratings. The following descriptions were given for each DAC.

- Merge to the Right → You are driving along a multi-lane, divided highway and are approaching a work zone. Your lane is about to end, which of the following signs is more effective in advising you what to do in this scenario?

- Zip Merge → You are driving along a multi-lane, divided highway and are approaching a work zone. Traffic is to be condensed down to one lane, which of the following signs is more effective in advising you what to do in this scenario?
- Continue Travel Normally → You are driving along a multi-lane, divided highway and are approaching a work zone. Normal traffic flow is to be maintained at this point, which of the following signs is more effective in advising you what to do in this scenario?

The ratings were grouped by several factors, including driving advisory conditions (D), message type (M), age group (A), and gender (G). An initial analysis of variance (ANOVA) was conducted to test the significance of these factors. In addition, the ANOVA is capable of showing interaction between factors. The interaction between D and M (main factors), as well as the interaction between A and G (blocking factors) was investigated using the model below.

$$\boldsymbol{Y} = \boldsymbol{\mu} + \boldsymbol{D} + \boldsymbol{M} + \boldsymbol{D} \times \boldsymbol{M} + \boldsymbol{A} + \boldsymbol{G} + \boldsymbol{A} \times \boldsymbol{G} \qquad (1)$$

From the ANOVA (Table 4), driving advisory condition, message type, and their interaction were found significant but not age or gender. Figure 17 shows the significant factors' effects on message ratings and their interaction.

Table 4. ANOVA Table for Ratings (Range 1 - 5)

Source	DF	SS	MS	F	P
Driving Advisory Condition	2	29.326	14.663	6.96	0.001*
Message Type	1	32.895	32.895	15.61	0.000*
Driving Advisory Condition*Message Type	2	18.597	9.298	4.41	0.012*
Age	2	4.765	2.383	1.13	0.323
Gender	1	1.601	1.601	0.76	0.384
Age*Gender	2	6.691	3.345	1.59	0.205
Error	1447	3048.380	2.107		
Total	1457	3141.946			

* Significant at α= 0.05

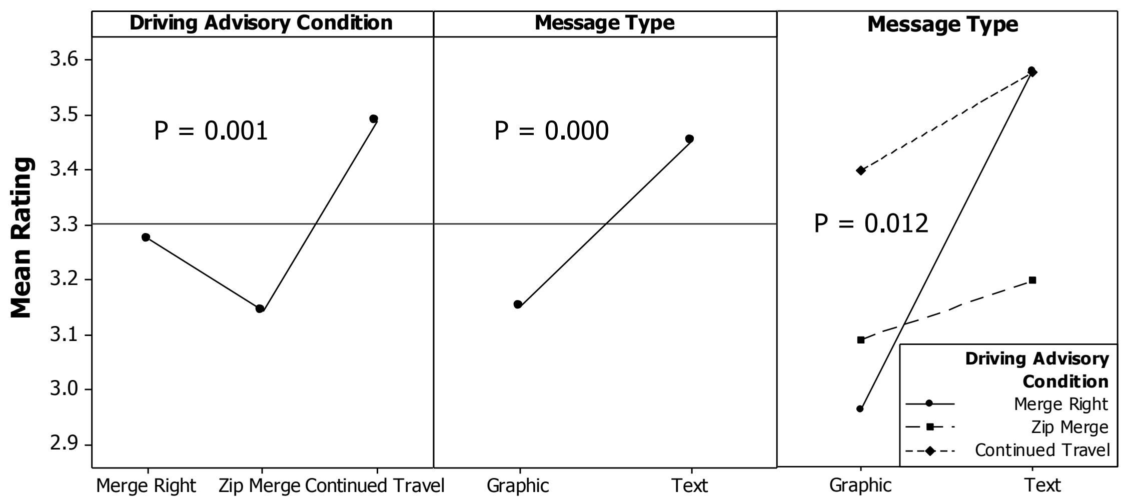


Figure 17. Questionnaire Survey: Main Effects and Interaction for Mean Rating

In the analysis of variance, the “Zip Merge” DAC was found to produce the lowest ratings for messages among the three DACs at 3.14. “Continue Travel Normally” had the highest ratings among the DACs at 3.48, while the “Merge to the Right Lane” DAC had the middle mean rating at 3.26. Text sign messages (3.44 mean rating) had significantly higher ratings than graphic sign messages (3.14 mean rating).

The interaction between DAC and message type shows that the greatest mean rating difference between text and graphic sign messages occurred in the "Merge to the Right Lane" DAC, with ratings of 3.58 for text and 2.96 for graphic sign messages. The "Zip Merge" and "Continue Travel Normally" DACs had less severe differences.

In addition to the ANOVA, the nature of the 1-5 ascending scale of message rating was very well suited using an ordinal logistic regression analysis, with $p(\pi_j)$ is the probability of being at or below rating value j (1-5). The four factors are each given a constant, β_i , pertaining to their predictive capability. Ordinal logistic regression is ideal in situations where responses follow a numerical, ascending scale or categorical data following ranked responses. One example of this would be a survey with opinionated responses of "Strongly Agree, Agree, Indifferent, Disagree, and Strongly Disagree."

$$\ln\left(\frac{p(\pi_j)}{1-p(\pi_j)}\right) = \alpha_{0j} + \beta_1 D + \beta_2 M + \beta_3 A + \beta_4 G \qquad (2)$$

Table 5 shows the ordinal logistic regression output. The goodness-of-fit tests show adequately high p-values for both of the tested methods. The reference levels for this regression are cited in the table, where the coefficients and p-values show comparisons between these levels for each factor. The reference level indicates the level of the factor to compare other levels against, or in other words, the level of the factor of greatest interest. In this case, for DAC, ZM is chosen because it is the DAC of focus for this study, and we are most interested in how these newly introduced messages are rated when compared with other DACs. For age, the oldest age group was selected as a reference level. Either the youngest or oldest age group as a reference level was used throughout logistic regression analyses in this study so that distinctions could be made regarding possible generational differences. With that said, the selection of the age reference level was not considered nearly as important as the DAC reference level. From the regression output, we found that both DAC (D) and message type (M) are significant predictors for message sign rating. The positive coefficients for "Merge to the Right" (MR) and "Continue Travel Normally" (CTN) indicated that "Zip Merge" (ZM) messages obtained significantly lower message ratings when compared with MR and CTN. Conversely, the negative coefficient under message type suggests text messages were rated significantly higher than graphic messages overall.

Table 5. Ordinal Logistic Regression Output for

Questionnaire Survey: Message Ratings

		Coeff	p-value
DAC	MR	0.265	0.021
	CTN	0.408	0.000
	ZM	Reference Level	
Message Type		Coeff	p-value
	Text	Reference Level	
	Graphic	-0.358	0.000
Age		Coeff	p-value
	18-25	Reference Level	
	26-40	-0.011	0.929
	41+	0.162	0.138
Gender		Coeff	p-value
	Female	Reference Level	
	Male	0.082	0.382

Link Function: Logit
Variable: Sign Ratings (1-5 Scale)

		Value	Count
Responses	Worst	1	276
		2	159
		3	318
		4	272
	Best	5	433
		Total	1458

Goodness-of-Fit Tests

Method	Chi-Squared	DF	p-value
Pearson	25.9309	29	0.629
Deviance	30.2912	29	0.400

Using α = 0.05 for significance

5.1.2 Message Type Preference

Three questions in the questionnaire survey, one for each DAC, were designed to determine whether text or graphic messages were preferred. For each DAC, subjects were choosing between one text and one graphic message. Each subject viewed a unique pairing of text and graphic messages based on their rating responses, where their highest rated message for each message type appeared in the text-versus-graphic question. If more than one text or graphic message tied for the top rating score, the message included was determined randomly. Therefore, all the data collected from the message type preference analysis was as a result of the message ratings attained on a subject-by-subject basis. This sequence was made possible by VisualBasic macros using OnClick commands. So, when subjects gave ratings for signs and clicked the "Next" button, the results were stored and the subject was sent to the appropriate next PowerPoint question slide. Errors with the OnClick command were later observed when a small number of subjects used keyboard arrow keys to advance from slide to slide in PowerPoint, which resulting in subjects viewing more questions than intended based on their responses. This data was not included in the final 81 subject data set.

Overall, there was a 79.4% preference towards text over graphic messages among all participant responses in the questionnaire survey. The complete findings on text message preferences can be found in Table 6.

Table 6. Text Message Preferences by Gender, Age, and Driving Advisory Condition

Driving Advisory Condition	Age Group	Female	Male	Overall by Age	Overall
Merge to the Right Lane	18-25	77.8%	76.5%	77.1%	76.5%
	26-40	62.5%	58.3%	60.0%	
	41+	91.7%	85.7%	88.5%	
Zip Merge	18-25	83.3%	76.5%	80.0%	82.7%
	26-40	75.0%	75.0%	75.0%	
	41+	91.7%	92.9%	92.3%	
Continue Travel Normally	18-25	77.8%	76.5%	77.1%	79.0%
	26-40	62.5%	66.7%	65.0%	
	41+	91.7%	92.9%	92.3%	
Overall	18-25	79.6%	76.5%	78.1%	79.4%
	26-40	66.7%	66.7%	66.7%	
	41+	91.7%	90.5%	91.0%	
	Overall	80.7%	78.3%		

A binary logistic regression was performed to analyze the text versus graphic preference responses in the survey, with *p(γ)* representing the probability of choosing a text message. Therefore, a text message choice was given the value "1" and a graphic message choice was given the value "0." The value represents the coefficient for the predictor variables in the following model. Driving advisory condition (*D*), age (*A*) and gender (*G*) were the predictor variables to be analyzed in predicting the probability of a text sign message choice. As in the message ratings logistic regression analysis, ZM is chosen as the reference level for DAC and 41+ is chosen as the reference level for age. A more detailed explanation of chosen reference levels can be found in section 5.1.1.

$$\ln\left(\frac{p(\gamma)}{1-p(\gamma)}\right) = \beta_0 + \beta_1 D + \beta_2 A + \beta_3 G \quad (3)$$

The goodness-of-fit tests shows that the model fits very well with the data set (Table 7), which is more predictable in the binary case when compared to the ordinal logistic regression fit. The output shows that age was the only significant factor among tested factors to influence text preference, where the 41+ age group showed a significantly stronger text preference compared to the other groups. However, age did not correlate with text preference, as the 18-25 age group had a slightly greater preference towards text messages than the 26-40 age group. There seemed to be no effect on message type preference as a result of gender. Similarly, the different DACs did not seem to impact participants' preferences of either text or graphic messages. A small sample of six non-native English speakers showed a less significant difference in preference of 61.1% text and 38.9% graphic messages.

Table 7. Binary Logistic Regression Output for

Questionnaire Survey: Message Type Preference

		Coeff	p-value
DAC	MR	-0.151	0.697
	ZM	Reference Level	
	CTN	0.252	0.539
Age		Coeff	p-value
	18-25	-1.055	0.022
	26-40	-1.624	0.001
	41+	Reference Level	
Gender		Coeff	p-value
	Female	Reference Level	
	Male	-0.115	0.727

Link Function: Logit Variable: Text Preference			
Responses		Value	Count
	Text	1	193
	Graphic	0	50
		Total	243
Goodness-of-Fit Tests			
Method	Chi-Squared	DF	p-value
Pearson	0.9570	12	1.000
Deviance	0.9458	12	1.000
Hosmer-Lemeshow	0.3005	6	0.999

Using = 0.05 for significance

5.2 Driving Simulation Experiment

Six modules with five messages each were created for the driving simulation experiment. Response time for each message was recorded as the duration from subject's vehicle reached the second marker until a verbal response was given. As noted, a visual sight distance for the signs was selected so that responses could not be made prior to the starting point, producing absent data.

5.2.1 Mean Response Time

Analyzing mean response time allowed for an analysis of variance (ANOVA). The same factors used in the questionnaire survey analyses were used in the ANOVA. The ANOVA allowed a definitive analysis of the possible interaction between factors affecting the quantitative response variable being a mean time. The interaction of the factors driving advisory condition and message type (*D* and *M*) was analyzed to indicate if the speed of responses is affected by a combination of these factors. With 3 DACs and 2 message types, six combinations could be analyzed to interpret any existing interaction. In addition, the blocking factors of age group and gender (*A* and *G*) were observed for interaction effects, giving six combinations for the blocking factors.

$$\boldsymbol{Y = \mu + D + M + D \times M + A + G + A \times G} \qquad (3)$$

Interaction can only be relevant if the factors involved in the interaction were considered significant in influencing the response variable. In the response time ANOVA, all four factors and both interactions were found to be significant with p-values near zero. Table 8 shows the ANOVA table of the factors' effects and their interactions on response time. Figure 18 represents the data in the main effects' and interactions' plots.

Table 8. ANOVA Table for Driving Simulation: Mean Response Time (sec)

Source	DF	SS	MS	F	P
Driving Advisory Condition	2	225.74	112.87	16.55	0.000*
Message Type	1	2086.34	2086.34	305.92	0.000*
Driving Advisory Condition*Message Type	2	441.24	220.62	32.35	0.000*
Age	2	1680.78	840.39	123.22	0.000*
Gender	1	273.75	273.75	40.14	0.000*
Age*Gender	2	243.66	121.83	17.86	0.000*
Error	853	5817.44	6.82		
Total	863	10768.94			

* Significant at α= 0.05

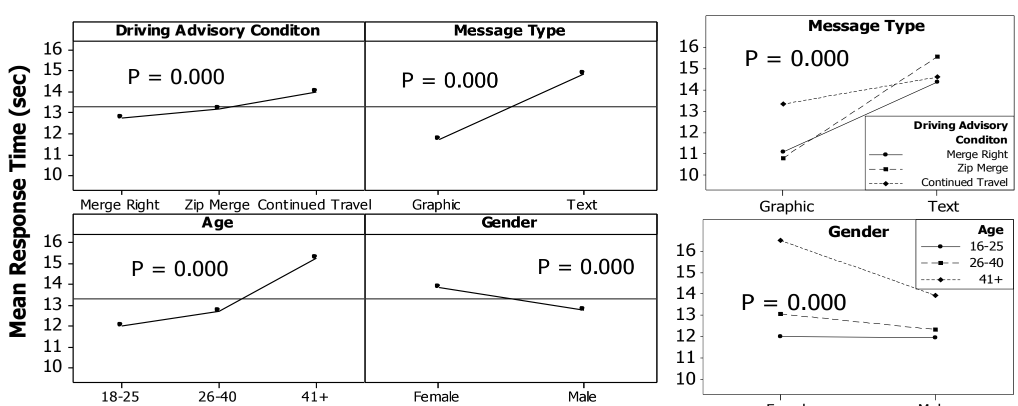


Figure 18. Main Effects and Interaction Plots for

Driving Simulation: Mean Response Time

Participants responded the quickest to the "Merge to the Right Lane" messages among all the DACs at an average of 12.74 seconds. "Zip Merge" and "Continue Travel Normally" messages had average response times of 13.18 and 13.97 seconds. Among all tested factors, message type showed the most significance. Graphic messages were responded to much quicker than text messages (11.74 versus 14.85 seconds), and this was true for each individual DAC. For the "Merge to the Right Lane" DAC, graphic sign messages yielded an average response time of 11.10 seconds, whereas text sign messages yielded responses of 14.38 seconds. In the "Zip Merge" DAC, graphic and text sign messages showed response times of 10.80 and 15.56, respectively, the greatest split between graphic and text sign message response times for any DAC. In the "Continue Travel Normally" DAC, graphic and text sign messages response times showed the least significant difference at 13.34 and 14.61 seconds.

As participant age increased, so did participant response times. The 18-25, 26-40 and 41+ age ranges had average response times of 11.97, 12.69 and 15.23 seconds, respectively. Males responded quicker at an average of 12.7 seconds versus females at 13.9 seconds. Considering the age and gender interaction, 18-25 year old male and females showed similar response times of 11.9 and 12.0 seconds, respectively. As participants' ages increased, the response time gap widened between males and females. Males in the 26-40 age range showed response times averaging 12.33 seconds, whereas females in the same age range yielded responses of 13.06 seconds. In the 41+ age range, males had an average response time of 13.94 seconds, and females showed a significantly longer average response time of 16.52 seconds.

For the driving simulation response time analysis, a possible learning curve was investigated that could lead to faster response times as the subject became increasingly familiar with the process of making responses and message memory. It is likely that the memory of messages would be mostly attributed to the second viewing of a particular message, as each message was viewed twice. The randomness of modules for different subjects highly limited a possible learning curve effect on the response time associated with a particular message or group of messages. As noted in the Methodology section, message type and message DAC designation for messages within a module was completely randomized. The method of randomization greatly would reduce any error associated with subject familiarity gained through the process of the 30-minute experiment and from quicker responses to messages viewed the second time around. The messages contained in each module for the driving simulation experiment can be seen in Appendix B. A further randomization was done by randomizing which order modules were presented, 1-6. The sheet of module viewing order by subject is included as Appendix D.

The first element of the learning curve analysis shows the experiment sequence versus the average response time. For the 12 messages displayed twice each, there were 24 messages viewed per subject for the analysis.

Each data point in Figure 19 represents the average of all 36 subjects' timed responses for a given experiment number. So, the point on the far left denotes a slow average response time by subjects in the first message they observe in the driving simulation experiment. Overall, there is an observable pattern based on ascending experiment sequence and a slightly decreasing average response time.

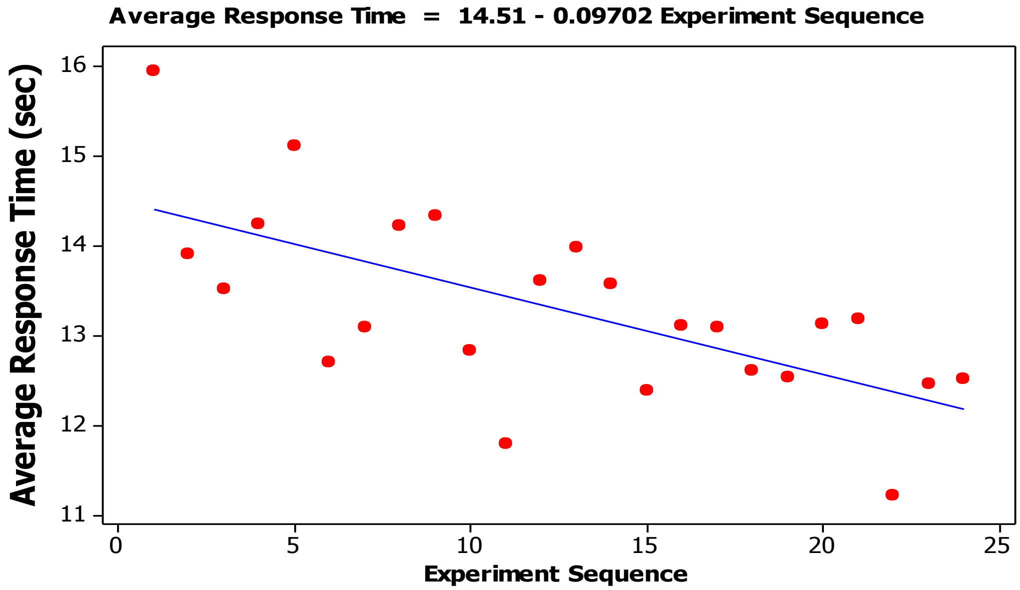


Figure 19. Fitted Line Plot for Possible Presence of Learning Curve in Driving Simulation Experiment: Mean Response Time by Experiment Sequence

A learning curve analysis was conducted for individual subjects in the experiment using regression analysis. Table 9 shows the R-squared values for the regression, and notes if the p-value for each subject indicated a significant learning curve for that subject throughout their 24 responses to messages in the three DACs.

Table 9. Regression Analysis Output on Possible Learning Curve on Individual Subjects in Driving Simulation Experiment for Mean Response Time

Subject	1	2	3	4	5	6	7	8	9	10	11	12
Significance	m	X	X		X	X	X		X			X
R_Square (%)	14.20	21.94	24.88	7.65	34.10	23.43	20.80	11.09	27.47	0.25	0.08	35.26

Subject	13	14	15	16	17	18	19	20	21	22	23	24
Significance	m	X				m	X					
R_Square (%)	13.78	17.97	2.78	3.87	9.96	13.14	32.8	7.07	1.31	7.42	5.29	7.99

Subject	25	26	27	28	29	30	31	32	33	34	35	36
Significance					X	m						
R_Square (%)	8.29	0.02	0.51	1.17	16.95	12.64	4.53	9.00	1.41	4.63	5.24	6.08

X: Significance in regression, m: marginally significant, $\alpha = 0.05$

An α value of 0.05 was used for significance determination in Table 9, where an X denotes a subject that had a p-value of less than 0.05 in their individual regression, throughout the duration of the experiment, and m denotes a subject showing marginal significance. A total of 10 out of 36 subjects showed significance in regression, indicating their own regression slope does not equal zero, while 4 more subjects showed marginal significance. However, low R-Square values indicate a poor correlation between the decrease in response time and the experiment order. The R-square values drive the conclusion that no significant learning curve is present in the response time analysis, because of the lack of a meaningful correlation.

5.2.2 Message Identification Accuracy

In the driving simulation experiment, it was necessary to determine how accurately subjects identified a particular message with its designated DAC. A message may be easily visible and produce quick response times, but may be confusing in its content. The recorded responses during the driving simulation experiment would help to understand the effectiveness of each message in conveying the desired message by analyzing the accuracy of responses by the subjects.

While the better analysis method for correct and incorrect responses is binary logistic regression (included), an ANOVA was conducted to show interactions between the factors D and M, as well as interaction between A and G in the following model.

$$\boldsymbol{Y} = \boldsymbol{\mu} + \boldsymbol{D} + \boldsymbol{M} + \boldsymbol{D} \times \boldsymbol{M} + \boldsymbol{A} + \boldsymbol{G} + \boldsymbol{A} \times \boldsymbol{G} \quad (4)$$

The accuracy of responses was analyzed using the same model as response time. The ANOVA (Table 10) shows that the main factors of driving advisory condition and message type were found to be significant in effecting participants' response accuracy, as was the interaction between these two factors. Gender was also found significant, while age was not. The significant factors' effects and their interaction on response accuracy can be seen in Figure 20. The accuracy level denotes the rate at which participants responded correctly in associating a message with its DAC.

Participants responded more accurately to graphic sign messages (97.22%) as opposed to text sign messages (89.81%). The "Zip Merge" messages received the lowest accuracy (89.24%) compared to the other two DACs (95.49% and 95.83%). The interaction between DAC and message type shows a wide margin for accuracy between graphic and text sign messages in the "Zip Merge" DAC. Graphic sign messages in this DAC had a participant response accuracy of 95.83% versus 82.64%

to text sign messages. The three age groups showed no significant differences in their response accuracy levels, whereas females responded more accurately than males, 96.53% versus 90.51%.

Table 10. ANOVA Table for Response Accuracy (%)

Source	DF	SS	MS	F	P
Driving Advisory Condition	2	0.79398	0.39699	6.89	0.001*
Message Type	1	1.18519	1.18519	20.56	0.000*
Driving Advisory Condition*Message Type	2	0.37731	0.18866	3.27	0.038*
Age	2	0.04398	0.02199	0.38	0.683
Gender	1	0.78241	0.78241	13.57	0.000*
Age*Gender	2	0.01620	0.00810	0.14	0.869
Error	853	49.17130	0.05765		
Total	863	52.37037			

* Significant at α= 0.05

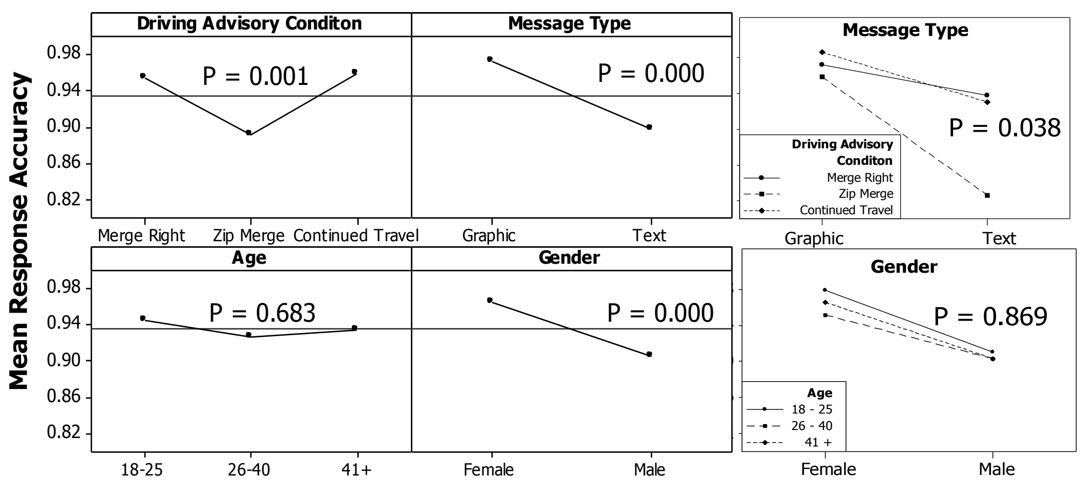


Figure 19. Main effects, blocking effects, and interactions for mean response accuracy

The accuracy of responses was further analyzed using binary logistic regression in the following model, with *p(γ)* representing the probability of a correct response, and the factors of driving advisory condition (*D*), message type (*M*), age (*A*) and gender (*G*). Binary logistic regression was chosen, because it is typically more effective when a binary response exists (Correct, Incorrect). Perhaps the most important distinction for binary logistic regression over the use of ANOVA, or even binary linear regression, is that there is no assumption of normality; the normality assumption cannot be justified in a binary data set.

$$\ln\left(\frac{p(\gamma)}{1-p(\gamma)}\right) = \beta_0 + \beta_1 D + \beta_2 M + \beta_3 A + \beta_4 G \quad (5)$$

The factors are each given a coefficient, β_i , based on the factor's ability to predict an accurate response "1" versus an inaccurate response "0." Table 11 shows that the goodness-of-fit tests show that the binary regression model for response accuracy is adequate, with sufficiently high p-values. Table 11 also shows the significance of the levels of factors given the chosen reference levels. ZM is chosen as the reference level for DAC and 41+ is chosen as the reference level for age, consistent with the various logistic regression analyses from the questionnaire survey portion of the study. Age was the only factor not found to be a significant predictor of response accuracy. DAC, message type and gender were considered significant with message type being the greatest single predictor of response accuracy by coefficient.

Table 11. Binary Logistic Regression Output for

Driving Simulation: Response Accuracy

		Coeff	p-value
DAC	MR	0.985	0.005
	ZM	Reference Level	
	CTN	1.072	0.003
Message Type		Coeff	p-value
	Text	Reference Level	
	Graphic	-1.424	0.000
Age		Coeff	p-value
	18-25	0.195	0.59
	26-40	-0.115	0.734
	41+	Reference Level	
Gender		Coeff	p-value
	Female	Reference Level	
	Male	-1.117	0.000

Link Function: Logit
Variable: Correct Responses

Responses		Value	Count
	Correct	1	808
	Incorrect	0	56
		Total	864

Goodness-of-Fit Tests			
Method	Chi-Squared	DF	p-value
Pearson	25.9309	29	0.629
Deviance	30.2912	29	0.400
Hosmer-Lemeshow	1.4189	7	0.985

Using = 0.05 for significance

Graphic messages resulted in a significantly greater accuracy than text messages. When evaluating DACs, zip merge messages elicited much lower accuracy than either of the other two DACs. Upon further inspection, much of this lower accuracy was due to the response made to the zip merge-text message, whereas zip merge-graphic messages produced a similar accuracy as graphic messages in the other two DACs. Females responded more accurately than males in the driving simulation, despite males responding more quickly in the response time analysis.

5.2.3 Unusual Observations

A number of subjects also showed one or more of the following behavioral patterns that compromised the integrity of the results, and were subsequently removed from the final data set.

- Subjects had significant issues operating the simulator. Subjects moving in and out of lanes, unable to control the vehicle, became a major distraction in viewing signs.
- Subjects were unable to maintain a constant speed, despite instructions to do so and inputs to the scenario design. Subjects had unusually slow response times due to travelling at a very low speed.
- Subjects showed disinterest or declining interest in performing the study.
- Subjects were unable to finish due to motion sickness induced by the simulator screens, which is rare but a real concern.
- It became clear that the gift card incentive was the overriding motivation for participation, and the subject did not take instructions seriously.

The greatest portion of unusual observations was due to unusually quick response times for the individual messages: MR row 2 graphic and ZM rows 1 and 2 graphics (Table 2). This data was kept for inclusion in the analysis because it was recurrent and was shown to be attributed to the individual messages more so than any other predictors for response time.

Another contributor to unusual observations occurred when subjects drove much slower than the average subject but did so consistently, producing many of their observations to be noted unusual. In these cases, data was kept for inclusion in the analysis as long as subject response times were mostly <20 seconds. While there was an obvious variation between response times per subject, an effort was made to keep the majority of responses within the range between 5-20 seconds, consistent with the complete data set. Although subjects were instructed to aim for constant 65 miles per hour travel, there is a reasonable expectation that certain subjects would be uncomfortable reaching that speed. Once again, this allowance was not applicable to speeding drivers, since a constant speed of >70 miles per hour would force a pattern of speed ups and slowdowns due to the leading motorcycle that was included to monitor subject speed. In the >70 mile per hour case, constant speed was hopeless, whereas at lesser speeds the motorcycle speed served as a normalizing effect to subjects who were not constantly aware of minor speed changes.

5.3 Field Study

A traffic study on I-95 at Branch Avenue in Providence, RI was conducted to further analyze the bottleneck issue at freeway work zone lane closures. To do this, traffic volume and vehicle behavior was observed at this location of I-95 at the South overpass on two separate mornings in October 2011 and January 2012. On the first day, the MUTCD conventional lane-reduced work zone configuration was observed whereas the second day there was no work zone and no lane closures. At this location, the usual 3 lanes were reduced to 2 with a right lane closure due to the work zone. Using collected data from similar daily time windows (from about 10-11am), it was estimated that the traffic volume for the lane-reduced work zone in the MUTCD setup was 3564 vehicles per hour, compared to 3108 vehicles per hour at normal conditions.

When factoring in the open lanes in each of these estimates, that is 1782vphpl (vehicles per hour per lane) with the work zone and one lane closure versus 1036vphpl with no lane closures. Table 12 shows the comparison of 1-minute vehicle flows during the same 10-minute window on the two observation days. Table 13 shows a more detailed depiction of the 10-minute window for the work zone observation.

Table 12. One-minute Average Vehicle Flows by Lane,

I-95 @ Branch Ave Observation Study

	Left Lane	Middle Lane	Right Lane	Total
Non Work Zone	13.5	19.5	18.8	51.8
Work Zone	22.9	36.4	X	59.4
All values are vehicles per minute per lane				

Table 13. 10-minute Observation of Vehicles Merging from Closed Lane,

I-95 @ Branch Ave Observation Study (Work Zone)

Interval	Total Vehicles	From Closed Lane	Merge Rate
0-1m	68	15	22.06%
1-2m	59	13	22.03%
2-3m	62	15	24.19%
3-4m	54	11	20.37%
4-5m	38	10	26.32%
5-6m	60	12	20.00%
6-7m	82	20	24.39%
7-8m	52	14	26.92%
8-9m	54	12	22.22%
9-10m	65	15	23.08%

The merging vehicles from the closed lane to the middle lane accounted for the vast majority of vehicle movement, as one might expect. The merge rate calculates the percentage of vehicles passing through the work zone that are forced to change lanes. This is between 20-27% in any 1-minute interval. The information obtained through this traffic study can be further developed with a successful field study that tests a portable DLMS unit against the data found for the MUTCD setup for work zone merging.

The field study, as outlined, could not be completed due to unforeseeable issues with the portable DLMS unit, despite considerable effort put forth in understanding the system to make it consistently operational. Many of the ongoing problems were due to differences in materials and methods used in the Czech Republic as compared to the United States. Ongoing issues included blown fuses due to misunderstanding of system maintenance, misunderstanding of how to successfully charge the battery of the system, delayed fuel shipments, lack of detail in operational manuals and insufficient equipment to “Americanize” or work with unfamiliar wires and outlets.

On the day chosen for the portable DLMS setup, the field study was ready to be conducted at the same Interstate-95 location used in the traffic study. Upon positioning the unit at the designated location, a charge was blown, presumably, and the system never recovered. Since that time, a decision was made to “Americanize” the system for ease of use in the future. Because of the delay, the field study could not be completed in the time frame allotted, and future plans for continuing study have been put on hold, temporarily.

5.4 Discussion of Findings

Participants showed an almost 4-to-1 preference towards text as opposed to graphic sign messages in the survey, but responded much faster and more accurately to graphic sign messages in the simulation experiment. These results may reflect the unlimited time available to participants when conducting the survey, whereas time was limited in the driving simulation. In addition, participants' preferences towards text sign messages may be influenced by a built-in bias due to the majority of current signage being text-based.

In the survey, the "Zip Merge" DAC messages received the lowest ratings. In the driving simulation experiment, "Zip Merge" text messages were responded to the slowest and with the lowest accuracy, but the "Zip Merge" graphic messages were responded to the quickest among all the combinations of DACs and message type, while having a comparable accuracy level to other graphic DAC messages.

In the simulation alone, participants responded much quicker and far more accurate to graphic messages than text messages. The effect of message type was most evident in the "Zip Merge" DAC, where graphic messages were responded to much more quickly and much more accurately than text messages.

While males responded quicker than females, females responded more accurately. Age was found to be significant for response time, but was not significant in participants' accuracy in identifying messages.

A possible source of error for comparing the results between survey and simulation lays in the visual message displays. In the survey portion, subjects were informed that the duration should be about five minutes, but were left alone to take as long as they wanted to complete their answers. In the driving simulation experiment, messages were viewed in a time frame dependant on the subject's vehicle speed. In essence, survey messages on a computer screen being viewed over an unconstrained time period were compared to simulation messages that were viewed while driving. The likeness of a driving simulator to real world driving is a major reason why the driving simulation experiment results should be held with greater weight than the survey results. These results lead to the hypothesis of improved traffic merging patterns at lane-reduced work zones using the proposed DLMS setup. The dual panel display board will be capable of displaying the recommended graphic messages shown effective in the driving simulation as well as the construction worker (Figure 15) in the upper panel message to aid in driver understanding. This hypothesis is based on the work of past studies cited that have shown individual messages can have significant effects on driver behavior.

While the limited time aspect is embedded into the driving simulation experiment design, there can be investigations into driving simulator screens as to whether it may be easier to identify graphic over text messages due to the complex nature of many lines for text messages. Identification may also be explained by the need for more of a spread in dimensions typically with text messages, which has defined a one-pixel thickness in standardized lettering, whereas graphic messages typically have the ability to be created with a greater thickness.

CHAPTER 6

CONCLUSION

Through literature review, it became clear that the use of a portable DLMS has been proven effective in different merging situations involving high speeds. With the inclusion of the 2-panel LED board display in the proposed configuration, the positive results for graphic messages, noted in past studies, allowed for a successful follow up with evaluating experimental graphic messages to make recommendations for message inclusion in this multi-part study.

Through a collaborative effort, experimental and prior existing sign messages were chosen for inclusion in this study as stated in the Research Objectives. Furthermore, some experimental sign messages have been successfully shown to be effective in eliciting the desired response from drivers. The development of the separate driving advisory conditions (DACs) allowed structured evaluation of different factors and individual sign messages.

The survey and simulation portion identifies effective messages that could be displayed on portable VMSs to help mitigate bottleneck issues observed at work zones. The survey results showed that most of participants preferred text sign messages. The driving simulation experiment revealed, however, drivers responded far more quickly and accurately to graphic messages. As the driving simulation experiment was designed to mimic real life driving, without the added safety risks associated, it should be held at a higher weight than the survey findings.

The results showing graphic messages' effectiveness were most supported by the proposed "Zip Merge" DAC, where graphic messages outperformed text messages. This is an indication that graphic messages are more effective in painting the picture in drivers' minds as to how they should behave in unfamiliar driving conditions, and future study may investigate the effectiveness of text versus graphic sign messages for newly introduced driving conditions and the support of the assumption that many people may be visual learners.

The results lead to recommend the use of graphic sign messages in work zones, to mitigate the bottleneck issue, under the three tested work zone DACs of "Merge to the Right Lane," "Zip Merge" and "Continue Travel Normally." The optimal configuration at lane-reduced work zones may include multiple or multi-frame messages including a simple, non-confusing text sign message to aid the graphic message to convey the intended behavior and reduce traffic congestion.

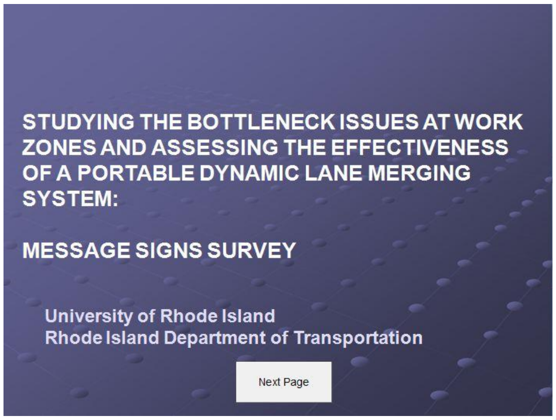
The higher text message preference in the survey and the faster graphic message response in the simulation are worth much attention. This, with the added result of zip merge-text combinations being so unidentifiable in simulation, leads belief of a comfort zone existing with a text bias. This would be further supported by the notion that text sign messages contribute to the greater majority of road advisory signs in Rhode Island today. Zip merging concepts is widely unknown and has not been formally introduced to the public. With the graphic messages having superior results to text messages, it can be speculated that over time, with introduction and implementation, the proposed zip merge messages and other graphic messages may alter the public's preferences towards sign messages.

A possible shift in preference is supported by results in the survey showing the greatest text bias observed in the oldest age group, where age showed to be the only significant predictor of preference. There may be future studies investigating how experimental advisory messages be implemented into real world application, given the superior results shown by graphic messages over text messages in the Zip Merge DAC. The simple and bold-faced graphics seemed to perform the best among all DACs when evaluating individual message performance. This is also worth continued study to gain an understanding of how certain graphic messages are perceived instantaneously upon first glance.

The most effective graphics were to be displayed on the portable DLMS as part of the field study. However, lingering issues with this unit made it impossible to conduct the outlined field study and associated drive through study. If this unit is operational in the future, there can be further study into how animated images either simplify or complicate drivers' understanding of the desired driving behavior, because of the unit's capability to display multiple frames.

APPENDICES

Appendix A. Complete Set of Questionnaire Survey PowerPoint Slides for use with VisualBasic Macros



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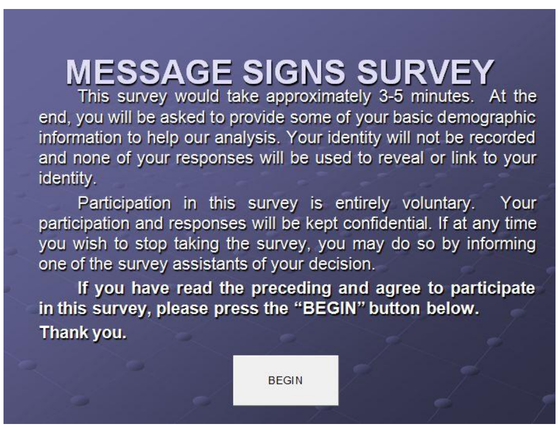
Slide 2



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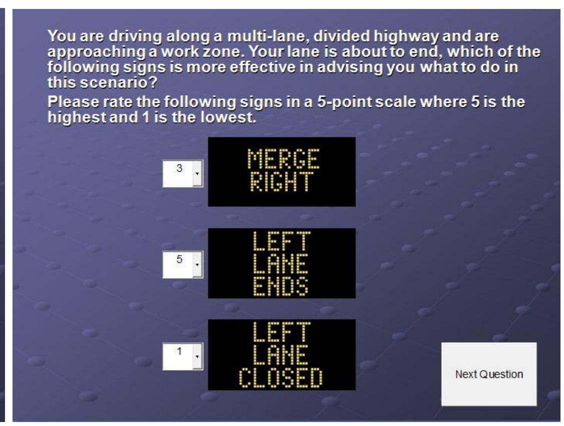

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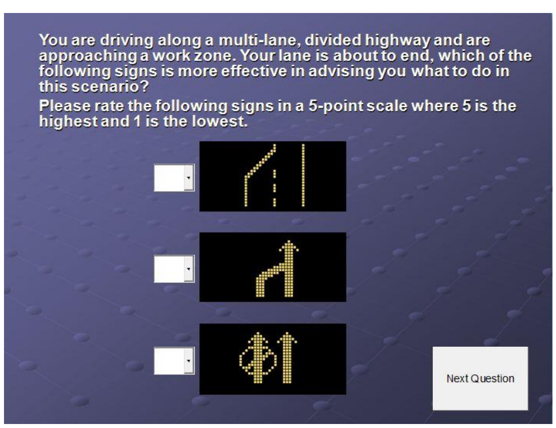

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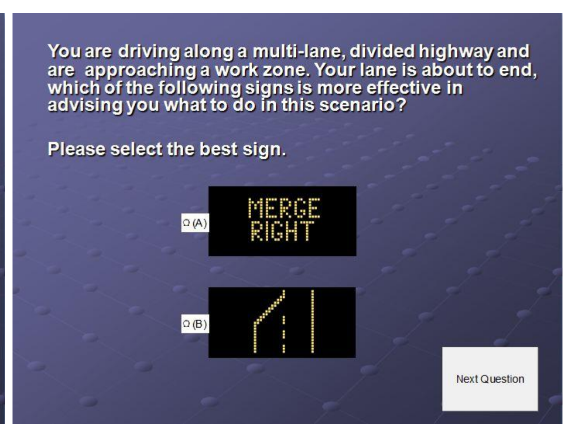

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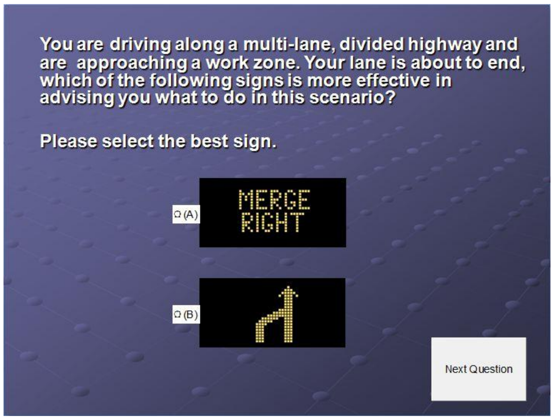

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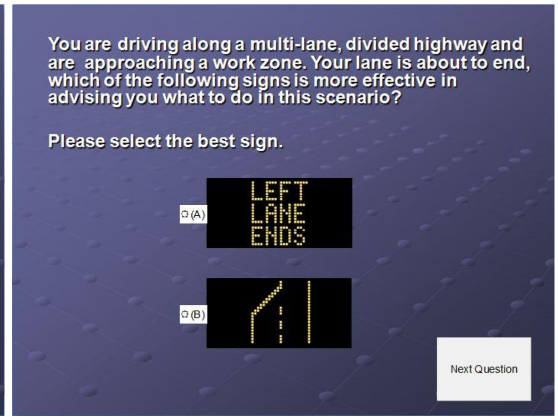

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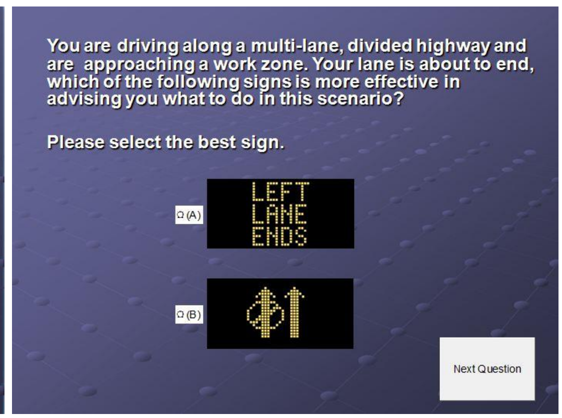
Slide 11



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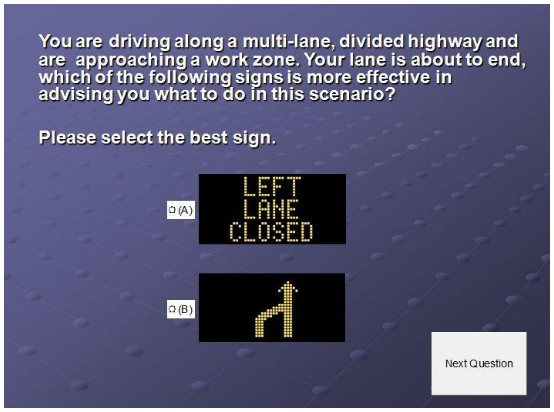
Slide 13

Slide 14



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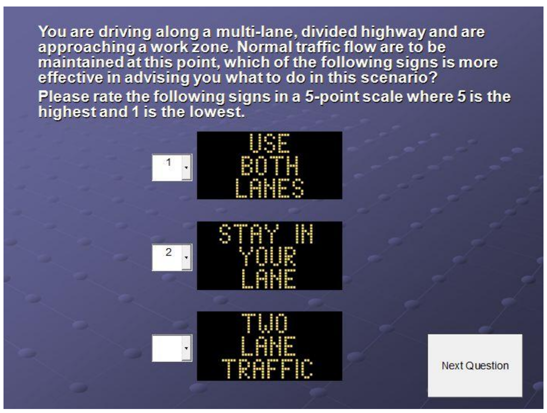

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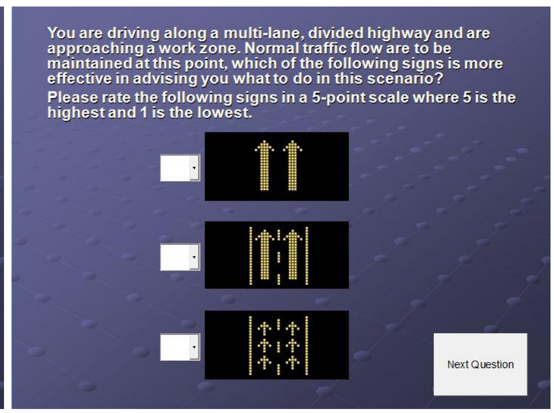

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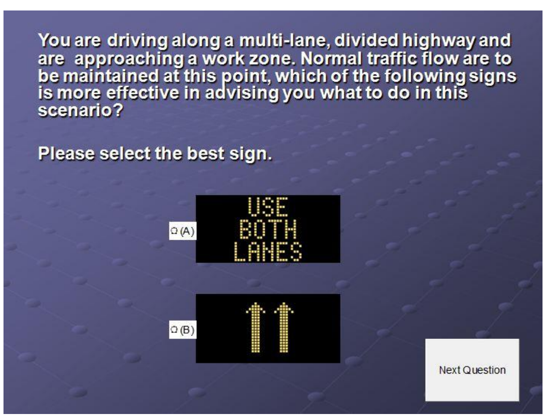

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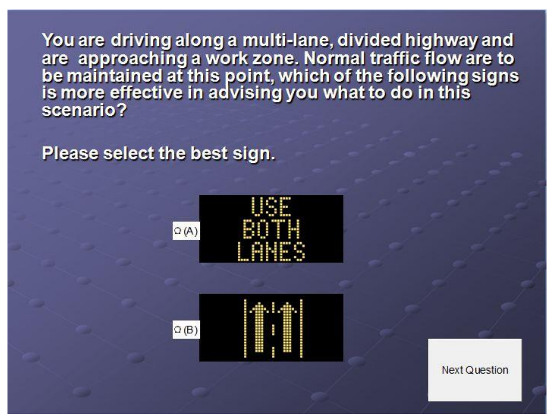

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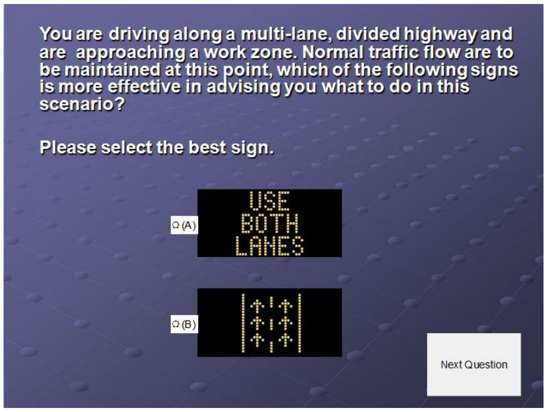

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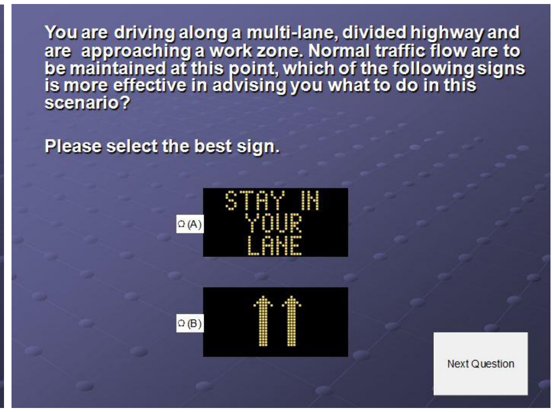

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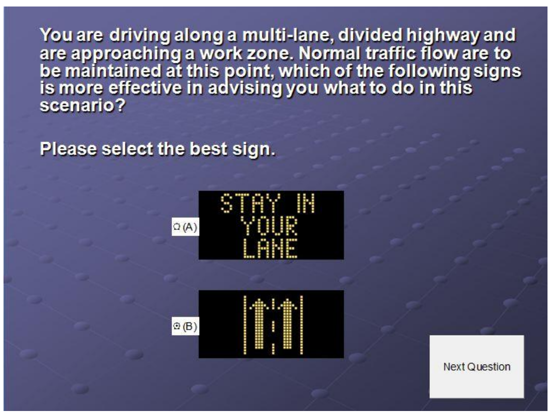

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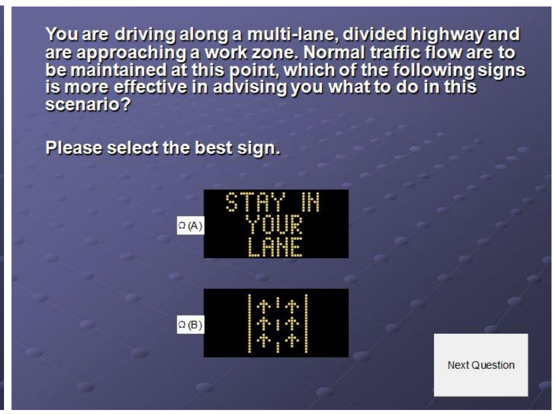

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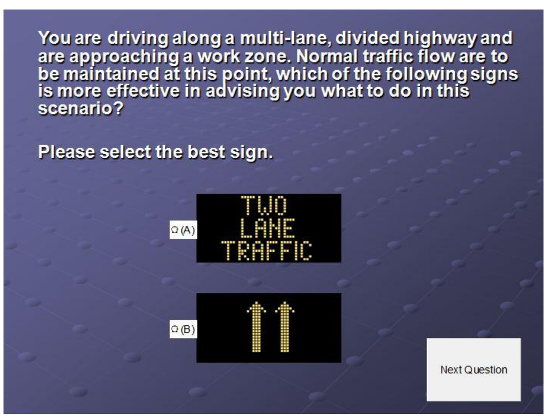

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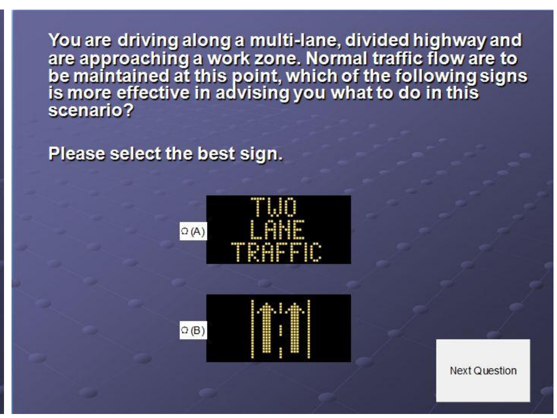

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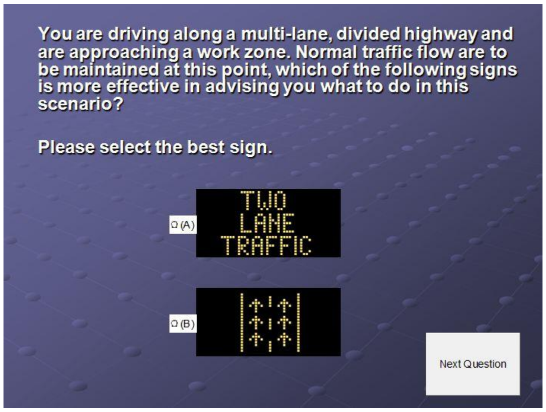

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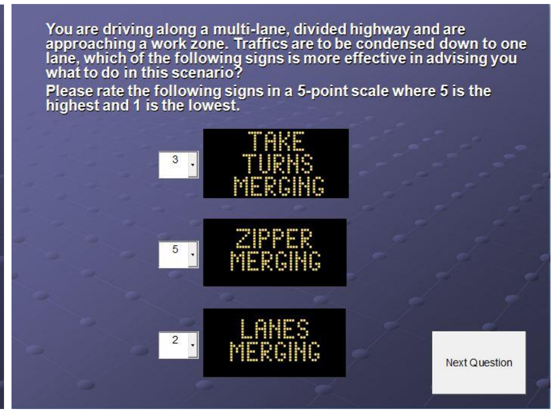

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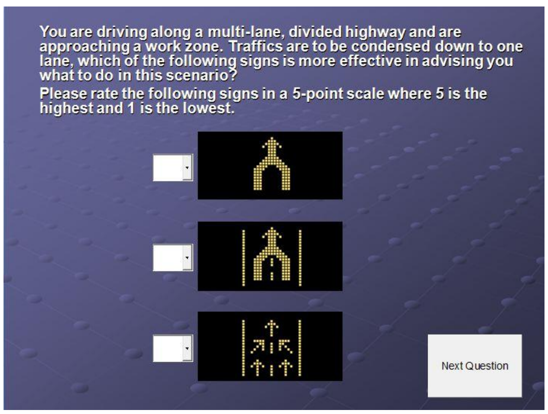

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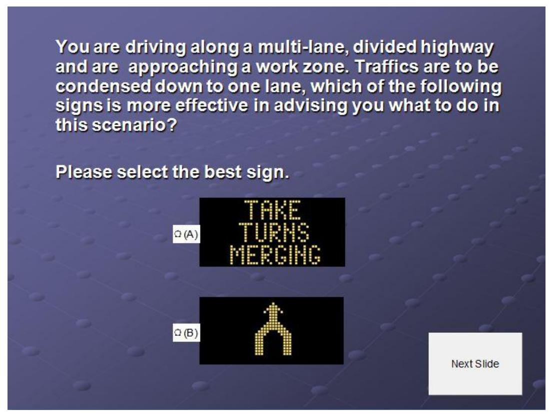

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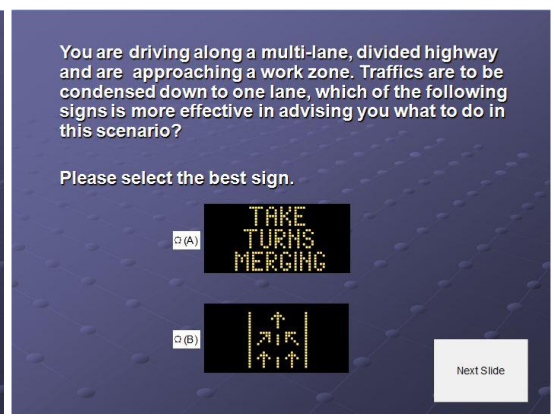

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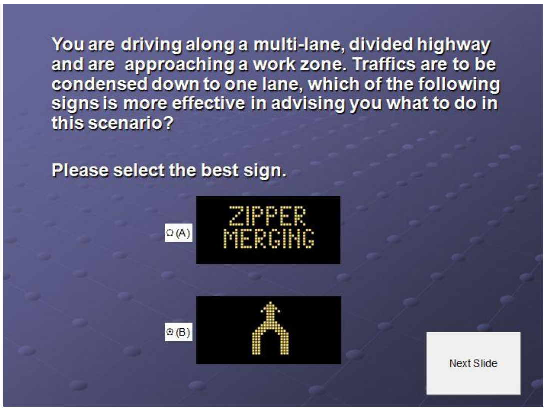

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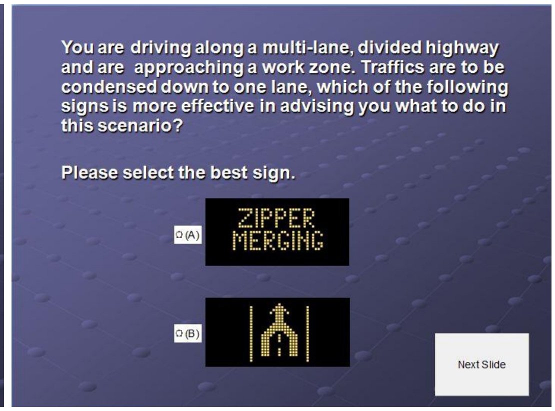

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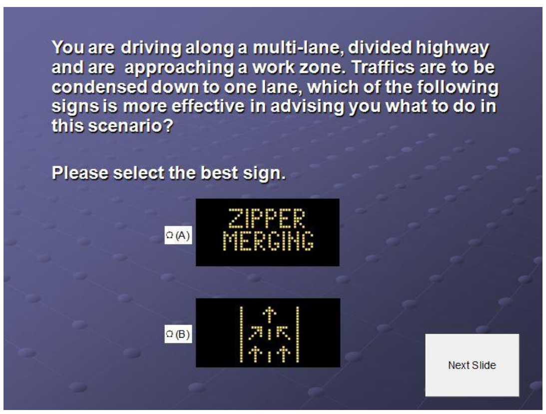

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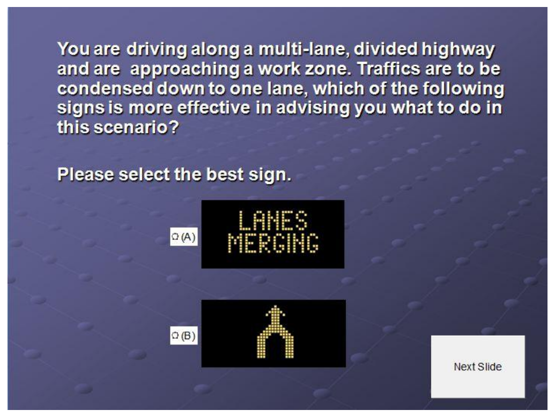

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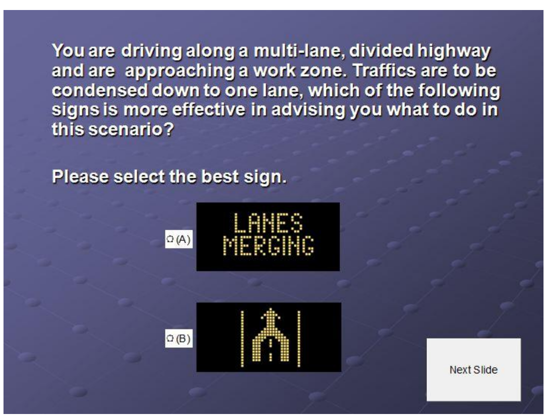

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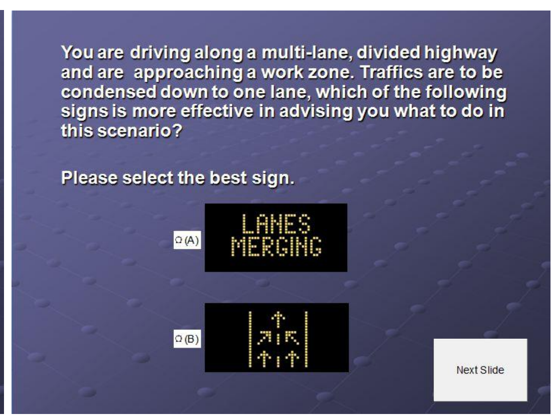

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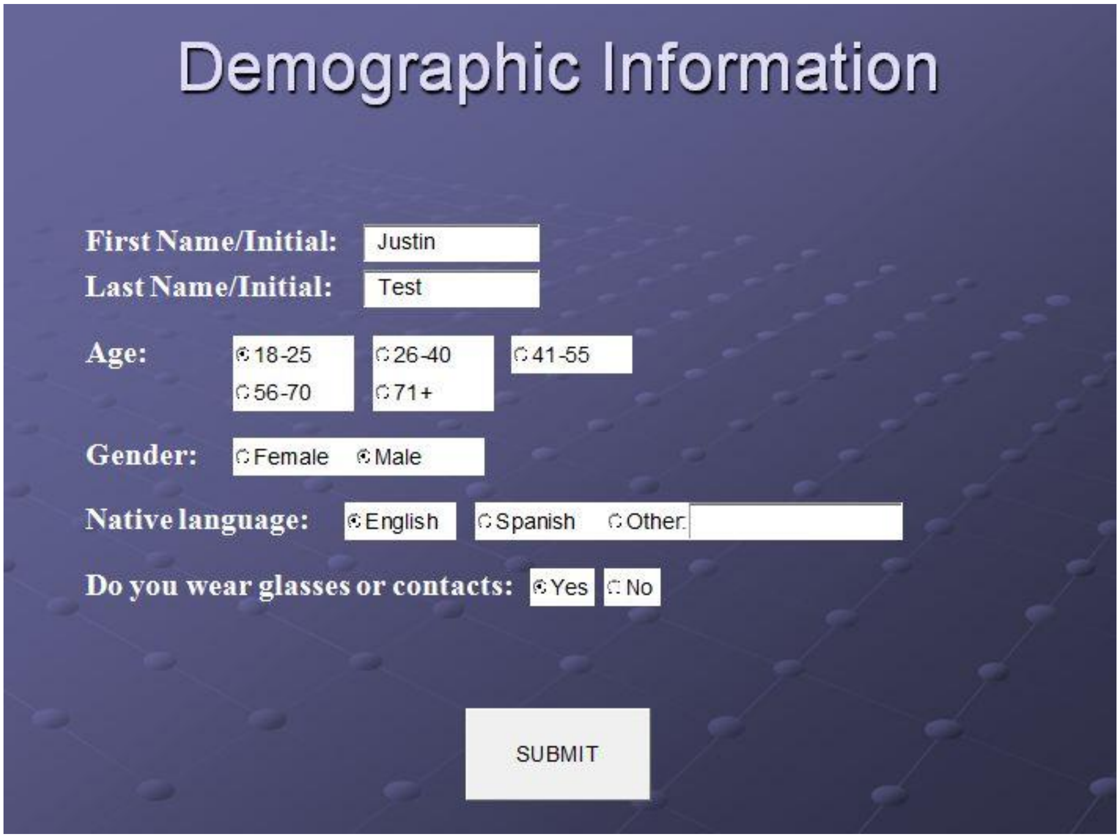
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Justin
Last Name/Initial:
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41-55
56-70
71+
Gender:
Female
Male
Native language:
English
Spanish
Other:
Do you wear glasses or contacts:
Yes
No
SUBMIT
Slide 43

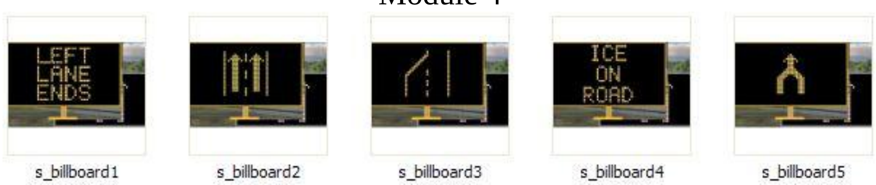
Appendix B. Modules (Message Sets) used for Randomization in the Driving Simulation Experiment

Module 1

Module 2

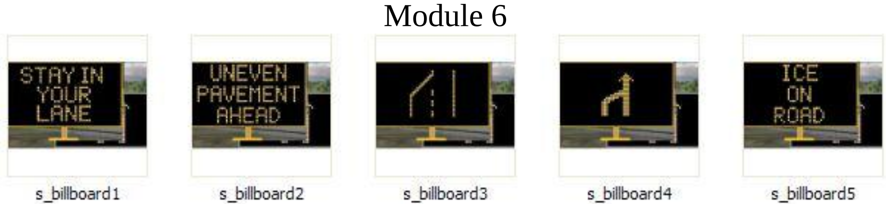
Module 3

Module 4



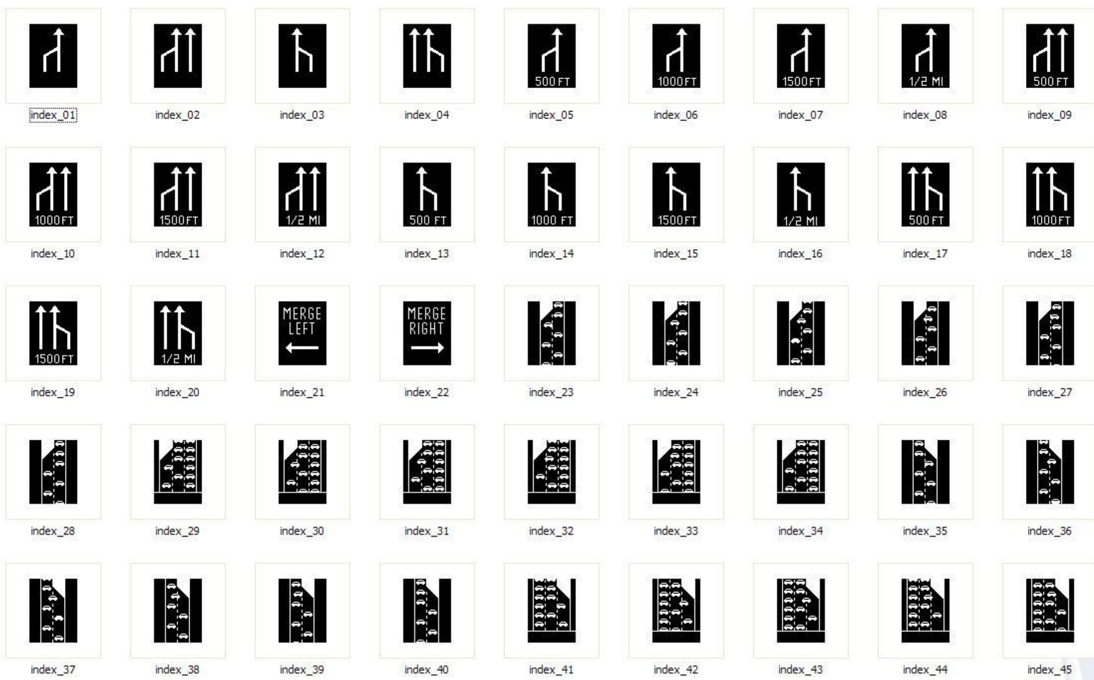
Module 5

Module 6



Appendix C. Sign Libraries for Portable DLMS Message Display

DLMS Unit Sign Library for Upper Panel



DLMS Unit Sign Library for Lower Panel

Appendix D. Module Order Randomization for Subjects in the Driving Simulation Experiment

Module Order (1st-6th) per Subject Number

RUN (1st – 6th)

Subject	1st	2nd	3rd	4th	5th	6th
T1	5	3	6	2	4	1
T2	3	6	4	1	2	5
1	4	1	6	3	5	2
2	5	3	2	6	1	4
3	1	2	3	4	5	6
4	2	6	1	5	3	4
5	2	5	1	3	6	4
6	5	4	2	6	1	3
7	3	2	6	4	1	5
8	4	3	5	2	6	1
9	2	1	5	6	4	3
10	6	3	5	4	1	2
11	2	1	5	3	6	4
12	4	2	6	1	5	3
13	1	5	6	4	2	3
14	4	2	6	1	5	3
15	4	3	5	6	1	2
16	1	2	3	4	5	6
17	6	1	5	4	2	3
18	5	2	1	6	4	3
19	5	4	3	2	6	1
20	5	2	4	1	3	6
21	4	1	6	2	5	3
22	1	5	6	2	3	4
23	6	3	5	4	1	2
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35	5	1	2	6	4	3
36	5	3	6	4	1	2
37	3	2	5	1	6	4
38	2	6	4	1	5	3
39	4	1	2	1	5	6
40	3	6	2	5	4	1
41	2	3	1	5	6	4
42	1	4	6	3	2	5
43	2	4	5	3	1	6

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