Enhancing the Preparedness and Response of Transportation Systems in case of Natural or Human-Caused Disasters

Jyh-Hone Wang, Ph.D.
Charles E. Collyer, Ph. D.
Valerie Maier-Speredelozzi, Ph.D.
Natacha Thomas, Ph.D.
Jeffry Severson
University of Rhode Island

December 2007

URITC PROJECT NO. URITC 50023050000001031

PREPARED FOR

UNIVERSITY OF RHODE ISLAND
TRANSPORTATION CENTER

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The rapid advance of technology has presented authorities with many new tools to monitor and control our roadways for safe, efficient, and convenient use by motorists, working toward an intelligent transportation system that adapt to dynamic situations to best serve motorists. Recent natural and human-caused disasters have demonstrated that there are significant challenges yet to be overcome by the advancing technology of transportation systems. A significant problem is a lack of clear, efficient communication during emergencies. The public requires timely information and guidance during and after a catastrophic event. This research investigates the feasibility of enhancing transportation system preparedness by creating messages to aid motorists during natural or human-caused disasters, supplementing the existing message display libraries for variable and dynamic message signs (VMS and DMS).

This human factors investigation considers the current transportation emergency communication environment and attempts to enhance communication and preparedness by improving the design and display of VMS/DMS messages. The study examined 223 Rhode Island drivers via paper-based public opinion questionnaire, 465 via computer survey, and 157 via driving simulation to research important factors in the design and deployment of message displays. Results demonstrate the viability of supplementing communication through VMS/DMS systems, and list design factors that can help develop new and improve existing messages through further testing and implementation.
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CHAPTER 1

INTRODUCTION

Recent natural and human-caused catastrophes have compelled authorities to prepare more robust, responsive action plans for large scale emergencies to help the public and ensure the ability to safely and effectively move people and goods during crises. However, the successful execution of any emergency action plan, no matter how well prepared or thorough, hinges upon timely, effective communication with the public. Such communication has not received enough emphasis in many emergency plans. This study examines the use of Variable and Dynamic Message Signs (VMS and DMS) as an alternative to inform and coordinate motorists and emergency responders to minimize incidents and maximize safety and functionality. It attempts to answer the question: “How and to what extent can VMS/DMS be used to enhance the emergency response capabilities of the transportation management system?”

The conveyance of pertinent, real-time information to motorists is essential to the success of an intelligent transportation system (ITS). Since 2002, Rhode Island has been accomplishing a significant portion of this communication task by using large electronic signs of two types: dynamic message signs (DMS) are mounted on overhead sign bridges and have 8534 mm x 2388 mm full-matrix, tri-color screens composed of 120 x 27 LED pixels capable of displaying 3 lines of up to twenty 7x6 double stroke, 18 inch characters; variable message signs (VMS) are smaller, portable roadside displays employing either digital box light elements forming alpha-numeric characters or a full-matrix, generally capable of displaying three rows of nine characters. These devices allow transportation authorities to inform motorists of changing conditions
nearly instantly. This greatly increases transportation management authorities’
capability to communicate with motorists on the road.

The content of a message presented on VMS/DMS is especially important given
that drivers must detect, comprehend, and use the displayed information while being
otherwise occupied with the task of driving. This task is severely complicated during
emergencies when there are significant hazards, time pressure, unfamiliar activities,
new traffic dynamics, increased or altered road occupation, and potentially a great deal
of stress, panic, and even physical injury. For this reason it is imperative to find ways to
augment existing communications systems during these trying times, when accurate,
timely information is more important than ever.

Unfortunately, technological advances occur at such a rate that transportation
authorities cannot keep up in studying these advances and implementing them to
optimal effect with the most meaningful integration of current capabilities possible. A
case in point is the implementation of VMS/DMS systems. At the beginning of their
implementation, the messages programmed into the electronic libraries for these signs
were the equivalent of the fixed signs currently in use. This provided the ability to
switch between the different regular signs at the same point in the roadway, but limited
the impact of these electronic signs and barely scratched the surface of the capabilities
of signs that could display any type of message to motorists. Even now, though there
are striking advantages in the use of VMS/DMS technology in emergency situations,
Rhode Island and other departments of transportation have no library of messages to
employ during significant large-scale disasters.
Currently there are situations where standard messages do not suffice and VMS operators must type custom messages to inform motorists. The construction of custom messages is time and effort consuming, and operators can not be sure that their intent is adequately conveyed or helpful to motorists. This could pose serious problems, especially in emergencies where timely, accurate information is critical.

To address these issues, the following human factors study was designed to examine the feasibility of expanding the role of VMS/DMS messaging during emergencies, create and assess various VMS messages for potential emergencies, identify factors in successful message design, generate message libraries, and research message deployment strategies. Each initiative thoroughly considered the demographic differences among drivers’ age, gender, and native language, etc. Successfully pursuing these initiatives would decrease the time it takes drivers to read and understand a message. It would help the public exit dangerous areas more quickly. It would help transportation authorities and drivers to successfully evacuate areas. It would help divert traffic from areas of crisis and aid first responders in performing their services. This way, when an emergency does occur and time is precious, the transportation management authorities will be well equipped to immediately implement measures for informing and guiding the public, to restore safety, security, and efficient function of the roadways.

To accomplish these advancements in emergency communication and preparedness a detailed review of transportation system emergency capabilities was made based on research into pertinent disaster scenarios, and three experimental
methodologies were developed: a paper-based public opinion questionnaire, a more in depth computer-based survey, and a driving simulation experiment.
CHAPTER 2
RESEARCH OBJECTIVES

This research examined the feasibility of enhancing aspects of the transportation communication system through a human factors approach to increasing the scope and effectiveness of VMS/DMS messaging to improve preparedness and performance during emergencies. The objectives of this study were as follows:

1. Identify potential natural and human-caused disaster scenarios that might have significant impacts on Rhode Island and its neighboring states.

The study reviewed the different disasters likely to impact Rhode Island’s transportation system. Rhode Island’s history, geography, and infrastructure were considered in conjunction with the most recent investigations into disasters conducted by researchers. The uniqueness, likelihood, scope, duration, and costs of the disasters were considered and similar disaster types were grouped by attribute. The study then selected a subset of representative disaster types that will be broadly applicable, and then dissected them to identify how they would tax the resources of Rhode Island specifically.
2. **Study the vulnerabilities of communication in the state’s current transportation emergency response architecture and characterize methods for addressing the different scenarios using electronic messaging.**

The examination of vulnerabilities for each representative disaster scenarios includes: consideration of potential high risk locations within the state; estimates of damage to be expected from such an incident; timelines enumerating how the disaster and subsequent response and recovery would unfold; an inventory of resources available and resources required to deal with such a catastrophe; an analysis of how transportation emergency communications would address the situation; an assessment of highly probable complications to the transportation and emergency management systems during such an event; and an inventory of specific messaging needs to be addressed by the careful creation of message designs and deployment strategies for supplemental VMS/DMS libraries.

3. **Thoroughly review the state of Rhode Island’s transportation communication systems and emergency response capabilities to assess the feasibility of expanding the role of VMS and DMS messaging.**

This conducted a comprehensive review of existing research and literature related to the use of VMSs/DMSs and the effects on drivers. It gathered information on current DMS operation practices in Rhode Island and neighboring states. This task
investigated several methods of mass emergency communication available to the state. Emergency management resources, capabilities, and techniques were surveyed both within the state as it presently operates and in more general cases. Action plans produced by the government and relief agencies were reviewed. Consultation with RIDOT personnel, RIEMA, public servants, ITS specialists, and other researchers in the field was sought and received. A summary of current practices and research findings on VMS/DMS messaging in the state and summaries of emergency communications and state response capabilities and architectures was generated. This summary helped assess the feasibility of employing VMS/DMS in emergency situations in this state and other areas. It also helped target areas of need in the current system and also factors that influenced drivers’ comprehension or response during emergencies. Specific relevant messaging factors were identified for further inquiry.

4. *Gain insights into drivers’ attitudes and understanding regarding potential emergency messages and examine variation in drivers’ interpretation of different messages through the use of a paper-based public opinion questionnaire.*

This task generated a questionnaire assessing drivers’ opinions regarding their understanding and interpretation of potential emergency messages and their preferences for different types of communication during emergency scenarios. A paper-based public opinion questionnaire was developed to obtain information regarding drivers’ messaging preferences and opinions regarding emergency messaging as well as their understanding and interpretation of various emergency message design elements, and
potential problems with the use of VMSs/DMSs in emergencies. The questionnaire collected scaled responses to questions as well as demographic information including gender, age group, driving experience, native language, and level of education.

5. Refine investigation of drivers’ understanding of potential emergency messages and examine variation in drivers’ interpretation of these messages and isolate significant factors in message design through the use of a computer-based survey.

This task extended the findings of the first survey by testing motorists’ preferences for a number of different potential emergency message designs, comparing their responses to these messages with their responses to messages from the existing libraries, and identifying factors in message design that improve messaging. Participants were also asked to provide certain demographic information including gender, age group, driving experience, native language, and level of education. Together with findings from the first three tasks, this task provides information for designing a driving simulation experiment that effectively assesses the pros and cons of emergency VMS/DMS design and implementation.

6. Design and conduct driving simulation experiments to assess drivers’ response to various types of emergency messages.
This task developed a simulated, virtual driving experiment to explore various types of emergency messages generated using the previous tasks. Based on the results of the literature review, scenario development, capabilities and resources assessment, and the public opinion questionnaire, the simulation was developed in conjunction with the electronic survey. Potential emergency VMS and DMS messages were designed for both survey and simulation, the experiment was refined through the administration of the first 115 surveys, and a selection of messages were tested through a driving simulation that employed digital videos taken on Rhode Island highways to capture a driver’s view of driving at highway speed. Raw video footage was transferred into a computer and edited to create a driving background. Computer generated graphical VMS and DMS animations were then superimposed onto the digitized message board in the driving background video and the composite video was projected onto a 9’ by 12’ screen. The sequence of VMS/DMS stimuli is introduced in a random but controlled manner. A test subject, sitting in the driver’s seat of a test vehicle, is instructed to press a certain key on a keypad mounted on the steering wheel to signify her or his comprehension of the message. A series of full factorial experiments were designed to test various factors in the driving simulation. The within-subject factors selected to be tested were: alternative designs for graphical display, message library type (emergency vs. non-emergency), and color-coded information. Between-subject factors considered are: age, gender, level of education, use of corrective lenses, and primary language. The different factors were considered for their influence on message effectiveness, and the performance of the research-generated messages was compared to that of existing
messages currently used in Rhode Island. The simulation recorded the accuracy and response time as subjects as well as key demographic information.

7. Analyze the experiment and develop a scenario-based VMS message library for quick and effective deployment of messages.

Statistical analyses were performed to analyze the experiment results. Analysis of variance (ANOVA) and other procedures were employed to identify significant factors and their interactions in the driving simulation experiments. Optimized settings for individual factors and their combinations were explored. Statistical results were combined with specific needs outlined in previous tasks of the research and messages were generated to most effectively fill those needs.

8. Summarize, conclude, and make recommendations.

Based on these analyses, interpretation and conclusions were drawn and specific recommendations for message design made. Findings from this project were compared with findings from other relevant studies. Strategies for the implementation of such messages during different disaster scenarios were developed based on message strengths and limitations ascertained from the simulation experiment. Guidelines for developing and deploying supplemental emergency VMS/DMS libraries were compiled to help the state of Rhode Island guide its motorists during these crises.
The overall goal was to further the state of knowledge of VMS/DMS design and display, enhance motorist understanding of the displayed messages, and promote safe and efficient driving on highways through the improvement of message sign libraries, thereby enhancing the preparedness and response of the Rhode Island transportation system in natural or human-caused disasters.
CHAPTER 3
REVIEW OF LITERATURE AND RESOURCES

This section provides an overview of the current emergency communication environment for Rhode Island’s transportation system. It considers current research and development on the subject, including: the most recent investigations into various natural and human-caused disasters most threatening to Rhode Island, established emergency plans and procedures, the different state organizations’ roles in emergency plans and communications, current command structures for roadway communication, guidelines and protocols governing present message usage, the present level of technological integration, the various available personnel, inventories of equipment and their capabilities, and initiatives for development.

3.1 Potential Disaster Scenarios

In considering emergency communication there are a number of disaster types to treat including: fires, floods, epidemics, seismic and volcanic activity, hurricanes and cyclones, draughts and famines, blizzards, landslides, etc. There are also several types of human caused disasters such as: explosions, Airline or rail crashes or shipwrecks, bridge or building collapses, biological or chemical or nuclear incidents, etc. The initial stages of this study categorized such events and conducted an overview of each to determine their potential impact on Rhode Island in terms of likelihood, vulnerability, scale, scope, damage, cost, and communication issues.

To provide a relative context for the evaluation of emergency capabilities and a structure from which to explain both present difficulties and proposed improvements
(including the impact they will have on the public in real life), and also to use as compelling/thought provoking examples to facilitate interaction with interview subjects and survey participants, a subset of three representative disaster scenarios were developed in depth: a hurricane landfall, a liquid natural gas explosion, and a bridge collapse. These three were selected for their relevance to the state of Rhode Island (including significant probability of occurrence), diverse emergency preparation and response requirements, and ability to generalize management issues and apply them to other emergencies.

Of all the disaster types, Rhode Island has suffered the most severe and costly damage from hurricane landfalls. Many hurricanes and tropical storms have made landfall in Rhode Island. At least five hurricanes hitting Rhode Island over the last century could be categorized as imposing significant damage to infrastructure and loss of human life. Recent investigations into hurricane Katrina and other catastrophes have also underscored the need to treat such emergency communication issues in more depth. The hurricane scenario can be extended to severe storms, flooding, or other natural disasters.

Rhode Island has some 748 bridges that are extremely vital to the state’s way of life given the percentage of the population living on islands and the many coastal industries (including tourism). The very recent bridge collapse on interstate 35W in Minnesota illustrates the loss of life and damage to infrastructure that can occur very rapidly but take an extended period of time and a large amount of resources to address. The bridge collapse scenario is applicable to a number of different incidents like building collapses...
or crashes that would compromise key links in Rhode Island’s transportation infrastructure.

There are many sites throughout Rhode Island that contain large quantities potentially dangerous fluids such as liquid natural gas, including facilities in or near the Providence metropolitan area. The LNG tank explosion scenario can be generalized to a number of different hazardous chemical spills, explosions, fires, biological incidents, or other disaster scenarios that would require immediate evacuations and changes in traffic dynamics over specific regions.

In conjunction with the emergency scenarios, and to help with communicating the use of various messages, the researchers adopted the 4 stage structure outlined in the State of Rhode Island Emergency Operations Plan (RI, 2006) (1) as a structure in the proposed emergency message library. The four stages of the structure are Awareness, Preparedness, Response and Recovery. The states can be classified by timeframe (more than 48 hours prior to the event, 48-24 hours before, 24 hours before through the occurrence of the event, and after the event has taken place), or by unique and characterizing management issues (Awareness reviews procedures and notifies the public of general hazards and determines a timeline for appropriate actions; Preparedness issues orders, mobilizes resources, monitors control points intensely, and declares a state of emergency and begins actions if possible; Response provides status reports, including road closures, alternate routes, and the re-localization of emergency workforce and equipment, damage assessment of the public infrastructure; Recovery coordinates relief efforts, clean up and inspection, and the monitoring of re-entry notifications). It is important to note that “In reviewing the full range of man-made and
natural disasters that are encountered, some provide no warning at all” (2). In this case (e.g. an LNG tank explosion) the stages are truncated and authorities and communication must respond accordingly.

3.2 Vulnerabilities of Communications Based on Scenarios

Hurricane

The most destructive of the hurricanes making landfall in Rhode Island were category 3 storms. This research increased the severity of such storms by an order of magnitude and investigated a scenario in which a category 4 hurricane with forward wind speed of 40 mph, sustained winds of 120 mph with gusts of up to 150 mph, and storm surges from 10-20 feet high with 35 foot swells. Most research indicates the state would have 1-3 days notice prior to landfall in order to make emergency preparations such as evacuation of portions of the population. The estimated effects of the impact/landfall of such a hurricane would be on the order of 100 fatalities, 2,000 hospitalizations, 200,000 individuals evacuated from their homes with 50% in need of long-term shelter, 50,000 homes threatened or destroyed, loss of electrical power for more than 24 hours, over 1 billion dollars in property damage, and a recovery period of several months long. Some significant implications of such a storm would be the concentration of damage to Rhode Islands’ many coastal areas, possibly exasperated by the large tourist populations of such areas at certain times of the year, the congestion of evacuation routes in such areas with few large traffic arteries possibly suffering weather related bottlenecks and being complicated by a lack of advance information due to loss of power, thousands of sheltered and stranded individuals in need of food and medical
attention without sufficient means of delivery, and damage to low elevation fuel tanks or other chemical storage sites that would contaminate water supplies.

LNG Tank Explosion

Liquefied Natural Gas and oil storage tanks in Providence harbor represent a potentially dangerous safety hazard due to their thousands of gallons of flammable fuel. This issue has been of significant interest to the people of Rhode Island of late due to pending proposals to introduce another such plant in the area. An explosion of such a facility would be highly destructive, cause many fatalities, ignite surrounding properties creating a series of fires, all with no advance warning. Impact from such an explosion would affect neighboring areas and infrastructure within 3 minutes, surrounding areas would be affected by smoke or debris for several hours (possibly as far as 15 miles away), and an even larger area would be subjected to hazardous fumes and/or contamination for a significant period of time. Damage estimates for such an event are 10,000 fatalities, 7,500 severe injuries, the evacuation of some 65,000 people, millions of dollars of property damage, extensive contamination of water ways and water supplies, and a recovery period of many weeks. In such a scenario hospitals would be overwhelmed with such a rapid influx of injured people, and evacuation would face tremendous difficulties do to the much shorter period time it would need to be executed in, the potential number of injured and hysterical individuals being evacuated, the hazards of poor visibility or significant obstructions or hazards for evacuees, damage to most methods of communication, and strain on emergency response personnel who need to address a number of significant hazards throughout the area simultaneously.
**Bridge Collapse**

Bridges represent a significant part of the transportation network in Rhode Island, with its large proportion of coastal regions and islands served by the network. The natural or man-made destruction of a bridge could cause up to 2,000 casualties depending on the time of day, immediate and imperative redirection of traffic around the bridge, potential contamination of water ways if vessels are struck, millions of dollars to repair the bridge and infrastructure with millions more lost from the impact on tourism and the economy, and a recovery timeline of months. The evacuation and redirection of motorists and the injured would be complicated due to the nature of bridges as traffic bottlenecks and the resulting lack of access for both emergency personnel attempt to aid victims and motorists attempting to leave the area. Depending on the location of the bridge, the redirection of individuals during the reaction and recovery periods could become quite lengthy and complicated.

In each of these scenarios the importance of effective emergency communication and need to address vulnerable aspects is plain. “Public Communications and Preparedness” was one of the seven key elements of evacuation planning and implementation as stated by the US Department of Transportation in a document entitled “Catastrophic Hurricane Evacuation Plan Evaluation: A Report to Congress” (3). This research also states that will communication prior to emergencies is adequate in most disaster plans, there needs to be improvement in communication during emergencies, and that real-time traffic information is vital for capturing the dynamics of emergencies. One common theme throughout much of the recent disaster preparation research is that most systems encounter problems stemming from “the lack
of communication between agencies in charge” (4) and that “Working partnerships were a key” (5) to most successful emergency plans and procedures. It is easy to see why communication becomes so vital when one considers that for an emergency such as a hurricane, Rhode Island needs to coordinate the efforts of the Department of Transportation, the Rhode Island Emergency Management Agency, the Department of Environmental Management, the Rhode Island National Guard, Rhode Island state and local police, Rhode Island Fire Departments, several different emergency medical care providers, the Red Cross Rhode Island Chapter, the Rhode Island Department of Health, the office of the Governor and other municipal governmental offices, and a host of other emergency service providers, including the federal equivalents of many of the above listed authorities. Recent events and subsequent research have generated focus on the necessity to improve communications within many of these organizations, meaning it will take much more to adequately communicate between them to the point of executing plans in a timely and efficient manner. Roadway management and communication will of course play a significant role in any such efforts.

The federal government, through FEMA, requires all states to have a comprehensive emergency operations plan (2). The Rhode Island Emergency Management Agency has published a new plan in 2006 that does much for hurricane preparation, but still needs to cover many more contingencies, both in emergency type and communication. Communication lines need more quantification and a better hierarchical and progressive structure. There needs to be much more done for the effective dissemination of all the information present, both for the publics preparation, and during the emergencies themselves.
Rhode Island has taken many positive steps toward informing the populace and coordinating authorities during emergencies. The governor of Rhode Island and RIEMA have sent out a hurricane safety and evacuation planner to homes in coastal Rhode Island, and several state agencies have run various disaster drills, from testing port evacuation procedures to conducting mock plane crashes, to statewide bioterrorism medical emergency drills, to emergency response exercises at train stations, and explosion drills for fire departments. Though many of them had comprehensive elements and attempted to include large components of inter-agency cooperation, they were more localized in their scope due to practical constraints and economic concerns, and did not have components that taxed the transportation system, communication lines, and mass displacement of individuals and resources that would accompany a real large scale disaster. The impracticality of ever being able to drill or prepare for such events underscores the need to develop robust communications systems and diverse methods for disseminating information that can withstand emergencies the exceed the capacities of standard procedures.

3.3 Current Emergency Communication Capabilities

Rhode Island’s current means of disseminating emergency information to motorists are: television (local news and a cable traffic channel), radio (advisories on local channels and on RIDOT’s Highway Advisory Radio system), the internet, the 511 call-in national traveler information system, fixed signs, and variable message signs. There are clear limitations to most of these media for communicating with motorists during emergencies. Both television and the internet can provide a vast amount of
information, but the majority of motorists have no access to these communication lines while driving (3). In many cases, “Methods of communicating information prior to an evacuation may not be available during an evacuation (3).” The 511 call-in traveler information system provides timely information, but is not available to individuals without cellular telephones and it is not clear how much of Rhode Island is familiar with this relatively new information service. Radio messages are also good sources of information but motorists are not likely to be listening if they are not prompted to find the proper station (3). Fixed signs can deliver helpful information, but can only communicate messages that already exist in inventory and require time and manpower to erect in places where changes in roadway conditions occur, which is difficult to predict for emergencies. Variable message signs (VMS) and dynamic message signs (DMS) can communicate a near limitless variety of messages to motorists effectively in real time, and VMS can be moved to critical locations if necessary. The flexibility of variable message signs also allows them to aid motorists in using the other emergency communication media (6).

3.4 Relevance of VMS/DMS Systems

There is a significant body of evidence corroborating the purported advantages of VMS/DMS systems as communication tools to effectively address motorists. A survey conducted in Washington, D.C. of more than 500 drivers found that about half of the participants often responded to DMSs while 38% occasionally responded (7). Another similar study (8) conducted in Wisconsin found that about 62% of the drivers responded to DMS messages more than once per week and 66% of them changed their
route at least once per month. According to surveys concerning drivers’ attitudes, most of the participants indicated that DMS information could be very useful to them (8, 9). These statistics show that DMS and VMS messages do have the potential to deliver useful, timely information to the drivers and enhance driving safety on highways; however it is still necessary to increase the effectiveness of these messages, and moreover, apply the effective design techniques proven through research to emergency messaging.

3.5 Review of Studies Related to VMS and DMS

Researchers have uncovered many important elements to consider in developing a successful VMS/DMS design. The U.S. Department of Transportation has established the standard for DMS and VMS messages in the MUTCD (10) that limits the number of phases (frames) per message to two phases. It also recommends that the message should be in capital letters with a desirable letter size and displayed for at least 5 seconds per panel. Message signs should be limited to not more than three lines, with no more than 20 characters per line, where “the top line should present the problem, the center line should present the location or distance ahead, and the bottom line should present the recommended driver action” (10). Kerr et al. (11) conducted experiments investigating the perception of VMSs, and provided evidence for the benefit of high contrast ratios and element spacing. Dudek (12) concluded that continuously scrolling messages were not appropriate for highway use. Wang and Cao (13) studied the design and display factors of variable message signs (VMSs) and found that discretely displayed messages demanded less response time than sequentially displayed messages.
and single-line messages were better than multiple-line messages. In another study, Wang et al. (14) evaluated the effects of message display on drivers’ comprehension of and responses to DMSs. They found that one-frame messages with minimum flashing, specific wording and no abbreviation, displayed in amber or amber-green color combination were the most preferred message display settings. Laboratory driving simulations conducted in their study also showed that messages with these display settings demanded less response time for identification of message content. In general, they found that those message display settings preferred by the majority of drivers in the questionnaire survey also resulted in lower average response times in the laboratory driving simulation. A study by Durkop and Dudek (15) similarly tested the identification and recognition of abbreviations and determined which the public recognize well, and Guerrier and Wachtel (16) also found that single frame messages produced better response times than alternating two frame messages.

Dynamic Features of DMS messages, such as message alternating and message flashing, were investigated in several studies. Dudek and Ullman (17, 18) found that reading times were higher with flashing messages and suggested: one-frame DMS messages should not be flashed; a line on a one-frame DMS message should not be flashed; and a line on a two-frame DMS message should not be alternated while keeping other lines the same. A survey conducted by Yang et al. (19) also suggested that static, one-framed messages with more specific wording and no abbreviations were the display formats most preferred by drivers.

Wardman, Bonsall, & Shires (20) surveyed the effect on motorists’ route choice based on information provided by VMS. They concluded that the impact of VMS
information depended on the message content, local circumstances, and motorists’ characteristics. Peeta et al. (21) studied the content of variable message signs and driver behavior through another on-site stated preference survey. Their analysis suggests that the content in terms of the level of detail of relevant information significantly affects drivers’ willingness to divert.

The reality of motorist communication via VMS and DMS is that not all of these suggestions can be followed at all times and still create messages that convey all of the important information drivers must absorb to make proper decisions. This is why it is imperative to actively test existing and proposed messages to ensure they possess a combination of positive design elements that best serves their intended use.

3.6 Use of graphics in potential emergency signs

One of the potential design features for improving emergency communications with VMS/DMS that has not been extensively addressed by highway authorities and researchers in the U.S. is the inclusion of graphics in message design. The inclusion of graphics on emergency messages may be extremely beneficial since graphics possess many advantages that could greatly aid drivers dealing with adverse situations. Compared with text messages, they can be identified easier, quicker, and from a further distance; they can be seen better under adverse viewing conditions; they can also be understood by people who cannot understand the language in the text messages (22). A picture being worth 1000 words is all the more useful in a crisis when seconds matter.

Using a laboratory simulation, Bruce et al. (23) examined the recognition time of drivers to text messages and symbolic messages. They found that recognition of text
messages took appreciably longer time than recognition of symbolic messages. This fact carries great value if VMS signs were to be deployed during emergencies in locations where motorists are not accustomed to look for information.

In another study, Cameron and McGill (24) used a slide show presentation to measure the response time difference between symbolic signs and signs presented in text format. They concluded the symbolic signs are more effective than text signs. Studies performed by Jacobs et al. (25), and Kline and Fuchs (261) found legibility distance for symbolic road signs to be far greater than text signs. Kline et al. (27) found a similar result in their study. They measured the visibility distance for text and symbolic traffic signs under day and dusk lighting conditions. This study found that the symbolic signs were visible at much greater distances than text signs for all of the age groups. This difference was more obvious under dusk lighting condition. Thus emergency messages displaying graphics may increase the ability of drivers to comprehend and follow emergency messages during the night or under conditions such as heavy smoke from a fire or precipitation during a hurricane.

Young (28) investigated the role of symbols in environmental safety signs. The study found that symbols play an important role in environmental safety signs. Many emergency messages would be most similar to present environmental signs, so this finding encourages a further investigation into graphics used during emergencies.

Considering VMS/DMS graphics directly, Colomb et al. (29) performed a laboratory study on recognizing matrix sign pictograms in simulations using slides representing VMSs. The results revealed that the parameters influencing symbol recognition include (in order of importance) complexity of pictogram, type of matrix
translation, matrix size, and presentation time. The study also found that the following reasons might cause ambiguous rendering of a pictogram in VMSs: lack of information (e.g. symbol excessively simplified or defined by a contour only), an excess of irrelevant information (masking of essential features by a plethora of meaningless details), and the existence of several possible interpretations (e.g. confusion of two or more similar symbols). Tsavachidis and Keller (30) employed driving simulation experiments to study graphical information displays. They mainly focused on assessing potential safety risks of these displays. The results did not indicate any potential safety risk for any of the tested graphical displays.

However Schieber (31) noted that the advantage of symbolic signs over text signs is highly related to the design of the symbols. Some well designed symbolic signs are legible from three times the legibility distance of text messages while poorly designed symbolic signs can be recognized at only half the distance of their textual equivalents. In the design of traffic sign symbols, understandability is rated as the most important factor over other factors, such as conspicuity, reaction time, legibility distance, glance legibility, and learnability (32). Stern (33) conducted research to examine performance on procedural tasks when instructions were presented verbally, graphically, or in combination. He found that graphics alone often lead to quicker completion times, but words lead to greater accuracy. In a study evaluating the information load and comprehension of new tourist signs for Ontario highways, Smiley et al. (34) compared subjects’ performance using highway signs with and without symbols. In this study drivers searched for their target destination on timed sequences of slides of signs and identified whether their target was presented, and if so what was its direction. From this
study they found that symbols need to be used with the destination names so that drivers can learn to connect a symbol with its meaning. These findings together indicate that it is of great importance to assess the characteristics of emergency signs that employ graphics along with text in communicating strategic information.

3.7 Review of Studies Related to Emergency Procedures

There has been an abundance of research on disaster preparation and emergency procedures in the wake of the many calamities suffered in recent years, including intelligent transportation systems (ITS) issues such as modeling transportation systems or directing traffic during evacuations, mobilizing resources, and distributing information to citizens to help them prepare. Wolshon et al. (2) published a two part review of policies and practices for hurricane evacuation. Buck (5) and Levesque (35) detailed successful inter-agency cooperation to improve incident response in Maryland and Rhode Island, respectively, and O’Connor et al. (36) discussed the integration of emergency medical resources. Flax et al. (37) explained the hazard mitigation possible via the Community Vulnerability Assessment Tool. Finally, Liu et al. (38) presented a framework for real time traffic management under emergency conditions and Yuan et al. (39) presented a framework for simultaneous optimization of evacuation traffic destination and route assignment.

Far fewer individuals have put research into applying elements of existing ITS as tools during emergencies. Jiang et al. (40) introduced an integrated Emergency Response & Surveillance (ERS) system designed to use the existing ITS technologies
to serve city traffic management and emergency response agencies, and Krueger (41) described an Airborne Traffic Surveillance System (ATSS) integrating remote sensing techniques with ITS, which provides data collection and dissemination to decision makers during crisis. Kodali, N. et al. (42) introduced SPUTERS, an integrated traffic surveillance and emergency response architecture that helps authorities make critical decisions and would establish an integrated emergency help center. To date, there has not been a significant focus on developing effective methods of disseminating information to the public during emergencies using variable message signs, particularly integration with an existing system or in a specific location. Such research seems well warranted since a common theme throughout much of the recent disaster preparation research is that most systems suffer from a “lack of communication between agencies in charge” (4) and that “working partnerships were a key” (5) to most successful emergency plans and procedures.

3.8 Review of RIDOT TMC’s Role in Emergency Communication

The majority of the emergency information communicated to motorists is coordinated by the RIDOT’s Transportation Management Center (TMC). This entity is responsible for monitoring and managing traffic on Rhode Island’s major roadways, controlling VMS and DMS, and coordinating incident response and other features of RhodeWays, Rhode Island’s budding intelligent transportation system program. The TMC is manned 24 hours a day, 365 days a year to serve Rhode Island’s transportation monitoring and regulating needs. The combination of closed circuit video equipment, VMS and DMS, detection equipment, information systems, and the accompanying
software and networking provide the ability to affect highway communication with motorists and first responders in real time. There are, however, a number of constraints impacting the effectiveness of the TMC. The first being the fact that at present it is only integrated into Rhode Island’s transportation system at points along the state’s major traffic arteries and so the elements of ITS are not yet prevalent enough to perform many of beneficial features ITS can provide (42, 43). Additionally, “to get real-time traffic information on evacuation routes, traffic monitoring equipment is required,” and currently in many areas “that equipment is not widely deployed (3).”

The TMC has an inventory of some 30 DMSs and 15 VMSs that are centrally controlled. The other VMSs residing on the side of Rhode Island’s roadways are actually owned and operated by road construction contracting firms, and at present have no integration with the TMC in times of emergency. The TMC also relies on outside approval for many of its operations. Since “TMC Operators are not trained in assessment of roadway conditions, messages regarding the condition of the roadway shall be posted only with the direction, confirmation, and approval from the TMC Manager or designee, or from RIDOT Maintenance personnel” (1). In other situations the TMC relies on other governmental agencies such as law enforcement officials to coordinate decisions. The TMC has attempted to integrate with some of these authorities, and even has a law enforcement official on staff at its operations center. During emergencies, TMC personnel should managing dynamic transportation system conditions and coordinating efforts with other agencies, rather than composing custom VMS messages. Personnel should take advantage of the unique ability of VMS systems to store a nearly unlimited library of messages that have been prepared, tested, and
approved in advance which will save critical time during natural or human-caused disasters.

At present, the TMC possesses four standard libraries of environmental, accident, roadwork, and congestion messages, but has no emergency message library. Some useful messages for emergencies exist in the other libraries, but they are insufficient for disseminating information to the public in catastrophic situations. Another significant fact is that the libraries are for DMSs, and are not always suitable for the smaller display parameters of the VMSs. This truncates a large portion of the TMC’s ability to respond with timely messages in emergency situations.

There are also many guidelines that VMS messages must adhere to in order to be used by RIDOT. These protocols come from a number of different sources including: federal documents such as the manual on uniform traffic control devices (MUTCD), the I-95 Corridor Coalition, relevant government statutes, and TMC protocols. Expanding the use of electronic messaging to aid in emergencies complies with the most basic requirements and purpose for a traffic control device, “to promote highway safety and efficiency by providing for the orderly movement of all road users on streets and highways,” and to “notify road users of regulations and provide warning and guidance needed for the reasonably safe, uniform, and efficient operation of all elements of the traffic stream” (5).

The use of VMS in emergencies fits with both the MUTCD’s guidelines for portable electronic message signs, and TMC usage which allows for “…special public safety messages” (1), although this is not typical current practice.
The TMC also stipulates a prioritized list of message types starting with road closures, safety/security messages, lane closures, weather advisories, and general advisories (1). When messages of equal priority are considered, events closest to the VMS location take precedence. Unfortunately, VMSs controlled by contractors can violate the priority system and create problems during emergencies. This further indicates the need for a cooperative system to coordinate all VMS displays, not just those of the TMC. In addition, the TMC guidelines make special note of motorists who are not familiar with local routes, street names, or landmarks. Thus, VMS messages should be written with distances or exit numbers, particularly for summer tourists.

The TMC recognizes its potential in creating emergency procedures that are dynamic and adaptive, and thus superior to the “paper plans” still employed by many authorities. It states that it has “developed full diversion routes” and so understands the value of robust, layered contingency plans that intelligent transportation systems can provide, but there is still much to do to make these plans effective on the proper scale and applicable in all emergency scenarios, eventually moving toward electronically adaptive plans such as those presented by Sawaya, et al. (44). There also need to be mechanisms in place for guiding testing and development of communication solutions. Even the MUTCD guidelines recognize that, “Continuing advances in technology will produce changes in the highway, vehicle, and road user proficiency; therefore… It is important to have a procedure for recognizing these developments and for introducing new ideas and modifications into the system” (5).

The ultimate goal is for Rhode Island to implement a completely intelligent transportation system that could adapt to emergency scenarios in real time—directing
traffic and allocating information and resources to troubled areas—to maintain traffic flow and ensure the safety, security, and mobility of motorists in an efficient and cost effective manner. The system would be robust, widely applicable, and even be able to anticipate traffic flow problems and correct or ameliorate such problems. This would mean Rhode Island would have the means to effectively implement a custom designed dynamic evacuation or flow model—like the framework for real time traffic management under emergency conditions presented by Liu et al. (38), or the framework for simultaneous optimization of evacuation traffic destination and route assignment introduced by Yuan et al. (397) or the proactive freeway safety strategy authored by Pande and Mohamed (45). But Rhode Island needs to develop many tools and purchase more technology before it can address such matters. The prudent first steps are to maximize the utility of the current system, incorporate more intelligent elements when possible, and steadily evolve toward an improved system with the proper technology, equipment, personnel, and training to positively impact the safety of Rhode Island motorists during an emergency.
CHAPTER 4

METHODOLOGY

This study was designed to: examine the feasibility of expanding the role of VMS/DMS messaging during emergencies, create and assess various VMS messages for potential emergencies and adverse conditions, identify factors in successful message design, find optimum settings for such factors to enhance driver comprehension of VMS/DMS messages while decreasing the amount of time it takes for a driver to read and understand a message (with consideration for demographic differences among drivers’ age, gender, and native language), and generate emergency libraries and deployment methods, so that when an emergency does occur and time is precious, the transportation management authorities will be well equipped to immediately implement measures for informing and guiding the public, to restore safety, security, and efficient function of the roadways.

Three approaches were employed in the study: a paper-based public opinion questionnaire that collected the scaled responses of driver’s presented with a number of types of emergency communication, a more in depth computer-based survey that ascertained drivers’ opinions and preferences through a number of multiple-choice questions, and a driving simulation experiment that recorded drivers’ responses to a series of VMS/DMS message stimuli. These approaches are described in detail in the following sections.
4.1 Paper-Based Public Opinion Questionnaire

After completing the review of existing resources that gained insight into the current capabilities, requirements, and goals of the Rhode Island emergency transportation communication infrastructure, this study examined alternatives and progress in the field to ascertain what current solutions can be applied quickly and effectively. It then targeted areas that do not have adequate solutions or those which can be greatly improved. Potential solutions are researched, developed, thoroughly tested and different implementations analyzed, and then results are compared and recommendations for improvements are given based on the best data available.

To aid proper construction and evaluation of potential emergency communication solutions and improvements, including assessing the viability of increasing the use of VMS to aid the dissemination of emergency information to motorists, a number of informal interviews with RIDOT and other agencies were conducted. In addition to providing valuable insight into the situation and helpful feedback, these interviews underscored the need to design an experimental method for gathering representative, useful, and applicable information about the actual interaction of emergency procedures and communication with Rhode Island’s drivers.

4.1.1 Design of the questionnaire

To assess the public’s understanding and relationship with roadway messaging, evaluate inconsistencies in the perception of the public, and determine the parameters for successful roadway message design, the study employed a public opinion
questionnaire as a preliminary assessment tool. The public opinion questionnaire was conducted to gather public response to VMS and other roadway messaging in emergency applications applied specifically to the state of Rhode Island. The questionnaire’s intention was to: assess the driving public’s familiarity with and attitudes toward basic emergency procedures on roadways; determine drivers’ current attitudes toward VMS and other emergency information communication systems; assess drivers’ approval of expanding the role of VMS in emergencies; and test driver’s preferences and comprehension with several potential emergency messages to assess basic design elements.

Several factors were considered in designing the public opinion survey, including message wording based on current standard practice and recent research, as well as question development that was appropriate for a wide demographic sample of different backgrounds, education levels, and physical conditions. In order to facilitate an acceptable level of returns, the survey had to include all relevant research factors but be only a few pages long, with wording that was clear, concise, and not offensive to the majority of the public. General categories for message design as well as example scenarios were included in the survey with the intention of having the results verified via future research and driving simulation experiments. Portable VMS message signs were presented in the survey, since their employment could be of great use in diverse emergency situations and messages for these signs can be implemented onto larger, fixed DMS, but the reverse is not possible. A complete emergency message library will be developed for VMS and DMS systems in subsequent phases of this research.
The questionnaire posed 12 distinct questions where the first 7 questions were used to collect participants’ opinions in terms of level of agreement with a given statement. The remaining questions surveyed participants’ experience with and interpretation of VMS messages in emergency scenarios. Demographic information was collected statistically analyzed for potential influence on survey results. A copy of the public opinion questionnaire can be viewed in Appendix A1.

The level of agreement drivers had with the first 12 questions posed to them was assessed using attitudinal ratings on a numbered scale. The scale was numbered one to five, with the number one indicating strong agreement and the number five indicating strong disagreement. This system is similar to what is commonly called a Likert Scale. Five levels of agreement were selected based upon human factors and psychological concerns the research team found to be relevant to the questionnaire.

In order to more fully capture the perspectives of a wide range of individuals with different backgrounds and aptitudes the final five questions presented to drivers employed a range of different response formats including: selecting a numbered or lettered alternative, filling in a blank, or free response. The questionnaire collected demographic information regarding: gender, age, years of driving experience, native language, area of residence (in the form of ZIP code), educational background, use of corrective lenses, and color blindness. These demographics were selected from a larger list of potential items based on their estimated impact on driver response to VMS/DMS stimuli, both from the research team’s previous experience and data from related studies.
To provide a relative context for the evaluation of emergency capabilities, three different disaster scenarios were developed: a category 4 hurricane landfall, a liquid natural gas explosion, and a bridge collapse. These three scenarios were selected based on the preceding research for their relevance to the state of Rhode Island, diverse emergency preparation and response requirements, and capability to generalize management issues for other emergency types. The 4 stage structure in the *Rhode Island Emergency Operations Plan* (1) was followed in the proposed emergency message construction. The four stages of the structure are: awareness, preparedness, response and recovery. The states can be classified by timeframes of more than 48 hours prior to the event, 48-24 hours before, 24 hours before through the occurrence of the event, and after the event has taken place, respectively, or by unique and characterizing management issues. It is important to note that “In reviewing the full range of man-made and natural disasters that are encountered, some provide no warning at all” (2). In such cases, as in an explosion, the stages are truncated and authorities must respond accordingly with well prepared communication plans.

4.1.2 Administration of the questionnaire

The questionnaire was presented to consenting volunteers with valid drivers’ licenses at locations including the main branch office of the Rhode Island Department of Motor Vehicles, a public university (University of Rhode Island), and selected private residences. The locations were chosen to obtain a representative and unbiased sample of the driving population (see Table 1). In each instance of questionnaire administration potential participants were greeted by a member of the research team on
location, briefed about the questionnaire and the study, and asked for their participation. Willing individuals, after expressing their formal consent (by indicating such in the appropriate section of the questionnaire document), completed the paper questionnaire with a writing utensil in the presence of a research team member. Upon receipt of the completed questionnaire document, researchers filed the form in a secured transport vessel and then deposited the questionnaires in a securely locked storage facility within the university’s research facility in order to protect the privacy of those who aided in the research and comply with the mandates of the University’s Institutional Review Board.

4.2 Electronic Survey

To gain further insight into drivers’ understanding of and interaction with emergency VMS/DMS messages, a computer-based electronic survey was created to assess drivers’ preference and to identify variations in drivers’ interpretations of message features of potential and currently used VMS/DMS designs.

4.2.1 Design of the computer-based survey

One of the most challenging tasks in creating the survey was to develop a bank of numerous potential emergency messages that could be used in conjunction with current VMS/DMS text messages. Research and literature review on the subject, informal interviews with RIDOT staff and other professionals, and the results of the paper-based questionnaire combined to help in the development of this potential emergency message library. In order to further assess potential message improvements, a library of graphics was also included as a factor in the survey. Graphics were included because
previous research indicates they are likely to improve response times, and while not currently in use in the U.S. they have had positive responses in Europe and are currently being considered for use by many U.S. transportation authorities.

In addition to messages currently in use on highways, two types of electronic messages were created: messages that were adapted from fixed emergency signage or that otherwise made use of terms or symbols already in common use, and original message designs based on the above research inputs to fulfill a perceived messaging need. Figure 1 shows images taken from the potential emergency message library and graphics bank for the questionnaire survey.

![Figure 1. Images investigated in the electronic survey](image-url)
The electronic survey was designed using Microsoft PowerPoint® and Visual Basic macros. Each question in the survey contained two or three VMS/DMS signs carrying the same basic message but with varying design or display features. To avoid the confounding effect, a single feature was examined in each question respectively. Table 2 shows the type and the content of the VMS/DMS messages used in the survey.

Table 1 US Department of Transportation Bureau of Statistics age demographics for RI

<table>
<thead>
<tr>
<th>State</th>
<th>Number of licensed drivers</th>
<th>Licensed drivers per registered vehicle</th>
<th>Resident population</th>
<th>Driving age population (16 and over)</th>
<th>Drivers per 1,000 total resident population</th>
<th>Drivers per 1,000 driving age population</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rhode Island</td>
<td>746,465</td>
<td>0.93</td>
<td>1,076,189</td>
<td>859,993</td>
<td>694</td>
<td>868</td>
</tr>
<tr>
<td>AGE</td>
<td>15 to 19</td>
<td>20 to 24</td>
<td>25 to 29</td>
<td>30 to 34</td>
<td>35 to 39</td>
<td>40 to 44</td>
</tr>
<tr>
<td>NUM %</td>
<td>81557</td>
<td>78574</td>
<td>67676</td>
<td>64641</td>
<td>75438</td>
<td>82832</td>
</tr>
<tr>
<td></td>
<td>7.64%</td>
<td>7.36%</td>
<td>6.34%</td>
<td>6.05%</td>
<td>7.07%</td>
<td>7.76%</td>
</tr>
<tr>
<td>50 to 54</td>
<td>75932</td>
<td>67027</td>
<td>48619</td>
<td>36126</td>
<td>31179</td>
<td>25286</td>
</tr>
<tr>
<td></td>
<td>7.11%</td>
<td>6.28%</td>
<td>4.55%</td>
<td>3.38%</td>
<td>2.92%</td>
<td>2.83%</td>
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<tr>
<td>75 to 79</td>
<td>30252</td>
<td>25286</td>
<td>25123</td>
<td>25123</td>
<td>25123</td>
<td>25123</td>
</tr>
<tr>
<td>80 to 84</td>
<td>25286</td>
<td>25123</td>
<td>25123</td>
<td>25123</td>
<td>25123</td>
<td>25123</td>
</tr>
<tr>
<td>85+</td>
<td>25123</td>
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<td>25123</td>
<td>25123</td>
<td>25123</td>
</tr>
</tbody>
</table>

Figure 2 Age distributions for experiments
Table 2 DMS messages used in the survey

<table>
<thead>
<tr>
<th>Non Emergency Messages</th>
<th>Emergency Messages</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Library</strong></td>
<td><strong>Message Content</strong></td>
</tr>
<tr>
<td>Road Work</td>
<td>ROAD WORK</td>
</tr>
<tr>
<td></td>
<td>1 MILE AHEAD</td>
</tr>
<tr>
<td></td>
<td>EXPECT DELAYS</td>
</tr>
<tr>
<td>Road Work</td>
<td>LANE SHIFT</td>
</tr>
<tr>
<td></td>
<td>EXIT XX</td>
</tr>
<tr>
<td></td>
<td>EXPECT DELAYS</td>
</tr>
<tr>
<td>Road Work</td>
<td>CONSTRUCTION AHEAD</td>
</tr>
<tr>
<td></td>
<td>LEFT LANE CLOSED</td>
</tr>
<tr>
<td></td>
<td>KEEP RIGHT</td>
</tr>
<tr>
<td>Road Work</td>
<td>RAMP CLOSED</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>Congestion</td>
<td>CONGESTION</td>
</tr>
<tr>
<td></td>
<td>REDUCE SPEED</td>
</tr>
<tr>
<td></td>
<td>NEXT 3 EXITS</td>
</tr>
<tr>
<td>Accident</td>
<td>CAUTION</td>
</tr>
<tr>
<td></td>
<td>EMERGENCY</td>
</tr>
<tr>
<td></td>
<td>VEHICLES</td>
</tr>
<tr>
<td>Environmental</td>
<td>SLIPPERY ROAD</td>
</tr>
<tr>
<td></td>
<td>1 MILE AHEAD</td>
</tr>
<tr>
<td></td>
<td>USE CAUTION</td>
</tr>
<tr>
<td>Environmental</td>
<td>DANGER</td>
</tr>
<tr>
<td></td>
<td>HIGH WIND</td>
</tr>
<tr>
<td></td>
<td>USE CAUTION</td>
</tr>
<tr>
<td>Environmental</td>
<td>WET PAVEMENT</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>Environmental</td>
<td>CAUTION ICE</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>Bridge Collapse</td>
<td>BRIDGE OUT</td>
</tr>
<tr>
<td></td>
<td>ROAD CLOSED</td>
</tr>
<tr>
<td></td>
<td>USE EXIT 12</td>
</tr>
<tr>
<td>Bridge Collapse</td>
<td>DANGER</td>
</tr>
<tr>
<td></td>
<td>ROAD CLOSED</td>
</tr>
<tr>
<td></td>
<td>USE EXIT 12</td>
</tr>
</tbody>
</table>

The electronic survey contained a total of 58 slides posing 51 questions to investigate drivers’ preferences on a number of VMS/DMS design and display features including: message wording; message length and abbreviation; alternative graphics; message type (graphic-aided vs. text-only); animated graphics (moving vs. stationary images); message color (amber or red); contrasting graphic color (red vs. amber, etc.);
contrasting text outlines; position of the text (justified on the right, left, or center); and flashing effect of the graphic image or alert words. Even more important than the individual factors to be tested was the comparison of the within subject factors for both research-generated emergency messages and non-emergency messages to assess if such constructions were viable tools for communication. Details of each feature assessed in the electronic survey are described below:

a. Message wording:

Four questions assessing message wording appeared in the survey. For each question a set of roughly equivalent alert words were used to compose an emergency message (e.g. “emergency,” “danger,” or simply the event such as “bridge out”) and the survey participant selected the configuration they found most useful. Figure 2 gives an example.

Figure 3 Example Message Wording Slides

b. Message length and abbreviation:

Four questions assessed the use of abbreviation to condense messages to increase content by providing subjects with the same message truncated to different degrees
through abbreviation. The subject selected the message length and type of abbreviation they felt most comfortable with. An additional four-part question was included at the end of the survey to assess the retention of subjects when presented with a two panel set of emergency detour instructions and asked to make two-alternative route choices. Figure 3 provides examples.

![Figure 3: Examples of message abbreviation slides](image)

Figure 4 Example Message Abbreviation Slides

c. Alternative graphics:

A question that surveyed drivers’ preferences on alternative graphic images was configured with three different graphical images accompanying the same text. Six different questions of this type were included in the survey. Figure 4 gives an example.

![Figure 4: Example of alternative graphics](image)
d. Message type:

Eight questions solicited the preferences of subjects regarding message type, i.e., graphic-aided message vs. text-only message. The same message was displayed in two different sign snapshots: one was composed of larger, double stroke text and the other contained smaller text and an additional graphic aid. Figure 5 gives an example.
e. Animated graphics:

Four different questions presented the same message display with identical graphic and text, but one of the displays contained a second panel with the graphic in an alternate position so when viewed by subjects the graphic appeared to be moving. Subjects were asked to indicate which of the two types they preferred. Figure 6 gives an example.

![Figure 7 Example Animated Graphics Message Slide](image)

f. Message color:

To find drivers’ preferences regarding message color, eight questions were included. Each question presented the same message in a red or amber color scheme. Both graphic-aided and text-only messages were exhibited with different colors. Figure 7 shows an example.
Four questions were employed to survey drivers’ preferences on the use of the graphic images that contrasted from text color. Two panels were presented to participants for each question. Once panel contained a graphic of the same color as the accompanying text, and one presented a graphic of contrasting color. Figure 8 shows an example.
h. Contrasting text outlines:

Four questions assessed drivers’ preferences regarding different methods for outlining text. Each question presented the same message three times, and in a random order presented text that was: amber with a red outline, amber only, red with an amber outline. Figure 9 gives an example of this type of question.

Figure 9 Example Message Contrasting Graphic Color Slide

Figure 10 Example Message Contrasting Text Outline Slide

i. Position of the text:
Positioning of text was assessed in four questions of the survey. Each question presented the same message in three formats: left justified, right justified, and center justified. This presentation of choice was implemented for both graphically aided and text-only messages. Figure 10 shows an example.

![Figure 10 Example Message Positioning Slide](image)

Flashing effect:

To investigate subjects’ preferences on this feature, four questions were designed where a key word in the message or a graphic image was presented either in static mode or flashing mode. Flashing messages were composed of two frames, the first frame presented only the static message and the second frame showed the same message with the key word or graphic image. Figure 11 shows an example.
A complete list of survey questions is given in appendix A.

4.2.2 Administration of the electronic survey

The survey was presented to consenting volunteers with valid drivers’ licenses at locations including the Warwick Mall, a public university (University of Rhode Island), and selected private residences (including retirement communities). The locations were chosen to obtain a representative and unbiased sample of the driving population (see Table 1). In each instance of survey administration potential participants were greeted by a member of the research team on location, briefed about the survey and the study, and invited to participate. Willing individuals were provided with a consent form approved by the university’s institutional review board to confirm their understanding of their role in the research and formally agree to participate. Participants who completed the consent form administered to them by research team members were introduced to the survey presented on a laptop computer by first viewing two consecutive introductory slides (see Figures 12, 13). Then the participant was
asked to start the survey by using the mouse provided with the laptop to click on the start button if she/he was ready. Survey questions were then presented one at a time. To help mitigate survey bias with respect to the sequence of the survey questions certain subjects were presented with the questions in altered sequences. In each question, the subject was asked to choose a DMS message that she/he most preferred by clicking on the option button beside that message with the mouse (see Figure 14). After each choice was selected, the subject could move on to the next question by clicking the “Next Question →” button with the mouse. Subjects were not constrained by any time limits so they could take as much time as they needed to answer a question.
Questionnaire Survey
Conducted by University of Rhode Island
Sponsored by URITC and RIDOT

You are taking part in a survey to help enhance the design and display of Dynamic Message Signs (DMSs). DMS is an electronic bulletin board, usually mounted overhead on highway, which communicates real-time traffic information and travel advice to motorists. The research findings from this survey will benefit the general public and enhance driving safety on state and interstate highways.

Figure 13 First electronic survey introductory slide

In this survey, you will be prompted with a variety of DMS images or animations and you will choose the one that you preferred the most. There isn’t any foreseeable risk or discomfort associated with the survey. The survey will take probably 20 minutes.

Your part in this study is confidential. All records will be kept in a computer that is only accessible to the project investigators. The responses made by you will only be used in statistical analysis.

Please feel free to contact the project director, Dr. Wang (874-5195), if you have any questions or concerns.

If you read the above and agree to participate in this survey, please press the “START” button below to start the survey. Please read each question carefully and choose your best answer. Thank you!

Figure 14 Second electronic survey introductory slide
Upon completion of all the survey questions the subject was asked to fill in a demographic information form in the last slide and click the submit button to exit the survey (see figure 15). The subject’s answers and demographic information were then automatically stored as text files and entered in an MS Excel® database for later analysis. Subject’s name was stored only to assist in sorting the data results to ensure that the same subject was not tested twice or the data was not used twice in the analysis. Participants’ confidential participation was guaranteed by storing the data in password protected computers housed in secure locations within the research facility, as mandated by the university’s institutional review board.
4.3 Driving Simulation Experiment

A driving simulation experiment was developed to gauge drivers’ response time and accuracy when interacting with simulated VMS/DMS messages. The main purpose of the simulation experiment was to validate the findings of the surveys regarding specific features of VMS/DMS messages and test the actual performance of potential emergency messages in an environment that is much more closely resembles real driving.

4.3.1 Experiment Factors and Design

Two types of factors were considered in the simulation experiment: main factors and blocking/demographic factors. A blocked factorial experiment design was
employed to investigate the effects of the main factors, blocking factors, and their interactions. Table 3 shows these factors and their levels. Message library type, display type, and color were chosen as main factors here since they provided a means to gauge driver’s responses to various VMS/DMS messages while allowing a comparison to be made between survey findings and lab experiment results. They also were the best indicators that could be used to assess the relative performance of potential emergency messages. A total of 166 subjects participated in the study. Subjects were recruited from three age groups of 18~40, 41~60, and over 61 years old. Each participant was required to have a valid driver license and interstate highway driving experience.

| Main Factors       | Factors                  | Levels                      |
|--------------------|--------------------------|                            |
| Message Library Type | Emergency, non emergency |                            |
| Message Display Type | Graphic-aided, Text-only |                            |
| Message Color       | Amber, Red               |                            |
| Age                | 18-40, 41-60, over 60 years old |            |
| Gender             | Female, Male             |                            |
| Education          | High School, College, Post Grad |             |
| Color Blindness    | No, Yes                  |                            |
| Corrective Lenses  | No, Yes                  |                            |
| Native Language    | English, Other           |                            |

4.3.2 Experiment Development

A video-based simulation was employed in this experiment to simulate the driving environment. Using tools and methods developed through previous research undertaken by the department, seven major tasks were carried out to prepare the
simulation video that was used in the experiment. Figure 16, appearing courtesy of Siamak Ghanizadeh Hesar, shows the different steps of this process.

![Flowchart for the simulation video development](image)

**Figure 17** Flowchart for the simulation video development

Step1: A video was recorded during a drive along RI route 4 moving in the southbound lanes from exits 6 to exit 5 where an overhead DMS board was operating. This route was chosen because of its light traffic and the presence of the in-service DMS in between the two exits. Driving speed was kept constant at 50 mph while recording the video. A Canon XL1 digital video camcorder, leveled at driver’s eye height on a tripod,
was used to shoot the video. This video was transformed in subsequent steps to serve as the background of the simulation videos presented in the driving experiment.

Step 2: The video was digitally downloaded onto a desktop computer and individual frames were extracted using Sonic Foundry VideoFactory™ software. Extracted frames were saved in the same folder location as bitmap pictures. Figure 17, appearing courtesy of Siamak Ghanizadeh Hesar, shows a snapshot of this process.

![Figure 17](image)

Step 3: The overhead blank display of the DMS board in the original video first appeared in the distance as a small dot and gradually increased in size as the vehicle moved closer. In order to superimpose a test message on the blank DMS board, the exact size and position of the DMS board in each frame of the video had to be determined. This task was accomplished by a computer program written in Visual...
Basic® called “Positioning” that could be used to determine the size and position of the board by clicking on the top-left and bottom-right corners of the blank board, in each frame of the video. Figure 18, appearing courtesy of Siamak Ghanizadeh Hesar, provides a snapshot of using this program to determine the coordinates of upper left corner of the board. The source code of this program and a sample of the coordinate database appear in appendix B.

![Figure 19 Screenshot of the “Positioning” program at work](image)

Step4: Individual DMS test messages were created by Vanguard® VMS Central Controller, the same software system used by RIDOT to generate and control DMS messages. These messages were capable of being displayed on a typical full matrix (120x27 pixels) black background displayed on an in service Daktronics Vanguard®
VMS system (model VF-2000-27x120-18-W). These viable images of the DMS board with various messages were cut and saved as bitmap pictures for later use.

Step 5: Using the Adobe® Photoshop® software, individual DMS images saved in step 4 were resized to fit the various blank DMS message boards depicted in the frames of the background video. Operational Actions (Macros) were developed to perform this resizing task automatically one after another until the entire video was completed.

Step 6: Through another computer program written in Visual Basic.Net called “Merging” the resized DMS images were automatically merged onto the blank DMS board in different frames of the background video. Coordinates and position of DMS boards in various video frames determined earlier were used to merge the proper test message on the correct frame and in the right position. The source code of this program is presented in appendix C.

Step 7: After the test messages were merged onto respective frames, these video frames were next rendered into a video clip at a rate of thirty frames per second. The completed simulation video had a length of 27 seconds. Since forty different DMS messages were used in the experiment (48×27×30=38,880 frames), forty video clips were created.

4.3.3 Experiment Setup

Driving simulation experiments were originally conducted in the Driver Performance Laboratory at University of Rhode Island. In order to duplicate the process nearly exactly to administer the experiment at remote locations such as the Warwick
Mall, a number of steps had to be taken. The main elements of the laboratory apparatus include:

1. A high speed computer with internet access; a Dell Dimension 4500 server with an enhanced video processor to administer the experiment and to record experimental data
2. A 1998/2001 Ford Taurus Sedan to accommodate test subjects
3. A high resolution, BenQ PB8230 DLP digital projector to project the driving simulation video
4. A Draper Cinefold wide projection screen (3.67 m wide x 2.15 m high) – a front projection, flat-surface, tensioned, wide screen with 16 x 9 aspect ratio that was used for video projection. 12’ x 9’ were the overall dimension of the projection screen.
5. A Microsoft Sidewinder force feedback wheel to capture the subject’s responses
6. Various Texts providing information about statistics
7. Technical reports and papers about Dynamic Message Signs, human factors, message design, driving safety, and statistics
8. Minitab statistical software
9. Microsoft Visual Basic 6, Microsoft Visual Basic.net, Adobe® Photoshop®, Vanguard® VMS Central Controller, Daktronics Vanguard® VMS system Sonic Foundry VideoFactory™
10. Microsoft Office
11. Laptops for on-location survey administration
12. Existing messaging libraries, protocols, and resources used by RIDOT
Items 1, 2, 3, 4, 5, 8, 9 and 10 were made available from the IME department. Items 6 and part of 7 were available through libraries and the IME department. The remainder of item 7 was available through the internet access. Item 11 was available through partnership with the URITC. Item 12 was made available through cooperation and partnership with RIDOT.

Figures 19 and 20 show schematic diagrams of the laboratory setup with actual dimensions. The front bumper of the test vehicle was 0.62 meters away from the wide screen. The distance between the screen and the subject sitting in the driver’s seat of the vehicle was 2.24 meters. The distance between the subject’s eyes and ground surface was approximately 1.06 meters. The projector was mounted at a height of 2.22 meters from the ground surface at a distance of 5.64 meters from the wide screen. The video image projected on the screen was 3.67 m wide and 2.06 m high in size and was 0.58m from the floor.
As mentioned earlier, individual DMS images were created by Vanguard® VMS Central Controller, the same system used by RIDOT to generate and control DMS messages. Text messages and graphic images could be displayed on an 120x27 pixel
full-matrix black background. Figure 21 shows a snapshot of the in-process screen of the software. The DMS image generated was designed to mimic the Daktronics Vanguard® DMS system (model VF-2000-27x120-18-W) that is currently in-service in Rhode Island.

Figure 22 Snapshot of the Vanguard Message Editor

Messages with emergency themes, currently used messages and some nonessential test messages were included in the experiment. The same message was presented in various types and color combinations. Table 4 lists message content for the simulation, and Figure 22 shows examples of alternate configurations for two different messages. Double-stroke characters were used in the text-only messages due to the
advantage of double-stroke over single-stroke characters. However in the graphic-aided messages because of space limitation single-stroke characters were used. Graphics and text only messages were each presented in both red and amber.

Table 4 Simulation Message Content

<table>
<thead>
<tr>
<th>Type</th>
<th>Library</th>
<th>Message Content</th>
</tr>
</thead>
<tbody>
<tr>
<td>Non-Emergency</td>
<td>Road Work</td>
<td>ROAD WORK</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1 MILE AHEAD</td>
</tr>
<tr>
<td></td>
<td></td>
<td>EXPECT DELAYS</td>
</tr>
<tr>
<td></td>
<td>Congestion</td>
<td>CONGESTION</td>
</tr>
<tr>
<td></td>
<td></td>
<td>REDUCE SPEED</td>
</tr>
<tr>
<td></td>
<td></td>
<td>NEXT 3 EXITS</td>
</tr>
<tr>
<td>Emergency</td>
<td>Hurricane/LNG</td>
<td>SHELTER</td>
</tr>
<tr>
<td></td>
<td></td>
<td>NEXT EXIT</td>
</tr>
<tr>
<td></td>
<td></td>
<td>RTE 1-A S</td>
</tr>
<tr>
<td></td>
<td>Hurricane</td>
<td>HURRICANE</td>
</tr>
<tr>
<td></td>
<td></td>
<td>EVACUATE</td>
</tr>
<tr>
<td></td>
<td></td>
<td>RTE 1 N</td>
</tr>
<tr>
<td>Non-Essential</td>
<td>Slippery Road</td>
<td>SLIPPERY ROAD</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1 MILE AHEAD</td>
</tr>
<tr>
<td></td>
<td></td>
<td>USE CAUTION</td>
</tr>
<tr>
<td></td>
<td>Accident</td>
<td>ACCIDENT</td>
</tr>
<tr>
<td></td>
<td></td>
<td>AT EXIT 9</td>
</tr>
<tr>
<td></td>
<td></td>
<td>EXPECT DELAYS</td>
</tr>
</tbody>
</table>

Currently employed messages were presented for comparison. Figure 23 displays a sample of such messages, some with graphics added to determine if the
addition of graphics produces the same effect in emergency and non-emergency messages.

The nonessential messages mentioned above were included to prevent the subject from guessing and not paying enough attention to the entire messages. There were two types of the nonessential test messages used in the lab experiment, graphic aided and text-only messages. Figure 24 shows an example of a graphic-aided nonessential test messages.

The nonessential text-only test messages were created to prevent subjects from guessing the content of a text-only message in simulation based on the overall shape of
the message formed by words in different lines with different lengths. These messages were selected for use based upon their similarity to their essential counterparts. Examples are provided in Figure 25.

![Essential messages](image1)

![Nonessential messages](image2)

Figure 26 Similarly-shaped essential and nonessential text-only test messages

4.3.4 Simulation Experiment Execution

This research differed considerably in practice from previous related research conducted by the department because the experiment was configured to run on location at the Warwick Mall rather than in the Motorist Performance Laboratory. This change of venue required extensive preparation in order to conduct a proper experiment. A location within the Warwick Mall had to be secured and custom fit with the necessary devices to make the space conducive to the simulation. A rental vehicle in the form of a 2006 Chrysler 300 had to be secured (since the laboratory test vehicle was not roadworthy and the research was limited to using university approved renters), a custom projector stand had to be created to achieve the proper image characteristics, and a force feedback wheel had to be customized to fit the new vehicle (see Appendix F).
Computers and equipment for the electronic survey administration and the simulation had to be moved into place and fit with various new components in order to function properly in the new environment. The new simulation space itself had to be altered to achieve the proper level of light by adjusting light sources and positioning pipe and drape partitions provided by the mall. Extensive work was done to advertise the event to the public, create consent forms, instructional aids, and other informative materials, coordinate staffing and manage the administration event, and supply incentives for participation. Detailed photographs and a floor plan of the survey and simulation space can be viewed in Appendix F. The execution of the Warwick Mall took place with the aid of mall and RIDOT staff from Friday, May 11th, 2007, until Thursday, May 17th, 2007. The event space was generally opened to the public from 9:00 A.M. to 1:00 P.M. and 5:00 P. M. until 9:00 P. M. This space was generally staffed by three graduate students, two undergraduate students, and a faculty advisor.

As with the other experimental inquiries, prior to the start of the simulation experiment, a research team member gave potential experiment participants a briefing about the simulation experiment, answered any questions the individual had, and asked the subject to read, understand, and then sign a consent form approved by the university’s institutional review board. During the entire period of the experiment, the space around the test vehicle was kept dark except for an interior light illuminating steering wheel buttons guide materials to help participants remember the steering wheel input designations for the various message types. The subject was first asked to sit in the driver’s seat of the vehicle and make herself/himself comfortable by adjusting seat position and seat height. A step by step introduction was then presented to the subject
on the screen as the researcher gave detailed explanations about the experiment. Figure 26 shows these steps. The subject was instructed to press one of the five pre-defined buttons on the Sidewinder wheel according to the content of the DMS message. The subject was asked to press: button “1” for the “ROAD WORK” class of messages; button “2” for the “CONGESTION” class of messages; button “3” for “HURRICANE” class of messages; button “4” for the “SHELTER” class of messages; and button “5” for the nonessential test massages regardless of message type or message color. An instruction sheet was also placed on the instrumentation panel in the test vehicle to further assist subjects with response button selection.
Figure 27 Introduction slides given by the computer program
Participants were informed that both response speed and accuracy were important in the experiment. The response time was measured as the time difference between the start of a video and the moment when a subject pressed a button to respond. If the subject did not make a proper response before the video finished, a warning message would appear in a window to alert the subject. Figure 27 shows this message.

![Figure 27 Warning message of not responding](image)

The accuracy was calculated for each test subject as the ratio of the correct responses to the total number of responses that she/he made in the experiment. An accuracy report was presented to the participant at the end of each experimental run. Figure 28 shows one such report.

A short practice session was provided at the beginning of the simulation program to help subjects adjust to the particular characteristics of the simulation experiment as well as the laboratory environment. The subject could repeat the practice run as many times as she/he desired. After the practice run, the subject was asked to enter basic demographic information and signal the researcher to start the experiment. Figure 29 shows the demographic data entry form. During the experiment, individual simulation video clips were projected onto the projection screen where the DMS image
would initially appear on the horizon as a small dot and gradually increase in size as seen in actual driving. Forty simulation videos with different DMS images were shown to each subject consecutively in a random sequence. Figure 30 shows a simulation video on the screen.

![The Experiment is over. Thank you for your cooperation.](image)

*Figure 29 Simulation experiment's accuracy report*

![Please inform the researcher to enter your information below.](image)

*Figure 30 Driving simulation data entry form*
A set of Visual Basic computer programs were developed by the department to administer this experiment (see appendix D for the source code of this program). Figure 31 provides a snapshot of one of the instruction slides generated by this computer program. The response time and accuracy for each DMS test message made by each subject were recorded in a Microsoft Access® database in the computer. Each record in the database file corresponded to a test message shown in the simulation video. It recorded the name, age, gender of the subject; the message content, message type, message color, response time, response key, and the correctness of the response for that message. The recorded data is presented in appendix E. The overall experiment included a total of 40 test messages and took about 15 to 25 minutes to complete.
Figure 32. Simulation video introduction on the screen

Figure 33 Snapshot of one of the instruction slides in driving simulation
CHAPTER 5

RESULTS

5.1. Paper-Based Public Opinion Survey

The survey responses collected from 233 Rhode Island residents were tabulated in a Microsoft Excel® worksheet (see Tables 5 and 6). Using this software totals and percentages were calculated for each question. To report agreement the percentages for responses of “1” and “2” were combined, while responses of “4” and “5” indicated disagreement. It can be seen that 46.1% of survey participants were not familiar with evacuation routes near their home while 32% were. Regarding the utility of radio and television in providing emergency information, 42.7% and 51.9% of participants agreed that radio and television respectively were useful sources of highway information, while 33.4% and 28.8% disagreed. The data indicates that 62.3% of those polled disagreed with the assertion that the 511 Call in traffic information line was useful and only 17.8% agreed. Additionally, 47.2% of participants disagreed with the internet being a useful source of information and 30.9% agreed. The most useful sources of information according to the public’s opinion were fixed signs and to a slightly lesser extent electronic VMS signs, with 65.3% and 57.1% of the sample agreeing with the statement that such methods of communication were useful.

The public opinion was mixed regarding the frequency of radio usage (35.3% agreed that they use it frequently, but 42% disagreed) and television usage (41.2% strongly agreed that they use it frequently, and 35.3% disagreed). A 71.1% majority of the population sample disagreed with the assertion that they frequently used the 511
call in system and 55.9% disagreed with the statement that they frequently used the internet. In contrast to this, 67% of the motorists frequently used fixed signs, and 52.9% indicated that they frequently used VMS signs.

Based on the response to the fourth survey question, more than 70% of motorists would like to have more information about emergencies provided by the transportation system. As indicated by responses to questions 5 and 6, most motorists thought that they followed VMS advice regarding roadwork or other functions (76.6%), and would be willing to follow VMS instructions during emergencies (89%).

From the responses to question 7, it was generally found that the public reacted positively to the helpfulness of a few existing emergency preparation signs including “icy road ahead,” “blizzard,” and “expect high winds” (82.8%, 72.9%, and 71.2% respectively). The polled public also found the proposed emergency preparation signs: “prepare for outages,” “fill gas tanks,” “secure loose objects,” and “secure water supplies” helpful (60.9%, 57.6%, 56.6%, and 51.9% respectively).

When given the choice of four sign designs presented in question 8 (see Table 6) indicating the need to detour during an emergency, 69.7% of the sample of motorists chose the sign that indicated the specific emergency (HURRICANE), the required action (EVACUATION), and the method/direction for that action (RTE 1 N). This preference is in agreement with the RIDOT TMC’s established protocols for three line messages. When a message display of abbreviated directions to a hurricane shelter was given in question 9, 62.2% of those surveyed came to the same conclusion as to what it meant when translated to a route on a map, indicating they were able to fill in the missing information sufficiently well. The rest of the questions (10-12) were more
qualitative in nature, with free response content that will be used to guide in the design of future research studies and driving simulation experiments.

To analyze the significance of percentages reflecting participants’ preferences a Chi-Squared Goodness of Fit test was used to compare observed frequencies with expected frequencies in order to establish whether there was enough evidence to consider the measured variations in preference distribution attributed to something other than an even distribution—meaning a difference did indeed exist. As can be seen in Table 6, in every instance but that of the whether the internet was a useful source of information to motorists (question 2e), goodness of fit tests show that the preferences are significant in their distribution.

Table 5. Totals for demographics provided by survey participants

<table>
<thead>
<tr>
<th>Number of Participants by Demographic Category</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gender</td>
</tr>
<tr>
<td>F</td>
</tr>
<tr>
<td>102</td>
</tr>
<tr>
<td>Age (years)</td>
</tr>
<tr>
<td>&lt;22</td>
</tr>
<tr>
<td>49</td>
</tr>
</tbody>
</table>
Table 6. Public Opinion Questionnaire Responses

Q1. I am familiar with current evacuation routes near my home
Q2. The following methods of highway communication are useful sources of information for me:
Q3. I use the following methods of highway communication frequently:
Q4. I would like the highway transportation system to provide more information about emergencies:
Q5. I follow advice from electronic variable message signs (VMS) regarding road work or detours:
Q6. I am willing to follow instruction provided by VMS during emergency situations:
Q7. I find the following VMS messages helpful in preparing for emergencies:

<table>
<thead>
<tr>
<th>Question</th>
<th>Strongly Agree</th>
<th>Strongly Disagree</th>
<th>Total</th>
<th>χ2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Q1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Q2 Radio</td>
<td>18.7% 13.3% 21.7% 17.3% 28.8%</td>
<td>225</td>
<td>15.24</td>
<td></td>
</tr>
<tr>
<td>Q2 TV</td>
<td>20.3% 16.4% 24.9% 16.0% 17.4%</td>
<td>213</td>
<td>10.58</td>
<td></td>
</tr>
<tr>
<td>Q2 511</td>
<td>26.2% 25.7% 19.3% 14.4% 14.4%</td>
<td>202</td>
<td>13.74</td>
<td></td>
</tr>
<tr>
<td>Q2 VMS</td>
<td>30.0% 27.1% 21.3% 11.6% 10.6%</td>
<td>207</td>
<td>31.97</td>
<td></td>
</tr>
<tr>
<td>Q2 Internet</td>
<td>14.7% 16.2% 21.8% 20.8% 26.4%</td>
<td>197</td>
<td>8.56</td>
<td></td>
</tr>
<tr>
<td>Q2 Fixed Sign</td>
<td>44.3% 21.0% 14.8% 10.5% 9.5%</td>
<td>210</td>
<td>85.95</td>
<td></td>
</tr>
<tr>
<td>Q3 Radio</td>
<td>25.9% 9.4% 22.6% 13.7% 28.3%</td>
<td>212</td>
<td>27.86</td>
<td></td>
</tr>
<tr>
<td>Q3 TV</td>
<td>27.0% 14.2% 23.5% 14.7% 20.6%</td>
<td>204</td>
<td>12.52</td>
<td></td>
</tr>
<tr>
<td>Q3 511</td>
<td>7.7% 4.1% 17.0% 18.0% 53.1%</td>
<td>194</td>
<td>146.52</td>
<td></td>
</tr>
<tr>
<td>Q3 VMS</td>
<td>28.9% 24.0% 23.0% 10.3% 13.7%</td>
<td>204</td>
<td>24.33</td>
<td></td>
</tr>
<tr>
<td>Q3 Internet</td>
<td>10.8% 12.8% 20.5% 18.5% 37.4%</td>
<td>195</td>
<td>43.23</td>
<td></td>
</tr>
<tr>
<td>Q3 Fixed Sign</td>
<td>47.4% 19.6% 18.2% 7.2% 7.7%</td>
<td>209</td>
<td>111.74</td>
<td></td>
</tr>
<tr>
<td>Q4 Radio</td>
<td>45.0% 25.5% 16.4% 6.8% 6.4%</td>
<td>220</td>
<td>113.05</td>
<td></td>
</tr>
<tr>
<td>Q4 TV</td>
<td>47.2% 29.4% 12.4% 4.6% 6.4%</td>
<td>218</td>
<td>142.78</td>
<td></td>
</tr>
<tr>
<td>Q4 511</td>
<td>68.7% 20.3% 4.6% 1.8% 4.6%</td>
<td>217</td>
<td>344.13</td>
<td></td>
</tr>
<tr>
<td>Q4 VMS</td>
<td>28.9% 24.0% 23.0% 10.3% 13.7%</td>
<td>204</td>
<td>24.33</td>
<td></td>
</tr>
<tr>
<td>Q4 Internet</td>
<td>10.8% 12.8% 20.5% 18.5% 37.4%</td>
<td>195</td>
<td>43.23</td>
<td></td>
</tr>
<tr>
<td>Q4 Fixed Sign</td>
<td>47.4% 19.6% 18.2% 7.2% 7.7%</td>
<td>209</td>
<td>111.74</td>
<td></td>
</tr>
</tbody>
</table>

| Q7 fill gas tanks | 38.6% 19.0% 22.9% 7.6% 11.9% | 210 | 60.14|
| Q7 blizzard       | 48.6% 24.3% 16.2% 3.3% 7.6% | 210 | 134.43|
| Q7 secure water supplies | 33.0% 18.9% 28.2% 7.3% 12.6% | 206 | 46.67|
| Q7 prepare for outages | 36.7% 24.2% 23.7% 6.3% 9.2% | 207 | 63.70|
| Q7 icy road ahead | 62.7% 20.1% 10.0% 2.9% 4.3% | 209 | 257.10|
| Q7 expect high winds | 47.6% 23.6% 17.3% 6.3% 5.3% | 208 | 123.44|
| Q7 secure loose objects | 36.6% 20.0% 20.5% 10.7% 12.2% | 205 | 43.27|

<table>
<thead>
<tr>
<th>Question</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>Total</th>
<th>χ2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Q8</td>
<td>7.2% 19.2% 69.7% 3.4%</td>
<td>208</td>
<td>302.86</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Q9</td>
<td>11.6% 62.2% 9.9% 16.3%</td>
<td>172</td>
<td>128.51</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Q10a</td>
<td>10.1% 89.9% 10.1% 89.9%</td>
<td>148</td>
<td>94.08</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Q10b</td>
<td>89.3% 10.7% 89.3% 10.7%</td>
<td>84</td>
<td>51.86</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Q10c</td>
<td>16.5% 83.5% 16.5% 83.5%</td>
<td>109</td>
<td>48.89</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Q10d</td>
<td>80.3% 18.9% 80.3% 18.9%</td>
<td>132</td>
<td>49.71</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

5.2. Electronic Survey

The electronic survey was presented using laptops at retirement communities, a public university, a shopping center, and private residences to extend the findings of the paper-based public opinion survey. The survey was administered to 477 participants over a period of two months (see Tables 7 and 8). This data was recorded automatically using macros programmed into the Microsoft Powerpoint® file the survey was created.
Records from the subjects were then compiled into Microsoft Excel® worksheets and Minitab14 databases for analysis. The data was filtered down to 465 participants who successfully completed the majority of the questions. The 51 questions were analyzed individually and then compiled according to the factors they treated. The statistical significances of the preference distributions were again tested using a goodness of fit test. Portions of the data were also tabulated to evaluate differences in preference for non-emergency and emergency message types (and other factors). To evaluate the significance of these factors a two-proportion test was implemented with a two sided $\alpha$-level of significance of 0.05 (corresponding to 95% confidence and using Z values).

Table 7 Subject participation Totals

<table>
<thead>
<tr>
<th>Participants</th>
<th>Initial</th>
<th>Final</th>
</tr>
</thead>
<tbody>
<tr>
<td>Survey</td>
<td>475</td>
<td>465</td>
</tr>
<tr>
<td>Simulation</td>
<td>166</td>
<td>157</td>
</tr>
<tr>
<td>Both</td>
<td>140</td>
<td></td>
</tr>
</tbody>
</table>

Table 8 Initial Survey Demographic Breakdown

<table>
<thead>
<tr>
<th>Age</th>
<th>Gender</th>
<th>Language</th>
<th>Education</th>
<th>Color blind</th>
<th>Glasses</th>
</tr>
</thead>
<tbody>
<tr>
<td>18-40</td>
<td>279</td>
<td>200</td>
<td>431 High Sch.</td>
<td>no</td>
<td>447</td>
</tr>
<tr>
<td>41-60</td>
<td>115</td>
<td>265</td>
<td>31 College</td>
<td>yes</td>
<td>17</td>
</tr>
<tr>
<td>Over 60</td>
<td>70</td>
<td>68</td>
<td></td>
<td>yes</td>
<td>256</td>
</tr>
<tr>
<td>Total</td>
<td>464</td>
<td>465</td>
<td>462</td>
<td>464</td>
<td>464</td>
</tr>
</tbody>
</table>

Of the participants who successfully completed the electronic survey, a subset of 140 also successfully completed the simulation experiment (see Table 9). This enabled survey preferences to be compared with results from the simulation to correlations between stated preferences about message signs and motorists’ actual performance when interacting with said signs.
Table 9 Survey and Simulation Demographic Breakdown

<table>
<thead>
<tr>
<th>Age</th>
<th>Gender</th>
<th>Language</th>
<th>Education</th>
<th>Color blind</th>
<th>Glasses</th>
</tr>
</thead>
<tbody>
<tr>
<td>18-40</td>
<td>73 Women</td>
<td>58 English</td>
<td>126 High Sch.</td>
<td>no</td>
<td>135 no</td>
</tr>
<tr>
<td>41-60</td>
<td>43 Men</td>
<td>82 Other</td>
<td>13 College</td>
<td>yes</td>
<td>5 yes</td>
</tr>
<tr>
<td>Over 60</td>
<td>24 Post Grad.</td>
<td>21</td>
<td>140</td>
<td>140</td>
<td>140</td>
</tr>
<tr>
<td>Total</td>
<td>140</td>
<td>140</td>
<td>139</td>
<td>140</td>
<td>140</td>
</tr>
</tbody>
</table>

The statistical evaluation of questions by factor was performed for both the full 465 participants (e.g. Table 10) and for the extended participation subset of 140 subjects (e.g. Table 11). Demographics were also charted for each factor (e.g. Table 12).

In questions testing what level of abbreviation motorists most preferred (“some” indicating the use of only RIDOT approved abbreviations, “none”, or “all” referring to the use of as many abbreviations possible with the intent of minimizing the number of letters in a message), 70.18% stated that no abbreviation whatsoever was most appealing and useful to them. The subgroup of subjects participating in both survey and simulation similarly had a 70.30% preference. A goodness of fit test indicated that this distribution of frequencies was significant. Dividing the questions into those evaluating non-emergency messages and those evaluating reveals that 76.13% of the full sample of motorists preferred no abbreviations in the case of non-emergency questions, and 68.04% expressed the same preference for emergency messages. The preferences for the simulation subset were in agreement—76.43% for non-emergency and 68.26% for emergency messages. The two sample proportion test conducted on the simulation subset indicates there is no significant difference between the two values, but the test also shows the similar percentages in the larger set are actually slightly different.
In the four questions assessing whether motorists preferred messages with or without animated graphics (created by inserting different graphic images on a two panel alternating display) 68.22% responded positively to signs with animation present (68.57% of the simulation subset). Goodness of fit tests indicated that the animation questions’ distributions were significant ($\chi^2$ value of at least 77; greater than the critical value of 3.84). See Tables 13 and 14.
The eight questions examining the use of the color red vs. the default amber color in messaging found that 47.47% of the population preferred messages in amber and 52.52% preferred red (in the simulation subset the percentages were 44.09% and 55.91% respectively). Though these were quite similar results, goodness of fit tests indicated they were significant in their differences. Dividing the response data into non-emergency and emergency factor levels, it was found that 48.37% of motorists preferred amber in non-emergency signs, 46.58% preferred amber in emergency messages, 51.63% preferred red in non-emergency messages, and 53.42% preferred red in emergency displays. In the case of both the overall set and simulation subset the two sample proportion test found that there were not significant differences in the responses to non-emergency and emergency messages (Z value of 1.09 for overall set and 1.26 for simulation subset, less than the Z threshold of 1.96). See Tables 15, 16, and 17.
The results for the questions evaluating whether motorists preferred signs that had key word elements that flashed demonstrated that 73.44% found the messages that flashed to be more helpful than those that did not (76.02% in the simulation subset).

Goodness of fit tests revealed that these findings had significance (χ² value of at least 151). See Tables 18 and 19.
Table 18 Initial Survey Flashing Question Breakdown

**Initial Survey Flashing**

<table>
<thead>
<tr>
<th>Slide No.</th>
<th>9</th>
<th>20</th>
<th>31</th>
<th>48</th>
<th>TOTAL</th>
<th>Goodness of Fit X²</th>
</tr>
</thead>
<tbody>
<tr>
<td>No</td>
<td>101</td>
<td>112</td>
<td>170</td>
<td>107</td>
<td>490</td>
<td>26.56%</td>
</tr>
<tr>
<td></td>
<td>21.72%</td>
<td>24.09%</td>
<td>36.56%</td>
<td>23.01%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Yes</td>
<td>360</td>
<td>350</td>
<td>292</td>
<td>353</td>
<td>1355</td>
<td></td>
</tr>
<tr>
<td></td>
<td>77.42%</td>
<td>75.27%</td>
<td>62.80%</td>
<td>75.91%</td>
<td></td>
<td>73.44%</td>
</tr>
</tbody>
</table>

| TOTAL     | 1845  | 912.33|

Table 19 Survey and Simulation Flashing Question Breakdown

**Survey & Simulation Flashing**

<table>
<thead>
<tr>
<th>Slide No.</th>
<th>9</th>
<th>20</th>
<th>31</th>
<th>48</th>
<th>TOTAL</th>
<th>Goodness of Fit X²</th>
</tr>
</thead>
<tbody>
<tr>
<td>No</td>
<td>24</td>
<td>29</td>
<td>48</td>
<td>33</td>
<td>134</td>
<td>23.97%</td>
</tr>
<tr>
<td></td>
<td>17.14%</td>
<td>20.71%</td>
<td>34.29%</td>
<td>23.57%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Yes</td>
<td>116</td>
<td>111</td>
<td>91</td>
<td>107</td>
<td>425</td>
<td></td>
</tr>
<tr>
<td></td>
<td>82.86%</td>
<td>79.29%</td>
<td>65.00%</td>
<td>76.43%</td>
<td></td>
<td>76.03%</td>
</tr>
</tbody>
</table>

| TOTAL     | 559   | 151.49|

An analysis of the questions asking motorists whether they preferred messages that had a red graphic contrasting amber text over messages with graphics and text rendered in amber showed 69% of motorists did prefer the contrasting graphic color (62.04% of the simulation subset). Goodness of fit tests confirmed that this was a significant result ($\chi^2$ value of at least 80). Non-emergency messages with a red graphic were preferred 77.06% of the time, and emergency messages were preferred 60.93% of the time (70.56% and 53.57% for the survey subset). These values were found to be different when subjected to the two sample proportion test. The z-value in the overall sample was 4.12 and in the simulation subset 7.5 (exceeding the critical Z value of 1.96). See Tables 20, 21, and 22.
Six questions in the electronic survey tested preferences for different types of graphics. Slide 3 depicted three alternate graphics for a high wind message. 55.70% of participants (56.43% in the simulation subset) preferred the graphic of a flag waving over an electronic depiction of a typical truck rolling over fixed sign or a digital windmill picture. Slide 4 presented hurricane graphics of two different types to survey subjects. 57.63% of subjects (60% for the simulation subset) preferred a custom designed “spiral-shaped” graphic over a digital rendering of the hurricane symbol found on many fixed signs. The fifth slide gave participants a choice between two emergency vehicle graphics. 63.23% (70% for the simulation subset) of participants preferred an
ambulance vehicle graphic over the standard EMS symbol. Slide 10 depicted three alternate graphics for an emergency shelter message. The most preferred graphic was that of a simple peaked roof building shape. It was selected 43.87% of the time (40.28% for the simulation subset), while a graphic of people under a roof was selected 37.85% of the time (38.85% for the simulation subset) and a different building graphic was selected 17.42% of the time (20.86% for the simulation subset). The eleventh slide gave motorists the choice of three different graphics representing fire. 73.33% of motorists preferred a small flame graphic (69.29% for the simulation subset). Slide 25 displayed two bridge messages—one with a graphic of a simple truss bridge intact, and the other with a similar truss bridge but with the middle portion missing. 77.85% of subjects preferred the “missing span” truss graphic (82.14% for the simulation subset). See Tables 23 and 24.

Table 23 Results for Graphic Type questions: part I

<table>
<thead>
<tr>
<th>Graphic Type</th>
<th>Initial Survey</th>
<th>Survey &amp; Simulation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Slide No.</td>
<td>25</td>
<td>5</td>
</tr>
<tr>
<td>A</td>
<td>99</td>
<td>164</td>
</tr>
<tr>
<td></td>
<td>21.29%</td>
<td>35.27%</td>
</tr>
<tr>
<td>B</td>
<td>362</td>
<td>294</td>
</tr>
<tr>
<td></td>
<td>77.85%</td>
<td>63.23%</td>
</tr>
<tr>
<td>C</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 23 Results for Graphic Type questions: part I

<table>
<thead>
<tr>
<th>Graphic Type</th>
<th>Initial Survey</th>
<th>Survey &amp; Simulation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Slide No.</td>
<td>25</td>
<td>5</td>
</tr>
<tr>
<td>A</td>
<td>24</td>
<td>41</td>
</tr>
<tr>
<td></td>
<td>17.14%</td>
<td>29.29%</td>
</tr>
<tr>
<td>B</td>
<td>115</td>
<td>98</td>
</tr>
<tr>
<td></td>
<td>82.14%</td>
<td>70.00%</td>
</tr>
<tr>
<td>C</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
### Table 24 Results for Graphic Type questions: part II

**Initial Survey**

<table>
<thead>
<tr>
<th>Slide No.</th>
<th>3</th>
<th>4</th>
<th>10</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>259</td>
<td>191</td>
<td>81</td>
</tr>
<tr>
<td></td>
<td>55.70%</td>
<td>41.08%</td>
<td>17.42%</td>
</tr>
<tr>
<td>B</td>
<td>115</td>
<td>268</td>
<td>204</td>
</tr>
<tr>
<td></td>
<td>24.73%</td>
<td>57.63%</td>
<td>43.87%</td>
</tr>
<tr>
<td>C</td>
<td>84</td>
<td></td>
<td>176</td>
</tr>
<tr>
<td></td>
<td>18.06%</td>
<td></td>
<td>37.85%</td>
</tr>
</tbody>
</table>

**Survey & Simulation**

<table>
<thead>
<tr>
<th>Slide No.</th>
<th>3</th>
<th>4</th>
<th>10</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>79</td>
<td>54</td>
<td>29</td>
</tr>
<tr>
<td></td>
<td>56.43%</td>
<td>38.57%</td>
<td>20.71%</td>
</tr>
<tr>
<td>B</td>
<td>29</td>
<td>84</td>
<td>56</td>
</tr>
<tr>
<td></td>
<td>20.71%</td>
<td>60.00%</td>
<td>40.00%</td>
</tr>
<tr>
<td>C</td>
<td>29</td>
<td></td>
<td>54</td>
</tr>
<tr>
<td></td>
<td>6.24%</td>
<td></td>
<td>11.61%</td>
</tr>
</tbody>
</table>

Participants found center justified messages more to their liking than right or left justification, with 56.92% stating such a preference (57.09% for the simulation subset). Goodness of fit tests demonstrated that this distribution was significant ($\chi^2$ values of at least 182; greater than the critical value of 7.815). In considering the justification of non-emergency and emergency messages, 60.65% of participants preferred center justification for non-emergency messages, while only 44.95% exercised such a preference for emergency messages. The simulation subset likewise had differing percentages of 61.15% and 45% respectively. The two sample proportion test confirmed the differences in these percentages (with Z values of 5.88 and 3.34). See Tables 25, 26, and 27.
Table 25 Initial Survey justification question breakdown

<table>
<thead>
<tr>
<th>Slide No.</th>
<th>46</th>
<th>17</th>
<th>41</th>
<th>34</th>
<th>TOTAL</th>
<th>Goodness of Fit X²</th>
<th>Non Emergency</th>
<th>Emergency</th>
<th>Proportion Test Z value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Left</td>
<td>254</td>
<td>53</td>
<td>120</td>
<td>195</td>
<td>622</td>
<td>427</td>
<td>195</td>
<td>195</td>
<td>5.88</td>
</tr>
<tr>
<td>Center</td>
<td>155</td>
<td>391</td>
<td>294</td>
<td>209</td>
<td>1049</td>
<td>840</td>
<td>209</td>
<td>209</td>
<td></td>
</tr>
<tr>
<td>Right</td>
<td>53</td>
<td>17</td>
<td>48</td>
<td>54</td>
<td>172</td>
<td>118</td>
<td>54</td>
<td>54</td>
<td></td>
</tr>
</tbody>
</table>

|            | 1843 | 624.45 |

Table 26 Survey and Simulation justification question breakdown

<table>
<thead>
<tr>
<th>Slide No.</th>
<th>46</th>
<th>17</th>
<th>41</th>
<th>34</th>
<th>TOTAL</th>
<th>Goodness of Fit X²</th>
<th>Non Emergency</th>
<th>Emergency</th>
<th>Proportion Test Z value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Left</td>
<td>71</td>
<td>13</td>
<td>36</td>
<td>61</td>
<td>181</td>
<td>120</td>
<td>61</td>
<td>195</td>
<td>3.34</td>
</tr>
<tr>
<td>Center</td>
<td>44</td>
<td>119</td>
<td>92</td>
<td>63</td>
<td>318</td>
<td>255</td>
<td>63</td>
<td>195</td>
<td></td>
</tr>
<tr>
<td>Right</td>
<td>24</td>
<td>6</td>
<td>12</td>
<td>16</td>
<td>58</td>
<td>42</td>
<td>16</td>
<td>195</td>
<td></td>
</tr>
</tbody>
</table>

|            | 557 | 182.22 |

Table 27 Survey and Simulation justification question demographic breakdown

<table>
<thead>
<tr>
<th>Justification</th>
<th>Gender</th>
<th>Age</th>
<th>Language</th>
<th>Education</th>
<th>Corrective Lenses</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>F</td>
<td>M</td>
<td>18-40</td>
<td>41-60</td>
<td>61+</td>
</tr>
<tr>
<td>Nonemergency</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Left</td>
<td>81</td>
<td>115</td>
<td>117</td>
<td>117</td>
<td>48</td>
</tr>
<tr>
<td>Center</td>
<td>88</td>
<td>121</td>
<td>124</td>
<td>124</td>
<td>55</td>
</tr>
<tr>
<td>Right</td>
<td>29</td>
<td>25</td>
<td>33</td>
<td>11</td>
<td>50</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Emergency</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Left</td>
<td>184</td>
<td>248</td>
<td>246</td>
<td>109</td>
<td>40</td>
</tr>
<tr>
<td>Center</td>
<td>362</td>
<td>480</td>
<td>530</td>
<td>205</td>
<td>107</td>
</tr>
<tr>
<td>Right</td>
<td>52</td>
<td>96</td>
<td>57</td>
<td>29</td>
<td>32</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Left</td>
<td>285</td>
<td>358</td>
<td>363</td>
<td>157</td>
<td>103</td>
</tr>
<tr>
<td>Center</td>
<td>450</td>
<td>601</td>
<td>654</td>
<td>260</td>
<td>137</td>
</tr>
<tr>
<td>Right</td>
<td>81</td>
<td>91</td>
<td>90</td>
<td>40</td>
<td>42</td>
</tr>
</tbody>
</table>

Four survey questions polled motorists on whether they would prefer amber text with a red outline or red text with an amber outline in place of the standard amber text. 47.67% of participants (and 46.95% of the simulation subset) stated that they preferred the standard amber text over the outlined choices, and 32.28% (31.9% of the simulation subset) favored red text with an amber outline. Goodness of fit tests again revealed that
there was a non-uniform factor level in the distribution (with \( \chi^2 \) values of at least 56.25). In questions depicting non-emergency messages 42.15% of survey participants (and 40.71% of the simulation subset) favored standard amber text while 39.57% (37.14% in the simulation subset) found red text with an amber outline to be the best choice. The preferences for text in emergency messages was more biased toward plain amber text, as it was selected 49.46% of the time (49.04% in the simulation subset) as opposed to the 29.79% (30.14% in the simulation subset) that selected red text with an amber outline. The two sample proportion test found there to be a significant difference in the groups for the simulation subset (with a Z value of 1.71) but the larger data set demonstrated a slight difference in opinion (Z value of 2.72). See Tables 28, 29, and 30.

Table 28 Initial Survey outline color question breakdown

<table>
<thead>
<tr>
<th>Slide No.</th>
<th>43</th>
<th>33</th>
<th>50</th>
<th>14</th>
<th>TOTAL</th>
<th>Goodness of Fit X²</th>
<th>Non Emergency</th>
<th>Emergency</th>
<th>Proportion Test Z value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Amber w/ Red Outline</td>
<td>83</td>
<td>100</td>
<td>96</td>
<td>91</td>
<td>370</td>
<td>83</td>
<td>17.85%</td>
<td>21.51%</td>
<td>20.65%</td>
</tr>
<tr>
<td>Amber</td>
<td>196</td>
<td>205</td>
<td>244</td>
<td>235</td>
<td>880</td>
<td>196</td>
<td>42.15%</td>
<td>44.09%</td>
<td>52.47%</td>
</tr>
<tr>
<td>Red w/ Amber</td>
<td>184</td>
<td>156</td>
<td>122</td>
<td>134</td>
<td>596</td>
<td>184</td>
<td>39.57%</td>
<td>33.55%</td>
<td>26.24%</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1846</td>
<td>212.03</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 29 Survey and Simulation outline color question breakdown

<table>
<thead>
<tr>
<th>Slide No.</th>
<th>43</th>
<th>33</th>
<th>50</th>
<th>14</th>
<th>TOTAL</th>
<th>Goodness of Fit X²</th>
<th>Non Emergency</th>
<th>Emergency</th>
<th>Proportion Test Z value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Amber w/ Red Outline</td>
<td>31</td>
<td>29</td>
<td>25</td>
<td>33</td>
<td>118</td>
<td>31</td>
<td>22.14%</td>
<td>20.71%</td>
<td>17.86%</td>
</tr>
<tr>
<td>Amber</td>
<td>57</td>
<td>64</td>
<td>71</td>
<td>70</td>
<td>262</td>
<td>57</td>
<td>40.71%</td>
<td>45.71%</td>
<td>50.71%</td>
</tr>
<tr>
<td>Red w/ Amber</td>
<td>52</td>
<td>47</td>
<td>43</td>
<td>36</td>
<td>178</td>
<td>52</td>
<td>37.14%</td>
<td>33.57%</td>
<td>30.71%</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>558</td>
<td>56.26</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

86
Eight questions tested messages in a text only format in contrast to a message format that used a graphic to represent a key portion of the message information to motorists. Strikingly, motorists preferred the text only messages, picking those messages 71.25% of the time (66.28% in the simulation subset). Goodness of fit tests verified that these were significant differences in the data (with $\chi^2$ values in excess of 100). Motorists were also more likely to favor text in emergency messages (78.78% for the overall survey data and 73.66% for the simulation subset), than they favored text for non-emergency displays (63.72% in the overall survey data and 58.93% in the simulation subset). Proportion tests confirmed this difference in preference ($Z$ value of 10.11). See Tables 31, 32, and 33.
Table 32 Survey and Simulation Text vs. Graphic question breakdown

<table>
<thead>
<tr>
<th>Slide No.</th>
<th>21</th>
<th>30</th>
<th>35</th>
<th>19</th>
<th>12</th>
<th>29</th>
<th>24</th>
<th>44</th>
<th>TOTAL</th>
<th>Goodness of Fit X²</th>
<th>Non Emergency</th>
<th>Emergency</th>
<th>Proportion Test Z value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Text</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>80</td>
<td>77.14%</td>
<td>58.93%</td>
<td>330 5.21</td>
</tr>
<tr>
<td>Graphic</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>86</td>
<td>71.43%</td>
<td>61.43%</td>
<td>411</td>
</tr>
<tr>
<td></td>
<td>108</td>
<td>108</td>
<td>108</td>
<td>108</td>
<td>108</td>
<td>108</td>
<td>108</td>
<td>108</td>
<td>108</td>
<td>111</td>
<td>79.29%</td>
<td>73.66%</td>
<td></td>
</tr>
<tr>
<td></td>
<td>93</td>
<td>93</td>
<td>93</td>
<td>93</td>
<td>93</td>
<td>93</td>
<td>93</td>
<td>93</td>
<td>93</td>
<td>741</td>
<td>66.28%</td>
<td>58.93%</td>
<td>411</td>
</tr>
<tr>
<td></td>
<td>76</td>
<td>76</td>
<td>76</td>
<td>76</td>
<td>76</td>
<td>76</td>
<td>76</td>
<td>76</td>
<td>76</td>
<td>330</td>
<td>54.29%</td>
<td>33.72%</td>
<td></td>
</tr>
<tr>
<td></td>
<td>88</td>
<td>88</td>
<td>88</td>
<td>88</td>
<td>88</td>
<td>88</td>
<td>88</td>
<td>88</td>
<td>88</td>
<td>411</td>
<td>62.86%</td>
<td>41.07%</td>
<td></td>
</tr>
<tr>
<td></td>
<td>99</td>
<td>99</td>
<td>99</td>
<td>99</td>
<td>99</td>
<td>99</td>
<td>99</td>
<td>99</td>
<td>99</td>
<td>741</td>
<td>70.71%</td>
<td>66.28%</td>
<td>58.93%</td>
</tr>
<tr>
<td></td>
<td>111</td>
<td>111</td>
<td>111</td>
<td>111</td>
<td>111</td>
<td>111</td>
<td>111</td>
<td>111</td>
<td>111</td>
<td>330</td>
<td>79.29%</td>
<td>73.66%</td>
<td>411</td>
</tr>
<tr>
<td></td>
<td>741</td>
<td>741</td>
<td>741</td>
<td>741</td>
<td>741</td>
<td>741</td>
<td>741</td>
<td>741</td>
<td>741</td>
<td>411</td>
<td>66.28%</td>
<td>58.93%</td>
<td>330</td>
</tr>
</tbody>
</table>

Table 33 Survey and Simulation Text vs. Graphic question demographic breakdown

<table>
<thead>
<tr>
<th>Text vs. Graphic</th>
<th>Gender</th>
<th>Age</th>
<th>Language</th>
<th>Education</th>
<th>Corrective Lenses</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nonemergency</td>
<td>F</td>
<td>M</td>
<td>18-40</td>
<td>41-60</td>
<td>61+</td>
</tr>
<tr>
<td>Text</td>
<td>469</td>
<td>706</td>
<td>678</td>
<td>313</td>
<td>184</td>
</tr>
<tr>
<td>Graphic</td>
<td>324</td>
<td>347</td>
<td>433</td>
<td>142</td>
<td>96</td>
</tr>
<tr>
<td>Emergency</td>
<td>Text</td>
<td>625</td>
<td>830</td>
<td>855</td>
<td>374</td>
</tr>
<tr>
<td>Graphic</td>
<td>169</td>
<td>226</td>
<td>259</td>
<td>80</td>
<td>56</td>
</tr>
<tr>
<td>Total</td>
<td>Text</td>
<td>1094</td>
<td>1536</td>
<td>1533</td>
<td>687</td>
</tr>
<tr>
<td>Graphic</td>
<td>493</td>
<td>573</td>
<td>692</td>
<td>222</td>
<td>152</td>
</tr>
</tbody>
</table>

The survey also posed questions to evaluate what types of wording motorists preferred for informing them of emergency situations. For a variety of different emergency scenarios three separate displays of the same traffic guidance were presented: one type started the message with a general danger word, one began by stating the specific event (such as “hurricane”), and one type gave instruction without listing the event explicitly (by saying only “road closed” or “evacuate” etc.). 43.54% of motorists indicated they preferred the messages that simply named the event explicitly (46.15% of the simulation subset), while 28.99% preferred no specific reference to the emergency itself (28.98% in the simulation subset), and only 27.27% favored a general “danger” warning to start the message (24.87% in the simulation subset). See Tables 34 and 35.

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The final section of the survey explained a driving scenario and instructions to motorists and then presented them with a two-panel flashing messages that gave instructions about an emergency detour they were to follow. This message was displayed in the same aspect ratio as a real VMS, and appeared on the screen for the approximate length of time a motorist would be able to read it at typical highway speed (around 6 seconds of viewing time). After this time the sign disappeared and the motorist was presented with four sets of two fixed above highways signs depicting highway exits and other directions. The motorists were two choose which of the two signs in each question indicated the proper route to take to successfully follow the

---

Table 34 Initial Survey Word Type question breakdown

<table>
<thead>
<tr>
<th>Slide No.</th>
<th>38</th>
<th>45</th>
<th>15</th>
<th>47</th>
<th>TOTAL</th>
<th>Goodness of Fit $X^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Event</td>
<td>173</td>
<td>190</td>
<td>146</td>
<td>293</td>
<td>802</td>
<td>43.54%</td>
</tr>
<tr>
<td>Action</td>
<td>103</td>
<td>162</td>
<td>138</td>
<td>103</td>
<td>506</td>
<td>27.47%</td>
</tr>
<tr>
<td>Danger</td>
<td>185</td>
<td>108</td>
<td>179</td>
<td>62</td>
<td>534</td>
<td>28.99%</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1842</td>
<td>86.72</td>
</tr>
</tbody>
</table>

Table 35 Survey and Simulation Word Type question breakdown

<table>
<thead>
<tr>
<th>Slide No.</th>
<th>38</th>
<th>45</th>
<th>15</th>
<th>47</th>
<th>TOTAL</th>
<th>Goodness of Fit $X^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Event</td>
<td>59</td>
<td>58</td>
<td>47</td>
<td>94</td>
<td>258</td>
<td>46.15%</td>
</tr>
<tr>
<td>Action</td>
<td>31</td>
<td>39</td>
<td>39</td>
<td>30</td>
<td>139</td>
<td>24.87%</td>
</tr>
<tr>
<td>Danger</td>
<td>50</td>
<td>42</td>
<td>54</td>
<td>16</td>
<td>162</td>
<td>28.98%</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>559</td>
<td>42.77</td>
</tr>
</tbody>
</table>
directions provided by the six lines of the flashing two panel VMS display. 83.72% of participants correctly identified the first sign, 87.14% correctly identified the second sign, 79.74% identified the third sign properly, and 53.12% identified the fourth sign properly. However, 56.34% identified the first and second signs properly, 39.78% identified the first, second, and third signs properly, and only 26.24% identified all the signs properly to successfully complete the detour. This indicates a fair identification and comprehension of individual directions, but a highly diminishing ability to retain and use all of the information.

5.3. Driving Simulation Experiment

The video-based highway message identification simulation was successfully administered to 157 motorists from the state of Rhode Island, and 140 of those participants also participated in the electronic survey on VMS/DMS displays (see Table 36). Two replicates of 20 videos were administered to subjects in a random order that included both emergency and non-emergency messages, and also tested versions of these messages with and without graphics replacing text and in both red and amber colors. The simulation also recorded demographic information to help analyze the data. The program executing the simulation recorded both the accuracy and response time for subjects. The influence of several of the above listed treatment factors were evaluated for both of these response variables. Table 37 lists the response time and accuracy breakdown for the simulation categorized by each message type (an accident message with red color and graphics, etc.). Table 41 represents the response times and accuracies of the subset of subjects that participated in both the survey and simulation.
The average participant took 18.24 seconds to complete each simulation video and answered 33.67 questions correctly for an overall accuracy of 84%. By factoring the messages into emergency and non-emergency types, statistical analysis found that the average response time for a motorist to provide a correct answer was 15.06 seconds for non-emergency messages and 16.57 seconds for emergency messages. The accuracy in identifying non-emergency signs was 84.32% and emergency messages was nearly the same at 83.96%. Analysis of variance indicates that while response time is greater for emergency messages, the accuracy of emergency and non-emergency messages is no different based on statistical significance.
### Table 37: Simulation Results Quantified by Question Type Mean Performance

<table>
<thead>
<tr>
<th>Sign Type</th>
<th>Time</th>
<th># Correct</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Accident-Red Graphic</td>
<td>19.69</td>
<td>15.64</td>
<td>79.30%</td>
</tr>
<tr>
<td>Accident-Red Text</td>
<td>20.44</td>
<td>18.17</td>
<td>85.67%</td>
</tr>
<tr>
<td>Congestion-Amber Graphic</td>
<td>17.44</td>
<td>12.45</td>
<td>74.20%</td>
</tr>
<tr>
<td>Congestion-Red Graphic</td>
<td>18.19</td>
<td>13.08</td>
<td>72.61%</td>
</tr>
<tr>
<td>Congestion-Amber Text</td>
<td>17.77</td>
<td>15.48</td>
<td>83.44%</td>
</tr>
<tr>
<td>Congestion-Red Text</td>
<td>19.85</td>
<td>17.38</td>
<td>85.67%</td>
</tr>
<tr>
<td>Hurricane-Amber Graphic</td>
<td>18.15</td>
<td>16.42</td>
<td>84.39%</td>
</tr>
<tr>
<td>Hurricane-Red Graphic</td>
<td>18.91</td>
<td>15.36</td>
<td>80.25%</td>
</tr>
<tr>
<td>Hurricane-Amber Text</td>
<td>18.17</td>
<td>16.15</td>
<td>84.08%</td>
</tr>
<tr>
<td>Hurricane-Red Text</td>
<td>20.79</td>
<td>18.31</td>
<td>85.35%</td>
</tr>
<tr>
<td>Road Work-Amber Graphic</td>
<td>11.67</td>
<td>10.77</td>
<td>92.04%</td>
</tr>
<tr>
<td>Road Work-Red Graphic</td>
<td>14.56</td>
<td>13.18</td>
<td>91.72%</td>
</tr>
<tr>
<td>Road Work-Amber Text</td>
<td>18.26</td>
<td>16.58</td>
<td>87.58%</td>
</tr>
<tr>
<td>Road Work-Red Text</td>
<td>20.94</td>
<td>18.07</td>
<td>86.31%</td>
</tr>
<tr>
<td>Shelter-Amber Graphic</td>
<td>17.42</td>
<td>15.40</td>
<td>87.26%</td>
</tr>
<tr>
<td>Shelter-Red Graphic</td>
<td>19.24</td>
<td>15.59</td>
<td>79.62%</td>
</tr>
<tr>
<td>Shelter-Amber Text</td>
<td>19.52</td>
<td>17.81</td>
<td>87.26%</td>
</tr>
<tr>
<td>Shelter-Red Text</td>
<td>19.97</td>
<td>17.50</td>
<td>83.44%</td>
</tr>
<tr>
<td>Slippery Road-Amber Graphic</td>
<td>15.88</td>
<td>13.70</td>
<td>84.71%</td>
</tr>
<tr>
<td>Slippery Road-Amber Text</td>
<td>17.97</td>
<td>16.19</td>
<td>88.54%</td>
</tr>
</tbody>
</table>

### Table 38: Simulation Results Quantified by Factor Type Mean Performance

<table>
<thead>
<tr>
<th>Variable Tested</th>
<th>Time for Accurate Response</th>
<th>Accuracy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Graphics</td>
<td>14.16</td>
<td>82.61%</td>
</tr>
<tr>
<td>Text</td>
<td>17.16</td>
<td>85.73%</td>
</tr>
<tr>
<td>Nonemergency</td>
<td>15.06</td>
<td>84.32%</td>
</tr>
<tr>
<td>Emergency</td>
<td>16.57</td>
<td>83.96%</td>
</tr>
<tr>
<td>Red</td>
<td>16.23</td>
<td>82.99%</td>
</tr>
<tr>
<td>Amber</td>
<td>15.09</td>
<td>85.35%</td>
</tr>
</tbody>
</table>

### Table 39: Simulation Results Quantified by Factor Mean Cross tabulations

<table>
<thead>
<tr>
<th></th>
<th>Graphics</th>
<th>Text</th>
<th>Amber</th>
<th>Red</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nonemergency</td>
<td>Time</td>
<td>16.24</td>
<td>19.21</td>
<td>16.50</td>
</tr>
<tr>
<td></td>
<td>Accuracy</td>
<td>82.43%</td>
<td>86.20%</td>
<td>85.08%</td>
</tr>
<tr>
<td>Emergency</td>
<td>Time</td>
<td>18.43</td>
<td>19.61</td>
<td>18.31</td>
</tr>
<tr>
<td></td>
<td>Accuracy</td>
<td>82.88%</td>
<td>85.03%</td>
<td>85.75%</td>
</tr>
</tbody>
</table>

### Table 40: Simulation Results Quantified by Three Factor Mean Crosstabulations
It was found that messages containing graphics have a lower response time than text-only messages on average, but are a bit less accurate. The average time for a motorist to respond correctly to a message containing graphics was 14.16 seconds compared to the average text-only response time of 17.16 seconds. However, the accuracy of graphic messages was 82.61% and for text-only messages it was 85.73%. Analysis of variance considered these factor levels and found both the response time and accuracy for the selection of graphics vs. text to be significant.

### Table 41 Simulation & Survey Data Quantified by Question Type Mean Performance

<table>
<thead>
<tr>
<th>Sign Type</th>
<th>Time for Accurate Response</th>
<th>Number of Participants</th>
<th>Accuracy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Accident-Red Graphic</td>
<td>19.84</td>
<td>223</td>
<td>79.64%</td>
</tr>
<tr>
<td>Accident-Red Text</td>
<td>20.60</td>
<td>241</td>
<td>86.07%</td>
</tr>
<tr>
<td>Congestion-Amber Graphic</td>
<td>17.27</td>
<td>207</td>
<td>73.93%</td>
</tr>
<tr>
<td>Congestion-Red Graphic</td>
<td>18.16</td>
<td>205</td>
<td>73.21%</td>
</tr>
<tr>
<td>Congestion-Amber Text</td>
<td>17.57</td>
<td>230</td>
<td>82.14%</td>
</tr>
<tr>
<td>Congestion-Red Text</td>
<td>19.67</td>
<td>238</td>
<td>85.00%</td>
</tr>
<tr>
<td>Hurricane-Amber Graphic</td>
<td>18.15</td>
<td>236</td>
<td>84.29%</td>
</tr>
<tr>
<td>Hurricane-Red Graphic</td>
<td>19.04</td>
<td>228</td>
<td>81.43%</td>
</tr>
<tr>
<td>Hurricane-Amber Text</td>
<td>18.21</td>
<td>236</td>
<td>84.29%</td>
</tr>
<tr>
<td>Hurricane-Red Text</td>
<td>20.77</td>
<td>240</td>
<td>85.71%</td>
</tr>
<tr>
<td>Road Work-Amber Graphic</td>
<td>11.59</td>
<td>258</td>
<td>92.14%</td>
</tr>
<tr>
<td>Road Work-Red Graphic</td>
<td>14.50</td>
<td>258</td>
<td>92.14%</td>
</tr>
<tr>
<td>Road Work-Amber Text</td>
<td>18.21</td>
<td>248</td>
<td>88.57%</td>
</tr>
<tr>
<td>Road Work-Red Text</td>
<td>20.95</td>
<td>242</td>
<td>86.43%</td>
</tr>
<tr>
<td>Shelter-Amber Graphic</td>
<td>17.32</td>
<td>245</td>
<td>87.50%</td>
</tr>
<tr>
<td>Shelter-Red Graphic</td>
<td>19.22</td>
<td>223</td>
<td>79.64%</td>
</tr>
<tr>
<td>Shelter-Amber Text</td>
<td>19.47</td>
<td>247</td>
<td>88.21%</td>
</tr>
<tr>
<td>Shelter-Red Text</td>
<td>19.92</td>
<td>235</td>
<td>83.93%</td>
</tr>
<tr>
<td>Slippery Road-Amber Graphic</td>
<td>16.02</td>
<td>241</td>
<td>86.07%</td>
</tr>
<tr>
<td>Slippery Road-Amber Text</td>
<td>17.86</td>
<td>249</td>
<td>88.93%</td>
</tr>
</tbody>
</table>

93
The simulation discovered that red messages not only required more time to properly identify, but also were identified with less accuracy by the test subjects. Red messages took 16.23 seconds to properly identify on average while amber messages took only 15.09 seconds. The average accuracy in identifying messages using red was 82.99% while the accuracy for amber messages was 85.35%. Analysis of variance indicates that both time and accuracy experience significant changes for the two factor levels.

When the data is sorted to separate non-emergency messages from emergency messages, the same trends exist when examining the influence of the other two factors. Non-emergency messages increase in response time from 16.24 seconds for graphics to
19.21 for text only messages. However, accuracy also increases from 82.43% up to 86.20%. When emergency messages are considered, the response time climbs from 18.43 seconds for graphics aided messages up to 19.61 seconds for text-only messages. The accuracy climbed for emergency messages as well, from 82.88% for graphics to 85.03% for text only accuracy. Non-emergency messages in amber performed better than those rendered in red in both accuracy and response time. Amber had an average accuracy of 85.05% and a response time of 16.50 seconds, where as red had an average accuracy of 83.55% and an average response time of 18.95. The same relative performances can be seen when considering emergency message data. Amber messages had an average accuracy of 85.75% and a response time of 18.31 seconds while red messages displayed an average accuracy of 82.17% and an average response time of 19.73 seconds. So despite the increased response time for emergency messages, graphics and color choice have the same effect on non-emergency and emergency messages. Similar trends are also evident when all three factors are considered in conjunction. Graphics messages perform better in response time and less well in accuracy for red colored non-emergency and emergency messages (from 17.82 seconds down to 14.81 seconds but from 85.83% down to 77.5%; from 17.89 seconds down to 15.60 seconds but from 84.82% down to 80.54%). The same can be said when examining the characteristics with amber (from 15.97 seconds down to 12.31 seconds but from 86.55% down to 84.05% for non-emergency messages; from 17.28 seconds down to 15.79 seconds but from 88.39% down to 85.89% for emergency messages).
Viewing the data from another perspective, amber colored, text-only messages perform better in time and accuracy than red colored textual messages for both non-emergency messages (15.97 seconds and 86.55% accuracy compared to 17.82 seconds and 85.83% accuracy) and emergency messages (17.28 seconds and 88.39% accuracy compared to 17.9 seconds and 84.82% accuracy). Amber colored graphics aided messages are on average more accurate than their red counterparts for both non-emergency messages (84.05% vs. 77.5%) and emergency messages (85.89% vs. 80.54%). An exception to the overall pattern of agreement is the relative response times for amber and red colored graphics aided messages for non-emergency and emergency displays. In non-emergency displays with graphics, changing from amber to red increases average response time from 12.31 seconds to 14.81 seconds, but in emergency messages with graphics this alteration slightly decreases response time from 15.79 seconds to 15.60 seconds. Overall, there appears to be little difference in accuracy between non-emergency and emergency messages for a variety of different treatments (and levels). However emergency messages appear to have a slower response time and are affected far less by the use of amber in messaging, both in the

### Table 45 Simulation Results Quantified by Demographic Factors

<table>
<thead>
<tr>
<th>Corrective Lenses</th>
<th>Gender</th>
<th>Age</th>
<th>Language</th>
<th>Education</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>F</td>
<td>M</td>
<td>18-40</td>
<td>41-60</td>
</tr>
<tr>
<td></td>
<td>Accuracy</td>
<td>84.41%</td>
<td>84.60%</td>
<td>86.83%</td>
</tr>
<tr>
<td></td>
<td>Accuracy</td>
<td>82.54%</td>
<td>86.79%</td>
<td>86.01%</td>
</tr>
<tr>
<td></td>
<td>Accuracy</td>
<td>83.45%</td>
<td>82.74%</td>
<td>86.99%</td>
</tr>
<tr>
<td>Text</td>
<td>Time</td>
<td>16.73</td>
<td>17.36</td>
<td>16.52</td>
</tr>
<tr>
<td></td>
<td>Accuracy</td>
<td>83.39%</td>
<td>87.05%</td>
<td>87.14%</td>
</tr>
<tr>
<td></td>
<td>Accuracy</td>
<td>84.48%</td>
<td>86.46%</td>
<td>87.95%</td>
</tr>
<tr>
<td>Red</td>
<td>Time</td>
<td>16.12</td>
<td>16.31</td>
<td>15.73</td>
</tr>
<tr>
<td></td>
<td>Accuracy</td>
<td>82.84%</td>
<td>83.86%</td>
<td>86.78%</td>
</tr>
</tbody>
</table>
small differences between both graphic and text-only color choices and in the small amount of deviation from non-emergency response times for all red colored messages.

5.4. Testing for Significant Simulation Factors

The results of the driving simulation experiment for both response time and accuracy were analyzed against different statistical models to investigate the effects of demographics and other experimental factors on the response of simulation participants. Using MINITAB® software, analysis of variance (ANOVA) tests and regression analyses were performed on the simulation data. A significance level ($\alpha$) of 5% was employed in all analyses. Normal probability plots (an example of which can be seen in Figure 33) confirmed that the normality assumptions ANOVA methods operate upon were valid for all the models tested. This indicates that the models selected were appropriate for the statistical analyses presented below.
To establish whether there was a particular correlation within the simulation experiment between response time and accuracy that would dictate how any further analysis would be conducted, regression analyses were performed on the data. The ANOVA results and regression statistics are displayed in Table 46. It can be seen that no correlation was found between response time and accuracy, indicating the two were independent in the experiment. Figure 34 provides a scatter plot of response time and accuracy for individual subjects that was utilized to aid in analysis.
Table 46 Regression output testing for Accuracy and Response Time Correlation

The regression model:
Accuracy = 0.902 - 0.00287 Mean Response Time

<table>
<thead>
<tr>
<th>Predictor</th>
<th>Coef</th>
<th>SE Coef</th>
<th>T</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant</td>
<td>0.90228</td>
<td>0.07012</td>
<td>12.87</td>
<td>0</td>
</tr>
<tr>
<td>Mean Response Time</td>
<td>-0.00287</td>
<td>0.00377</td>
<td>-0.76</td>
<td>0.447</td>
</tr>
</tbody>
</table>

Analysis of Variance

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>SS</th>
<th>MS</th>
<th>F</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Regression</td>
<td>1</td>
<td>0.01137</td>
<td>0.01137</td>
<td>0.58</td>
<td>0.447</td>
</tr>
<tr>
<td>Residual Error</td>
<td>155</td>
<td>3.03422</td>
<td>0.01958</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>156</td>
<td>3.04559</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 35 Scatterplot for testing for Accuracy and Response time Correlation

The following describes the ANOVA methods applied in this particular experiment. The researchers first developed models to assess the effects of factors for response time in the experiment and then re-evaluated those model types again using the accuracy data.
The first model considered how the main effects of three experimental factors and their interaction influenced subject response time utilizing the following configuration:

\[
\text{Response Time} = \mu + T + M + C + M \times C + T \times M + T \times C + T \times M \times C + \varepsilon
\]  

Where (for all the model equations):

\(\mu\) – Overall mean in seconds;

\(T\) – Message library type (Emergency or Non-emergency);

\(M\) – Message display type (text only or graphic);

\(C\) – Message color (Amber or Red);

\(A\) – Subjects’ age;

\(G\) – Subjects’ gender;

\(S\) – Subjects’ education;

\(L\) – Subjects’ native language;

\(U\) – Subjects’ corrective lenses;

\(\varepsilon\) – Error.

Table 47 provides the ANOVA table statistical breakdown, Figure 35 expresses the main effects, and Figure 36 displays the interactions of the message library type, message display type, and message color factors for response time as generated from MINITAB®. It can be seen from these figures that all three factors’ main effects have are significant in determining participant response time (demonstrated by the fact that P-values of 0.000 are well below the 0.05 threshold for significance) as well as the
interaction of message library type and message display type as well as message library type and message color.

Table 47 General Linear Model: Response Time vs. NON/Emergency, G/T, A/R

<table>
<thead>
<tr>
<th>Factor</th>
<th>Type</th>
<th>Levels</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>T</td>
<td>fixed</td>
<td>2</td>
<td>1, 2</td>
</tr>
<tr>
<td>M</td>
<td>fixed</td>
<td>2</td>
<td>1, 2</td>
</tr>
<tr>
<td>C</td>
<td>fixed</td>
<td>2</td>
<td>1, 2</td>
</tr>
</tbody>
</table>

Analysis of Variance

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>Seq SS</th>
<th>Adj SS</th>
<th>Adj MS</th>
<th>F</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>T</td>
<td>1</td>
<td>2415.6</td>
<td>2415.6</td>
<td>2415.6</td>
<td>58.34</td>
<td>0.000</td>
</tr>
<tr>
<td>M</td>
<td>1</td>
<td>6805.4</td>
<td>5520.6</td>
<td>5520.6</td>
<td>133.32</td>
<td>0.000</td>
</tr>
<tr>
<td>C</td>
<td>1</td>
<td>6117.4</td>
<td>5274.5</td>
<td>5274.5</td>
<td>127.38</td>
<td>0.000</td>
</tr>
<tr>
<td>T*M</td>
<td>1</td>
<td>1065</td>
<td>1065</td>
<td>1065</td>
<td>25.72</td>
<td>0.000</td>
</tr>
<tr>
<td>T*C</td>
<td>1</td>
<td>401.6</td>
<td>401.6</td>
<td>401.6</td>
<td>9.7</td>
<td>0.002</td>
</tr>
<tr>
<td>M*C</td>
<td>1</td>
<td>0.5</td>
<td>1</td>
<td>1</td>
<td>0.02</td>
<td>0.878</td>
</tr>
<tr>
<td>T<em>M</em>C</td>
<td>1</td>
<td>2.6</td>
<td>2.6</td>
<td>2.6</td>
<td>0.06</td>
<td>0.803</td>
</tr>
<tr>
<td>Error</td>
<td>5592</td>
<td>231555.6</td>
<td>231555.6</td>
<td>41.4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>5599</td>
<td>248363.6</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Mean of Resp Time

<table>
<thead>
<tr>
<th>Emergency</th>
<th>Nonemergency</th>
<th>Graphic</th>
<th>Text</th>
<th>Amber</th>
<th>Red</th>
</tr>
</thead>
<tbody>
<tr>
<td>19.5</td>
<td>19.0</td>
<td>18.5</td>
<td>18.0</td>
<td>17.5</td>
<td></td>
</tr>
</tbody>
</table>

Figure 36 Main Effects Plot (fitted means) for Resp Time

Figure 36 Main Effects for Response time given message library, display and Color
To ascertain whether the display characteristics tested in the simulation experiment affected all the segments of Rhode Island’s driving population in the same manner, two more models were developed using the demographic information provided by participants. The first model tested the results of the emergency and non-emergency message library types against subject age and gender using the following expression:

\[
\text{Response Time} = \mu + A + G + T + A\times G + A\times T + L\times G + A\times G\times T + \varepsilon
\]

(1.2)

The ANOVA table, main effects plots, and interaction plots for this model can be seen in Table 48, Figure 37, and Figure 38. Once again, changing factor levels from non-emergency to emergency message library types has a significant affect on subject...
response time. Subject age, gender, and the interaction of message library type and age are all significant factors in determining the response time of a subject.

Table 48 General Linear Model: Response Time vs. NON/Emergency, Age, Gender

<table>
<thead>
<tr>
<th>Factor</th>
<th>Type</th>
<th>Levels</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>T</td>
<td>fixed</td>
<td>2</td>
<td>1,2</td>
</tr>
<tr>
<td>A</td>
<td>fixed</td>
<td>3</td>
<td>1,2,3</td>
</tr>
<tr>
<td>G</td>
<td>fixed</td>
<td>2</td>
<td>1,2</td>
</tr>
</tbody>
</table>

Analysis of Variance

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>Seq SS</th>
<th>Adj SS</th>
<th>Adj MS</th>
<th>F</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>T</td>
<td>1</td>
<td>2415.6</td>
<td>1241.5</td>
<td>1241.5</td>
<td>30.29</td>
<td>0.000</td>
</tr>
<tr>
<td>A</td>
<td>2</td>
<td>16062.8</td>
<td>14659.8</td>
<td>7329.9</td>
<td>178.86</td>
<td>0.000</td>
</tr>
<tr>
<td>G</td>
<td>1</td>
<td>356.5</td>
<td>184.1</td>
<td>184.1</td>
<td>4.49</td>
<td>0.034</td>
</tr>
<tr>
<td>T*A</td>
<td>2</td>
<td>458.9</td>
<td>452.8</td>
<td>226.4</td>
<td>5.52</td>
<td>0.004</td>
</tr>
<tr>
<td>T*G</td>
<td>1</td>
<td>3.0</td>
<td>3.5</td>
<td>3.5</td>
<td>0.09</td>
<td>0.769</td>
</tr>
<tr>
<td>A*G</td>
<td>2</td>
<td>67.8</td>
<td>66.5</td>
<td>33.3</td>
<td>0.81</td>
<td>0.444</td>
</tr>
<tr>
<td>T<em>A</em>G</td>
<td>2</td>
<td>1.0</td>
<td>1.0</td>
<td>0.5</td>
<td>0.01</td>
<td>0.987</td>
</tr>
<tr>
<td>Error</td>
<td>5588</td>
<td>228998.0</td>
<td>228998.0</td>
<td>41.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>5599</td>
<td>24863.6</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Mean of Resp Time

<table>
<thead>
<tr>
<th></th>
<th>Male</th>
<th>Female</th>
<th>18-40</th>
<th>41-60</th>
<th>61 and Above</th>
<th>Nonemergency</th>
<th>Emergency</th>
</tr>
</thead>
<tbody>
<tr>
<td>T</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>G</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 38 Main Effects for Response time with demographic factors age and gender
Figure 39 Interaction plot for Response time with demographic factors age and gender

By utilizing the combined survey and simulation data researchers could further test the potential influence of additional demographics such as education, native language, use of corrective lenses against the message library type factor following the equation presented below:

\[
\text{Response Time} = \mu + T + S + L + U + T \times S + T \times L + T \times U + L \times U + L \times S + U \times S + T \times S \times L + T \times L \times U + L \times U \times S + T \times S \times U + T \times S \times L \times U + \varepsilon
\]

(1.3)

Table 49 shows that language was not a significant factor in the experiment, but education, use of corrective lenses and of course message library type were all significant factors. However, the interaction of language and education, language and
corrective lenses, and language, education and corrective lenses were all significant.

Figures 39 and 40 provide visual references for these relationships.

Table 49 General Linear Model: Response Time vs. Language, Education, Lenses, Non/Emergency

<table>
<thead>
<tr>
<th>Factor</th>
<th>Type</th>
<th>Levels</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>L</td>
<td>fixed</td>
<td>2</td>
<td>1,2</td>
</tr>
<tr>
<td>S</td>
<td>fixed</td>
<td>3</td>
<td>1,2,3</td>
</tr>
<tr>
<td>U</td>
<td>fixed</td>
<td>2</td>
<td>1,2</td>
</tr>
<tr>
<td>T</td>
<td>fixed</td>
<td>3</td>
<td>1,2</td>
</tr>
</tbody>
</table>

Analysis of Variance

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>Seq SS</th>
<th>Adj SS</th>
<th>Adj MS</th>
<th>F</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>L</td>
<td>1</td>
<td>121.4</td>
<td>4.0</td>
<td>4.0</td>
<td>0.10</td>
<td>0.757</td>
</tr>
<tr>
<td>S</td>
<td>2</td>
<td>3164.7</td>
<td>1782.4</td>
<td>891.2</td>
<td>21.25</td>
<td>0.000</td>
</tr>
<tr>
<td>U</td>
<td>1</td>
<td>4073.3</td>
<td>749.6</td>
<td>749.6</td>
<td>17.87</td>
<td>0.000</td>
</tr>
<tr>
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</table>

S = 6.47648  R-Sq = 5.83%  R-Sq(adj) = 5.44%
Figure 40 Main Effects for Response time with language, corrective lenses, education

Figure 41 Interaction plot for Response time with language, lenses, education
After reviewing these models a refined model was generated to encompass only the most influential of demographic factors and investigate how they related to response time and the choice in presenting non-emergency vs. emergency message types. Though gender and lenses both appear to be significant, the experimental data set is not large enough to support including both of them so gender is reviewed first. This model can be expressed with the following equation:

\[
\text{Response Time} = \mu + T + S + A + G + T \times S + T \times A + T \times G + A \times G + A \times S + G \times S + T \times S \times A + T \times A \times G + A \times G \times S + T \times S \times G + T \times S \times A \times G + \epsilon
\]  

(1.4)

It can then be seen from Table 50, Figure 41, and Figure 42 that in this new model all of the factors that were previously significant remain so with the exception of gender. With a P-value of 0.194 it is no longer significant.
Table 50 General Linear Model: Response Time vs. NON/Emergency, Age, Gender, Education

<table>
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<th>Levels</th>
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<td>1,2,3</td>
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Analysis of Variance

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<th>Adj SS</th>
<th>Adj MS</th>
<th>F</th>
<th>P</th>
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<td>0.001</td>
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<td></td>
</tr>
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<td></td>
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<td></td>
</tr>
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</table>

S = 6.36276   R-Sq = 9.30%   R-Sq(adj) = 8.73%
Figure 42 Main Effects for Response time with age, gender, education

Figure 43 Interaction plot for Response time with age, gender, education
A final revision is made to the model by replacing the gender factor with the corrective lenses factor and analyzing the data with MINITAB®. The equation reflecting the model is now:

\[
\text{Response Time} = \mu + T + S + A + U + T \times S + T \times A + T \times U + A \times U + A \times S + U \times S + T \times S \times A + T \times A \times U + A \times U \times S + T \times S \times U + T \times S \times A \times U + \varepsilon
\] (1.5)

Table 51, Figure 43, and Figure 44 show that this final model indicates message library type, age, education, and corrective lenses are all significant factors in response time for subjects participating in the driving simulation. There are also six significant factor interactions (age x message library type; age x education; age x corrective lenses; corrective lenses x education; corrective lenses x education x message library type; age x corrective lenses x message library type) and three more marginally significant interactions (corrective lenses x message library type, \( p = 0.53 \); age x education x message library type, \( p = 0.085 \); age x education x corrective lenses x message library type, \( p = 0.065 \)). In short, there are a great number of factors that are of some significance in response time for simulation participants.
Table 51 General Linear Model: Response Time vs. Age, Lenses, Education
NON/Emergency

<table>
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<th>Factor</th>
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<th>Levels</th>
<th>Values</th>
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Analysis of Variance

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<th>Adj SS</th>
<th>Adj MS</th>
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S = 6.30225   R-Sq = 11.02%   R-Sq(adj) = 10.46%
Main Effects Plot (fitted means) for Resp Time

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<td>19</td>
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YesNo

PostGradCollegeHigh

EmergencyNonemergency

Figure 44 Main Effects for Response Time with age, lenses, education

Interaction Plot (fitted means) for Resp Time

Figure 45 Interaction plot for Response Time with age, lenses, education
The preceding ANOVA analysis was then began again using accuracy in the simulation as the response variable in place of response time. The first model was thus:

\[
\text{Accuracy} = \mu + T + M + C + M \times C + T \times M + T \times C + T \times M \times C + \varepsilon
\]

(2.1)

Analysis of this model revealed that the factor of message library type with levels of emergency and non-emergency was not significant for subject accuracy in the experiment (p-value of 0.916). Message display type and message color were both significant factors, but there were no significant interactions between factors. The complete ANOVA table can be seen in Table 52, and the main effects and interaction plots can be seen in Figure 45 and Figure 46 below.

<table>
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<th>Factor</th>
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<tr>
<td>C</td>
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<td>1, 2</td>
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Table 52 General Linear Model: Accuracy vs. NON/Emergency, G/T, A/R

<table>
<thead>
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<th>DF</th>
<th>Seq SS</th>
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</tbody>
</table>

\[ S = 0.361744 \quad R-Sq = 0.33\% \quad R-Sq(adj) = 0.20\% \]
Figure 46 Main Effects for Accuracy given message Library, Display, Color

Figure 47 Interaction plot for Accuracy given Message Library, Display, Color
The second set of models considering demographic factors of age and education together with the corrective lenses factor was constructed as follows:

\[
\text{Accuracy} = \mu + A + S + U + A \times S + A \times U + S \times U + A \times S \times U + \varepsilon
\]  

(2.2)

When evaluated using MINITAB®, this model demonstrates that age and education are significant factors for accuracy as well as the interactions of age with lenses and education with lenses, but lenses and the interaction of age with education and age, education, and lenses are not significant. These results are found in Table 53, and the main effects of the factors and their interactions are plotted in Figures 47, and 48.

Table 53 General Linear Model: Accuracy vs. Age, Education, Corrective Lenses

<table>
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<td>1,2,3</td>
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Analysis of Variance

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<th>Adj MS</th>
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<td>0.1</td>
<td>0.0</td>
<td>1.61</td>
<td>0.185</td>
</tr>
<tr>
<td>A*U</td>
<td>2</td>
<td>0.1</td>
<td>0.1</td>
<td>0.1</td>
<td>6.38</td>
<td>0.003</td>
</tr>
<tr>
<td>S*U</td>
<td>2</td>
<td>0.1</td>
<td>0.1</td>
<td>0.0</td>
<td>4.66</td>
<td>0.014</td>
</tr>
<tr>
<td>A<em>S</em>U</td>
<td>4</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.25</td>
<td>0.908</td>
</tr>
<tr>
<td>Error</td>
<td>54</td>
<td>0.6</td>
<td>0.6</td>
<td>0.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>71</td>
<td>1.2256</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Figure 48 Main Effects for Accuracy with factors age, education, lenses

Figure 49 Interaction plot for Accuracy with factors age, education, lenses
The next model again considered the demographics of language, education, and use of corrective lenses in conjunction with the message library type factor as specified by the equation:

$$\text{Accuracy} = \mu + T + S + L + U + T \times S + T \times L + T \times U + L \times U + L \times S + U \times S + T \times S \times L + T \times L \times U + L \times U \times S + T \times S \times U + T \times S \times L \times U + \varepsilon$$

(2.3)

The evaluation of this model, as seen in Table 54, demonstrates that the only significant factors are education, the interactions of language with corrective lenses, education with corrective lenses, education with message library type, education with language with corrective lenses, and education with corrective lenses with message library type. Thus it is dominated by the main effects and interaction effects of the education demographic factor.
Table 54 General Linear Model: Accuracy vs. Language, Education, Lenses, Non/Emergency

<table>
<thead>
<tr>
<th>Factor</th>
<th>Type</th>
<th>Levels</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>1,2</td>
</tr>
<tr>
<td>L</td>
<td>fixed</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>S</td>
<td>fixed</td>
<td>3</td>
<td>1,2,3</td>
</tr>
<tr>
<td>U</td>
<td>fixed</td>
<td>2</td>
<td>1,2</td>
</tr>
<tr>
<td>T</td>
<td>fixed</td>
<td>2</td>
<td>1,2</td>
</tr>
</tbody>
</table>

Analysis of Variance

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>Seq SS</th>
<th>Adj SS</th>
<th>Adj MS</th>
<th>F</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>L</td>
<td>1</td>
<td>0.02</td>
<td>0.02</td>
<td>0.02</td>
<td>1.19</td>
<td>0.281</td>
</tr>
<tr>
<td>S</td>
<td>2</td>
<td>0.10</td>
<td>0.10</td>
<td>0.05</td>
<td>2.89</td>
<td>0.065</td>
</tr>
<tr>
<td>U</td>
<td>1</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
<td>0.86</td>
<td>0.358</td>
</tr>
<tr>
<td>T</td>
<td>1</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
<td>0.37</td>
<td>0.545</td>
</tr>
<tr>
<td>L*S</td>
<td>2</td>
<td>0.02</td>
<td>0.02</td>
<td>0.01</td>
<td>0.55</td>
<td>0.582</td>
</tr>
<tr>
<td>L*U</td>
<td>1</td>
<td>0.04</td>
<td>0.04</td>
<td>0.04</td>
<td>2.27</td>
<td>0.138</td>
</tr>
<tr>
<td>L*T</td>
<td>1</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
<td>0.67</td>
<td>0.418</td>
</tr>
<tr>
<td>S*U</td>
<td>2</td>
<td>0.10</td>
<td>0.10</td>
<td>0.05</td>
<td>2.89</td>
<td>0.065</td>
</tr>
<tr>
<td>S*T</td>
<td>2</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
<td>0.35</td>
<td>0.709</td>
</tr>
<tr>
<td>U*T</td>
<td>1</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
<td>0.44</td>
<td>0.509</td>
</tr>
<tr>
<td>L<em>S</em>U</td>
<td>2</td>
<td>0.01</td>
<td>0.01</td>
<td>0.00</td>
<td>0.23</td>
<td>0.796</td>
</tr>
<tr>
<td>L<em>S</em>T</td>
<td>2</td>
<td>0.04</td>
<td>0.04</td>
<td>0.02</td>
<td>1.18</td>
<td>0.316</td>
</tr>
<tr>
<td>L<em>U</em>T</td>
<td>1</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.18</td>
<td>0.676</td>
</tr>
<tr>
<td>S<em>U</em>T</td>
<td>2</td>
<td>0.02</td>
<td>0.02</td>
<td>0.01</td>
<td>0.55</td>
<td>0.578</td>
</tr>
<tr>
<td>L<em>S</em>U*T</td>
<td>2</td>
<td>0.03</td>
<td>0.03</td>
<td>0.01</td>
<td>0.86</td>
<td>0.428</td>
</tr>
<tr>
<td>Error</td>
<td>48</td>
<td>0.81</td>
<td>0.81</td>
<td>0.02</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>71</td>
<td>1.23</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Figure 50 Main Effects for Accuracy given language, lenses, and education

Figure 51 Interaction plot for Accuracy given language, lenses, and education
The model is finally revised to include only factors likely to be significant when considered in conjunction with each other. Message library type is evaluated with age, corrective lenses, and education in a model using the following equation:

\[
\text{Accuracy} = \mu + T + S + A + U + T \times S + T \times A + T \times U + A \times U + A \times S + U \times S + T \times S \times A + T \times A \times U + A \times U \times S + T \times S \times U + T \times S \times A \times U + \epsilon
\]

(2.4)

The results of analyzing this model show that message library type is not significant, but that age, education, and to a lesser extent corrective lenses are all significant when considering the accuracy with which subjects completed the driving simulation. The two way interactions of age vs. corrective lenses, age vs. education, age vs. message library type, and corrective lenses vs. education were all significant. The specifics of this analysis are enumerated via an ANOVA table displayed in Table 55. The main effects and interactions are plotted in Figure 51 and Figure 52.
Table 55 General Linear Model: Accuracy vs. Age, Lenses, Education, NON/Emergency

<table>
<thead>
<tr>
<th>Factor</th>
<th>Type</th>
<th>Levels</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>T</td>
<td>fixed</td>
<td>2</td>
<td>1,2</td>
</tr>
<tr>
<td>A</td>
<td>fixed</td>
<td>3</td>
<td>1,2,3</td>
</tr>
<tr>
<td>S</td>
<td>fixed</td>
<td>3</td>
<td>1,2,3</td>
</tr>
<tr>
<td>U</td>
<td>fixed</td>
<td>2</td>
<td>1,2</td>
</tr>
</tbody>
</table>

Analysis of Variance

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>Seq SS</th>
<th>Adj SS</th>
<th>Adj MS</th>
<th>F</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>T</td>
<td>1</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
<td>0.52</td>
<td>0.474</td>
</tr>
<tr>
<td>A</td>
<td>2</td>
<td>0.24</td>
<td>0.24</td>
<td>0.12</td>
<td>10.23</td>
<td>0.000</td>
</tr>
<tr>
<td>S</td>
<td>2</td>
<td>0.10</td>
<td>0.10</td>
<td>0.05</td>
<td>4.07</td>
<td>0.025</td>
</tr>
<tr>
<td>U</td>
<td>1</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
<td>1.21</td>
<td>0.278</td>
</tr>
<tr>
<td>T*A</td>
<td>2</td>
<td>0.06</td>
<td>0.06</td>
<td>0.03</td>
<td>2.33</td>
<td>0.112</td>
</tr>
<tr>
<td>T*S</td>
<td>2</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
<td>0.49</td>
<td>0.618</td>
</tr>
<tr>
<td>T*U</td>
<td>1</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
<td>0.62</td>
<td>0.435</td>
</tr>
<tr>
<td>A*S</td>
<td>4</td>
<td>0.07</td>
<td>0.07</td>
<td>0.02</td>
<td>1.41</td>
<td>0.251</td>
</tr>
<tr>
<td>A*U</td>
<td>2</td>
<td>0.13</td>
<td>0.13</td>
<td>0.07</td>
<td>5.58</td>
<td>0.008</td>
</tr>
<tr>
<td>S*U</td>
<td>2</td>
<td>0.10</td>
<td>0.10</td>
<td>0.05</td>
<td>4.07</td>
<td>0.025</td>
</tr>
<tr>
<td>T<em>A</em>S</td>
<td>4</td>
<td>0.01</td>
<td>0.01</td>
<td>0.00</td>
<td>0.17</td>
<td>0.953</td>
</tr>
<tr>
<td>T<em>A</em>U</td>
<td>2</td>
<td>0.02</td>
<td>0.02</td>
<td>0.01</td>
<td>0.71</td>
<td>0.497</td>
</tr>
<tr>
<td>T<em>S</em>U</td>
<td>2</td>
<td>0.02</td>
<td>0.02</td>
<td>0.01</td>
<td>0.78</td>
<td>0.466</td>
</tr>
<tr>
<td>A<em>S</em>U</td>
<td>4</td>
<td>0.01</td>
<td>0.01</td>
<td>0.00</td>
<td>0.22</td>
<td>0.926</td>
</tr>
<tr>
<td>T<em>A</em>S*U</td>
<td>4</td>
<td>0.01</td>
<td>0.01</td>
<td>0.00</td>
<td>0.18</td>
<td>0.945</td>
</tr>
<tr>
<td>Error</td>
<td>36</td>
<td>0.43</td>
<td>0.43</td>
<td>0.01</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Total 71 1.2256

S = 0.356386  R-Sq = 3.74%  R-Sq(adj) = 3.13%
Figure 52 Main Effects for Accuracy given age, lenses, education

Figure 53 Interaction plot for Accuracy given age, lenses, education
5.5. Comparing of Survey and Simulation Data

Though it is not possible to compare the different types of results gathered from the surveys and simulation in a statistically rigorous fashion (since one is between subjects and the other is within subjects), it is still of use to examine how the exercise preferences of survey participants relates to their performance during the driving simulation experiment. Table 56 provides various data averages for comparison.

Table 56. Comparison of Survey Preferences and Simulation Performance

<table>
<thead>
<tr>
<th>Library</th>
<th>Message Type</th>
<th>Time (sec)</th>
<th>Accuracy (%)</th>
<th>Preference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Non</td>
<td>Text</td>
<td>16.90</td>
<td>86.19%</td>
<td>58.93%</td>
</tr>
<tr>
<td></td>
<td>Graphic</td>
<td>13.16</td>
<td>82.86%</td>
<td>41.07%</td>
</tr>
<tr>
<td></td>
<td>Red Text Signs</td>
<td>17.82</td>
<td>85.83%</td>
<td>54.04%</td>
</tr>
<tr>
<td></td>
<td>Amber Text Signs</td>
<td>15.97</td>
<td>86.55%</td>
<td>45.96%</td>
</tr>
<tr>
<td></td>
<td>Red graphic Signs</td>
<td>14.81</td>
<td>77.50%</td>
<td>77.06%</td>
</tr>
<tr>
<td></td>
<td>Amber graphic Signs</td>
<td>12.31</td>
<td>84.05%</td>
<td>22.94%</td>
</tr>
<tr>
<td>Emergency</td>
<td>Text</td>
<td>17.45</td>
<td>85.54%</td>
<td>73.66%</td>
</tr>
<tr>
<td></td>
<td>Graphic</td>
<td>15.70</td>
<td>83.21%</td>
<td>26.34%</td>
</tr>
<tr>
<td></td>
<td>Red Text Signs</td>
<td>17.9</td>
<td>84.82%</td>
<td>57.78%</td>
</tr>
<tr>
<td></td>
<td>Amber Text Signs</td>
<td>17.28</td>
<td>88.39%</td>
<td>42.22%</td>
</tr>
<tr>
<td></td>
<td>Red graphic Signs</td>
<td>15.6</td>
<td>80.54%</td>
<td>60.93%</td>
</tr>
<tr>
<td></td>
<td>Amber graphic Signs</td>
<td>15.79</td>
<td>85.89%</td>
<td>39.07%</td>
</tr>
<tr>
<td>Total</td>
<td>Text</td>
<td>17.12</td>
<td>85.93%</td>
<td>66.28%</td>
</tr>
<tr>
<td></td>
<td>Graphic</td>
<td>14.17</td>
<td>83.00%</td>
<td>33.72%</td>
</tr>
<tr>
<td></td>
<td>Red Text Signs</td>
<td>17.85</td>
<td>85.43%</td>
<td>55.91%</td>
</tr>
<tr>
<td></td>
<td>Amber Text Signs</td>
<td>16.38</td>
<td>86.43%</td>
<td>44.09%</td>
</tr>
<tr>
<td></td>
<td>Red graphic Signs</td>
<td>14.65</td>
<td>81.21%</td>
<td>69.00%</td>
</tr>
<tr>
<td></td>
<td>Amber graphic Signs</td>
<td>13.70</td>
<td>84.79%</td>
<td>31.00%</td>
</tr>
</tbody>
</table>

When considering the role of graphics in both the electronic survey and the driving simulation experiment, it was found that survey participants favored text only signs over graphics (graphics being preferred 59% less often) but in simulation performance there was only a small difference in actual accuracy (3.64%) for identifying these two message types. Figures 53 and 54 illustrate these differences for survey participants and the subgroup participating in survey and simulation.
When the role of color in messaging is compared in the survey and simulation data, it was found that survey participants exercised a preference for red messages (amber was preferred 9.61% less often for text messages and 38.83% less often for graphic messages) over amber messages, but their performance in the simulation showed that they were actually 2.76% less accurate in identifying red signs. The comparisons for these results are illustrated by Figures 55 and 56.
Figure 56. Comparing Survey and Simulation Results for Amber vs. Red Text

Figure 57. Comparing Amber vs. Red Text Survey and Simulation Results: Survey/Sim Subgroup

When viewing these comparisons in light of emergency vs. non-emergency messages, it was found that emergency messages demonstrate nearly the same trends as their non-emergency counterparts regarding color. For both graphics and text red was preferred to amber in the survey but performed worse in the simulation, and this is thoroughly evident in both emergency and non-emergency samples. In text vs. graphics
however, emergency messages had a better performance relative to text than non emergency messages, but were similar in preference. Figures 57, 58, 59, and 60 demonstrate these trends.

Figure 58 Comparing Survey and Simulation Results for graphics vs. text categorized by library

Figure 59 Graphics vs. Text Survey and Simulation Results by Library: Survey/Sim Subgroup
Figure 60. Comparing Survey and Simulation Results for Amber vs. Red by Library

Figure 61. Survey/Sim Subgroup Results for Amber vs. Red by Library
Like any scientific inquiry, there were several practical limitations to conducting this series of experiments. Time and money are always a factor, and the department could not afford to hold longer on-site experiments or pay for additional technology to help administer the tests. There are always additional difficulties when conducting experiments on site rather than in a more controlled setting. Surveys are especially susceptible to encountering strange responses from participants that cannot be assessed by the intended experimental design. Many times surveys had to be discarded that were barely filled out or filled out with data of the participants choosing not relevant to the research being conducted. Another difficulty in processing surveys is making certain all demographics are represented well enough to collect a usable data set from every demographic combination. In order to accomplish this, the survey had to obtain more surveys from groups usually under-represented, especially those that may be more likely to have problems with messaging (e.g. the elderly or non-native English speakers). This dynamic meant that certain groups were not represented according to ordinary demographic distributions. It is also important to note that a certain degree of thoroughness was sacrificed in order to make the survey approachable for individuals across the entire demographic range of Rhode Island’s population.

In order to solicit enough individuals to participate in the research so that the data carried with it statistically significant weight, the simulation experiment itself had to be short enough in duration so as not to dissuade individuals from participating. The
simulation also had to be limited in length due to the fact that the study had limited financial resources to draw from and so needed to conduct the appropriate number of trials within a set time frame. This of course meant that many of the factors treated in the surveys could not be included in the simulation. A compromise of 20 different message designs displayed twice each for a total of 40 messages presented to the participants were decided upon as the best available method for meeting the requirements of the research within the given constraints. With an average time per message video of some 19 seconds the subjects generally took nearly 13 minutes to complete the test, with an average of around another five videos as practice the total climbed to between 14 and 15 minutes. Adding in time for instruction, informed consent, recording demographic information, and subjects entering and leaving the test vehicle, and the time required to test a subject averaged nearly 20 minutes. Even this amount of time dissuaded many individuals from participating in the field.

The result of these time constraints was that several potential designs were not tested. Future tests must address these factors. The research conducted indicates that it would be prudent for RIDOT to test all message designs for maximum effectiveness, engaging in an iterative process of testing and redesign to maximize the positive characteristics as much as possible. This initiative has yet to be carried out extensively on the entire battery of existing signs, so it is questionable whether they will ever have the resources to fully undertake such a project, but from the research conducted so far it would seem the benefits may be well worth the effort.
Another limitation that was experienced due to the limited budget and timeframe for available “public” experimental space was that the experiment was only able to use one base video to create message videos rather than a variety of different sites shot in different weather conditions. The single video was shot during overcast conditions with the hope of achieving a compromise between all the different light and dark conditions on roadways and that would be challenging enough to flush out the differences in good and bad sign design without being demanding enough to alter normal driving behavior.

One future improvement to the experimental apparatus would be to replace the physical key to remind subjects which input button corresponded to which sign design with an electronic guide that would appear along the bottom of the video screen. This may better represent the experience of identifying signs while driving for motorists because it would not require them to move there eyes are far from the video display of the road in order to provide answers. It may also be beneficial to experiment with including names and pictures of sign designs directly on the buttons to help facilitate recognition of the proper button for subjects’ intended selection, though there may not be an effective way to present the necessary information in such a small space.

One unexpected result was the preference of textual signs over graphics-based signs in the electronic survey. Previous research conducted by the industrial engineering department found that subjects significantly preferred graphic-aided DMS over text-only DMS messages (94% over 6%, p < 0.001) (46). This preference was consistently observed across all demographic groups (gender, age, and native language). There are
two probable explanations for such findings. First is that the messages in this experiment purposely exceeded previous graphic aid treatments by not simply adding a graphic to an existing text-only message but by actually employing the graphic to replace key words in the message. This was undertaken to establish if it is possible to display a greater amount of information to motorists on a single panel by representing some of that information in a pictorial format instead of written form. Participants’ adverse reaction to this type of sign is supported by the work of Donald (47) that found traffic signs employing symbols (especially abstract symbols) with no necessary explanation of the symbol in text to be ineffective at conveying complex messages and caused a lower comprehension rate than non-symbolic signs. Shinar et al. (48) found that signs were comprehended best when they were consistent with general ergonomic guidelines for display design as they relate to conceptual compatibility, and physical representation, and Smiley et al. (34) found that symbols need to be used with the destination names so that drivers can learn to connect a symbol with its meaning, so it is less than beneficial to use symbols to replace textual information.

Another likely cause for the disparate response stems from another alteration in text message from the previous experiment. The previous experiment presented text messages in the same size as the text that appeared with a graphic aid. To push the limits of the preferences and also to see if more room could be generated to add content to messages, the messages with graphic aids had smaller text than the double stroke text-only messages presented in this experiment.

The simulation tested factors such as graphic vs. text only and amber vs. red messages to identify helpful factors for creating emergency signs and to ascertain if
non-emergency and emergency messages experienced the same dynamic effects under various treatments (further testing their similarities and behavior to find if VMS was an adequate format for displaying emergency information to motorists). Graphics were included to see if they could reduce comprehension time, increase accuracy, or allow sign designers to convey a large amount of information to motorists via a message panel. Red was selected to augment the currently used amber because the DOT has begun to experiment with it in a limited fashion as an “accent” color on custom messages, additional colors may prove to help set off emergency content, and many fixed signs and other warnings are associated in some ways with the color red.

Due to practical implications of conducting the experiment (such as time or the patience of participants), the research could not examine messages in parallel for both the DMS and VMS formats. As a compromise, some messages were designed with dimensions that could be presented on either VMS or DMS, and some, such as certain graphics messages, could only be displayed on DMS boards. Additionally, only VMS signs with full matrix digital displays can utilize graphics, and most all of Rhode Islands current inventory of VMS do not employ that technology.

The similarities in preference and accuracy of emergency and non-emergency electronic messages but differences in response time may be a product of the fact that many of the non-emergency messages were messages currently employed by RIDOT and so the content (even with the inclusion of graphics) was familiar and recognizable for motorists. Since there are no existing emergency message libraries, this segment of the signs tested could not include these sign types (and could only be created using
design features from other types of signs or uniquely designed). It is also possible that drivers were struck by the severe content of the emergency signs and lingered on them to absorb the more provocative messages.
CHAPTER 7

CONCLUSION

The overall survey results indicated that people in general desire more information from the current means of transportation communication, especially in times of emergency. This supports the intent of this study, that is, to expand the role of VMS in emergencies, since it is a system that drivers find more useful and believe they use more frequently than other means of communication such as radio, television, the internet, and the 511 call-in system.

The results further demonstrated that drivers are willing to follow VMS instructions in emergencies, and follow VMS instruction for other directives to a high degree. In testing the adequacy of certain types of emergency messages, it was found that motorists could process a considerable amount of abbreviated material and fill in missing terms in order to transform messages into directions that they could follow. They also highly preferred messages that gave simple but explicit information about emergencies, the desired course of action, and how to carry out that action. The use of preparatory signs was positive, but to a lesser degree than currently employed signs. This indicates a potential benefit for such a type of emergency sign, but further refinement must be done. It may also be true that motorists’ familiarity with existing signs positively influenced their reactions.

The three experimental methods indicate that VMS is a viable means of supplementing current emergency communication within the transportation system. Test emergency messages performed similarly to non-emergency messages for a number of different factor combinations, and the simulation data demonstrated no
significant difference in the accuracy of these two types of messages. Though there was
a significant difference in the time it took subjects to respond to emergency messages,
these differences may be accounted for by subjects’ familiarity with the other messages,
and more over could be corrected by further testing and the careful manipulation of
design factors such as those found to be significant in the experiment. For example, the
addition of a graphic was shown to reduce response time. Though in general graphics
also decreased accuracy, there is reason to be optimistic that a successful combination
of elements can be found.

Though there was strong preference for using red in emergency messaging, in
simulation emergency messages were found to perform just as poorly as their non-
emergency counterparts. However it may be useful to experiment further with using red
as a contrasting color for elements of the message, such as a graphic aid.

The trends from strong to weak performance for accuracy in emergency
messages were nearly the same as those for non-emergency messages for the different
demographics, indicating that subjects reacted to them similarly, and also that
weaknesses in performance may have arisen from VMS in general and not message
library type factors.

It is encouraging to note that in examining the data by demographic for both
accuracy and response time, in many cases groups that responded the slowest for
emergency messages actually demonstrated quicker response times for emergency
messages. Non-native English speakers, while showing an increase in response time
from non-emergency to emergency messages, actually took less time than native
English speakers to identify emergency messages. The same is true for females, and
persons over 61, while still performing slowly, virtually eliminated the gap in response time for non-emergency and emergency messages. Emergency messages even managed to increase accuracy for individuals wearing corrective lenses. On the whole the results were mixed for relative performance over different demographics, but this means that emergency messages are capable in the same way non-emergency messages are and further research must be done to isolate factors to improve the performance of emergency and non-emergency messages alike on a sign-by-sign basis. Though response time was determined to be significantly different for emergency messages, the results were still response times that were lower than those produced by other factors (e.g. the transition from graphics-aided to text-only produces a greater increase in time). In fact, the differences, while significant, still did not vary by more than a standard deviation in the response variable, which means differences in response time for example may still be within allowable limits for messaging performance, but should be corrected as much as possible through individual message testing.

In addition to supporting the viability of emergency messaging via DMS/VMS, the experimental methods also identified a number of potentially beneficial factors to include in emergency messages. Messages should be displayed in amber text, not red, with a graphic (potentially in a contrasting color) that supplements the text content but does not replace it. The content of the text in the message should be center justified, and it should fully disclose the emergency/disaster type. The surveys indicated a strong preference toward naming events specifically and simulation data did not show that using the word “hurricane” explicitly lead to substantially poorer performance between emergency signs or other signs (though tests isolating this factor more thoroughly
would have to be conducted to state this with certainty). Results also indicate that individuals can comprehend more than the standard RIDOT abbreviations for emergency messages, but that their general preference is to have as few abbreviations as possible. RIDOT should consider a limited expansion of acceptable abbreviations to cover a select group of emergency terms that demonstrate their effectiveness through further testing. Experiments indicated that motorists could follow multiple panels of detour/evacuation directions, but at steadily diminishing returns. RIDOT will have to consider what degree of accuracy will be acceptable for their purposes and institute such a policy based on their resources (number of signs, personnel, etc.). Additional features such as flashing, animation, and outline color could not be verified in the simulation due to limitations in the amount of material that could be tested, but survey preferences for these factors indicate that emergency messages should not contain a contrasting outline color around message text, but may benefit from flashing a single guide word or having a graphic that is animated to catch the eyes of motorists. The few individual sign designs explored in the experiments indicate that employing graphic items from existing fixed and other signs in an electronic format may not be the most effective means of representing an emergency concept graphically. Once again this underscores the need to test messages on a sign-by-sign basis to achieve the best possible results.

The following figures represent examples of VMS libraries for Hurricane, LNG explosion, and bridge collapse scenarios. Utilizing the near limitless capacity of electronic storage, these libraries would include standard messaging already in use (such as road closed, lane shift, expect delays, etc.) to aid in directing motorists during
these emergencies. The ideal implementation would be to generate such a library for every hurricane evacuation zone, chemical facility, and bridge in the state, and accordingly include all of the particular evacuation and alternate routing information for each location. Additionally, custom graphics (like those tested above) can be included with each message when these messages are created in the DMS format. Like all messages, these new constructions should be tested individually to yield the best possible product.

<table>
<thead>
<tr>
<th>EMERGENCY VMS LIBRARY I: HURRICANE</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>AWARENESS</strong></td>
</tr>
<tr>
<td>FILL GAS TANKS</td>
</tr>
<tr>
<td>GET SUPPLIES</td>
</tr>
<tr>
<td>HURRICANE WATCH</td>
</tr>
<tr>
<td>NOTIFY HOMEBOUND NEIGHBORS</td>
</tr>
<tr>
<td>GET PET SUPPLIES</td>
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</tbody>
</table>

Figure 62 General Example of Preliminary Hurricane VMS Library
<table>
<thead>
<tr>
<th>EMERGENCY VMS LIBRARY II: LNG EXPLOSION</th>
<th>EMERGENCY VMS LIBRARY III: BRIDGE COLLAPSE</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>RESPONSE</strong></td>
<td><strong>RECOVERY</strong></td>
</tr>
<tr>
<td><strong>FIRE</strong></td>
<td><strong>NO ENTRY</strong></td>
</tr>
<tr>
<td><strong>EVACUATE</strong></td>
<td><strong>GAS LEAK</strong></td>
</tr>
<tr>
<td><strong>RTE XX N</strong></td>
<td><strong>NO ENTRY</strong></td>
</tr>
<tr>
<td><strong>EVACUATE</strong></td>
<td><strong>POISON</strong></td>
</tr>
<tr>
<td><strong>WATCH FOR DEBRIS</strong></td>
<td><strong>GAS</strong></td>
</tr>
<tr>
<td><strong>FIRST AID</strong></td>
<td><strong>POWER OUT</strong></td>
</tr>
<tr>
<td><strong>NEXT EXIT</strong></td>
<td><strong>S OF I95</strong></td>
</tr>
<tr>
<td><strong>RTE XX N</strong></td>
<td><strong>NO ENTRY</strong></td>
</tr>
<tr>
<td><strong>SLOW</strong></td>
<td><strong>RE-ENTRY</strong></td>
</tr>
<tr>
<td><strong>HEAVY SMOKE</strong></td>
<td><strong>INFO ON</strong></td>
</tr>
<tr>
<td><strong>GAS LEAK</strong></td>
<td><strong>RE-ENTRY</strong></td>
</tr>
<tr>
<td><strong>CLOSE WINDOWS</strong></td>
<td><strong>NO ENTRY</strong></td>
</tr>
<tr>
<td><strong>GAS LEAK</strong></td>
<td><strong>SAFETY</strong></td>
</tr>
<tr>
<td><strong>SEEK AID</strong></td>
<td><strong>ENTER</strong></td>
</tr>
<tr>
<td><strong>HOSPITAL</strong></td>
<td><strong>POWER ON</strong></td>
</tr>
<tr>
<td><strong>NEXT EXIT LOCATION</strong></td>
<td><strong>USE ONLY</strong></td>
</tr>
<tr>
<td><strong>SHELTER</strong></td>
<td><strong>BOTTLED WATER</strong></td>
</tr>
<tr>
<td><strong>EXIT XX</strong></td>
<td><strong>USE ONLY</strong></td>
</tr>
<tr>
<td><strong>RTE XX S</strong></td>
<td><strong>WATER</strong></td>
</tr>
</tbody>
</table>

| **RESPONSE**                           | **RECOVERY**                               |
| **BRIDGE OUT**                         | **SLOW BRIDGE**                            |
| **EXIT NOW**                           | **OUT**                                    |
| **NO BRIDGE DETOUR RTE 1A N**          | **SLOW 1 LANE BRIDGE**                     |
| **NO BRIDGE TURN AROUND**              | **DETOUR USE**                             |
| **FIRST AID NEXT EXIT RTE XX**        | **DETOUR RTE XX**                          |
| **SLOW BRIDGE**                        | **NO BRIDGE**                              |
| **FIRE DETOUR**                        | **NO BRIDGE**                              |
| **RE-ENTRY**                           | **SAFETY**                                 |
| **INFO ON**                            | **ENTER**                                  |
| **RE-ENTRY**                           | **SAFETY**                                 |
| **NO ENTRY**                           | **SAFETY**                                 |
| **GAS LEAK**                           | **SAFETY**                                 |
| **CLOSE WINDOWS ONLY**                | **SAFETY**                                 |
| **GAS LEAK**                           | **SAFETY**                                 |
| **SEEK AID**                           | **SAFETY**                                 |
| **HOSPITAL**                           | **SAFETY**                                 |
| **NEXT EXIT LOCATION**                | **SAFETY**                                 |
| **SHELTER**                            | **SAFETY**                                 |
| **EXIT XX**                            | **SAFETY**                                 |
| **RTE XX S**                           | **SAFETY**                                 |

Figure 63 General Examples of LNG and Bridge Collapse VMS Libraries
Communication in the transportation system is a steadily evolving area of interest, and advancements in technology only make it more necessary to re-examine and refine this field. This research represents a new step toward enhancing roadway communication by using current VMS technology in emergency situations in order to better serve the public. The research has concluded that the best way to move forward in serving motorists in times of emergency is to carefully augment Rhode Island’s intelligent transportation system to serve its purposes in a new and more responsive way that better utilizes technology.

Both RIDOT and Rhode Island residents could benefit from having a special message library for emergency situations. This would lead to better information for the public using well tested messages, and also alleviate the strain on TMC resources during emergencies. Time that would otherwise be spent trying to construct signs can instead be used to manage the dynamic situation and coordinate relief agencies and motorists. A VMS emergency library would also increase the effectiveness of inter-agency cooperation, a cornerstone of any successful major disaster relief effort, since a standardized VMS library could put agencies on same page. In conjunction with this, RIDOT needs to reevaluate their alternate routes and create a framework of tiered alternate evacuation and emergency vehicle routes, all well documented in messaging libraries and tied to their present monitoring capabilities. This will then mean that when inevitable problems arise in the execution of emergency plans, the system can adapt without wasting time in deliberation or message design.

To maximize the effectiveness of such messaging Rhode Island must improve its ITS infrastructure by pursuing a larger, more interconnected network of DMS and
VMS systems so as to take much greater advantage of the benefits of these devices while giving them the tools to expand the scope of their communication for more than just emergencies. Significant investment in carefully placed new equipment would also yield positive results immediately.

The nearly unlimited electronic storage of the TMC system can easily accommodate very involved plans and create a system much better than the “paper plan” procedures currently employed. In fact, RIDOT could go even further and preplan tiered evacuation and emergency routes for incidents involving bridges, fuel storage depots, and any facility housing chemicals or hazardous materials, not just hurricanes or other major evacuations. The TMC could easily store such data to save precious time and effort in the event of natural or human-caused disasters. Such steps would also create a useful transition of thinking toward the eventual development of a truly intelligent transportation system that would model emergency traffic flow and allocate resources in real time to help manage the transportation system for the safety and security of all.
LIST OF REFERENCES


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Public Opinion Survey
This survey asks drivers about their familiarity with and opinions about different types of roadway communication, such as Electronic Variable Message Signs (VMS). To thank participants, individuals completing the survey and optional contact information below are given one of several gifts.

(optional)
First Name ______________  Last Name _________________________________
Street Address ________________________________ (Apt. #) _______________
City ________________________________ State ________  Zip  _____________
Telephone Number _____________  Email Address ________________________
[ ] I consent to providing responses that will be used for academic research
[ ] I am willing to aid the highway safety research being conducted by the University of Rhode Island by participating in a voluntary video-based driving simulation to be held on a future date.
Gender ___________ Age ___________ Years of driving Experience _____________

Native Language _____________ Home Zip Code _______ & work Zip code _______

Educational Background:    
[No High school] [Some High School]  
[High School Graduate] [Some College] [College Graduate]

Corrective Lenses [ Y | N ]  Color Blindness [ Y | N ]  Valid Driver’s License [ Y | N ]

Please respond to each statement by circling the number that reflects how you feel about the statement. Circle 1 if you strongly agree with the statement, 5 if you strongly disagree.

(Circle Choice Below)

1.  I am familiar with current evacuation routes near my home.  
   
2.  The following methods of highway communication are useful sources of information for me:
   - Radio (including 1610 & 1630 AM)  
   - Television  
   - 511 Call in traffic information line  
   - Electronic Variables Message Signs (VMS)  
   - Internet (RIDOT website, etc.)  
   - Fixed Signs  

3.  I use the following methods of highway communication frequently:
   - Radio (including 1610 & 1630 AM)  
   - Television  
   - 511 Call in traffic information line  
   - Electronic Variables Message Signs (VMS)  
   - Internet (RIDOT website, etc.)  
   - Fixed Signs  

4.  I would like the highway transportation system to provide more information about emergencies (e.g. a hurricane, bridge collapse, fire, etc.).
5. I follow advice from electronic variable message signs (VMS) regarding road work or detours.  

6. I am willing to follow instructions provided by VMS during emergency situations.  

7. I find the following VMS messages helpful in preparing for emergencies:
   - fill gas tanks  
   - blizzard  
   - secure water supplies  
   - prepare for outages  
   - icy road ahead  
   - expect high winds  
   - secure loose objects  

8. Suppose your home is located in coastal Rhode Island where a newly reported category 4 hurricane was expected to make landfall in a few hours. Which of the following highway messages would you prefer for informing you of such an emergency while driving?

   - [1] EVACUATE USE RTE | H
   - [2] EMERGENCY EVACUATE RTE | H
   - [3] HURRICANE EVACUATE RTE | H
   - [4] DANGER EVACUATE RTE | H
9. Suppose you were traveling north on Beach St. looking for a hurricane shelter. You see an electronic variable message sign (VMS) alternating between the following 2 panels. Which of the 4 maps below represents where you would drive to follow the directions given by the two panels?

Panel 1

Panel 2

[1] [2] [3] [4]
10. You are northbound on I-95, heading to I-195, and you see the following two-panel set of instructions. Select the proper turn in each of the four pairs of signs below:

![Panel 1](image1.png) ![Panel 2](image2.png)

11. In the empty boxes below please create the message that you would find most informative and helpful as a motorist in the event that the Jamestown Bridge collapsed and traffic toward the bridge on Rte 138 East needed to be informed of the situation and immediately rerouted to Rte 1-A North.

<p>| | | | |</p>
<table>
<thead>
<tr>
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<tbody>
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</tbody>
</table>

12. Do you have any further comments regarding the use of VMS messages? Do you have any concerns with expanding the use of VMS to deliver important information during emergencies? Please share your valuable opinions with us in the space below, and on the reverse side of the page if necessary:

______________________________________________________________________________
______________________________________________________________________________
______________________________________________________________________________
______________________________________________________________________________
______________________________________________________________________________

Thank you for your valuable time and input.
APPENDIX B: ELECTRONIC SURVEY QUESTION SLIDES

Questionnaire Survey
Conducted by University of Rhode Island
Sponsored by URI/TDC and RIDOT

You are taking part in a survey to better enhance the design and display of Dynamic Message Signs (DMS). DMS is an electronic bulletin board, usually mounted overhead on highways, which communicates real-time traffic information and travel advice to motorists. The research findings from this survey will benefit the general public and enhance driving safety on state and interstate highways.

Which of the following message signs do you prefer?

(A) [Message Sign Image]
(B) [Message Sign Image]
(C) [Message Sign Image]

Next Question

Which of the following message signs do you prefer?

(A) [Message Sign Image]
(B) [Message Sign Image]

Next Question

Which of the following message signs do you prefer?

(A) [Message Sign Image]
(B) [Message Sign Image]

Next Question

Which of the following message signs do you prefer?

(A) [Message Sign Image]
(B) [Message Sign Image]

Next Question

In this survey, you will be prompted with a variety of DMS images or scenarios and you will choose the one that you prefer the most. There is no right or wrong answer. You can change your mind at any time. The survey will take about 20 minutes to complete.

Your participation in this study is confidential. All records will be kept in a computer that is only accessible to the project investigators. The responses made by you will only be used for statistical calculations.

Please feel free to contact the project director, Dr. Young (61-71-59), if you have any questions or concerns.

If you read the above and agree to participate in this survey, please press the "START" button below to start the survey. Please read each question carefully and choose your best answer. Thank you!
The following question will present you with a flashing message display that will indicate to you an emergency route to follow. After the message has finished, you will be shown 4 pairs of road signs—for each pair choose which sign would lead you on the route the flashing message instructed you to follow.

Imagine you are driving north on I-95, heading to 1-495 East when you see the following 2 panel set of emergency detour instructions.

**Click Button To View The Message and Begin**

---

**Personal Data**

First Name: 

Last Name: 

Sex: 

Gender: 

Native Language: 

Education: 

Are you color blind?: 

Do you wear glasses/contacts?: 

---
APPENDIX C: POSITIONING PROGRAM

Source code of the positioning program and coordinate database sample are shown in this appendix (courtesy of Siamak Ghanizadeh Hesar and the ISE department).

```vbnet
Dim reflist As Object
Dim t As String
Dim cellno As Integer
Dim Counter, counter1 As Integer

Private Sub Command1_Click()
    '***** The path of the frames' file on the computer is defined in here*****'
    Picture2.Picture = LoadPicture("F:\Project files\Video files\original frames\f" & t & " copy.bmp")
End Sub

Private Sub Form_Load()
    '**** The path of the coordinates database (reflist) in defined here****'
    Set reflist = GetObject("F:\Project files\newidea\additionalreflist.xls")
    Counter = 1
    t = Trim(Str(Counter))
    cellno = 5
    counter1 = 1
End Sub

'**** Position of the mouse cursor is recorded into the database by clicking on picture****'
Private Sub Picture2_MouseDown(Button As Integer, Shift As Integer, X As Single, Y As Single)
    Dim i As Integer
    Text1.Text = X
    Text2.Text = Y
    i = 1
    If counter1 = 1 Then
        counter1 = 2
        reflist.worksheets(1).cells(cellno, "A").Value = "f" + Str(Counter) + " copy"
    End If

    reflist.worksheets(1).cells(cellno, "B").Value = Text1.Text
    reflist.worksheets(1).cells(cellno, "C").Value = Text2.Text
Else
    reflist.worksheets(1).cells(cellno, "D").Value = Text1.Text
    reflist.worksheets(1).cells(cellno, "E").Value = Text2.Text
End If
```

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counter1 = 1
Counter = Counter + 1
cellno = cellno + 1
t = Trim(Str(Counter))
End If
End Sub

'**** These commands show the position of the mouse in the text boxes****'

Private Sub Picture2_MouseMove(Button As Integer, Shift As Integer, X As Single, Y As Single)
Text1.Text = X
Text2.Text = Y
End Sub

<table>
<thead>
<tr>
<th>Frame Name</th>
<th>First point</th>
<th>Second point</th>
<th>Image Width</th>
<th>Image Height</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>X1</td>
<td>Y1</td>
<td>X2</td>
<td>Y2</td>
</tr>
<tr>
<td>Frame 62</td>
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<td>250</td>
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Note: the numbers in the table are in pixels
APPENDIX D: MERGING PROGRAM

Source code of the Merging program (courtesy of Siamak Ghanizadeh Hesar and the ISE department).

Imports System.IO
Imports System.Drawing

Public Class Form1
    Inherits System.Windows.Forms.Form
    Dim counter As Integer

    #Region " Windows Form Designer generated code "

    Public Sub New()
        MyBase.New()

        'This call is required by the Windows Form Designer.
        InitializeComponent()

        'Add any initialization after the InitializeComponent() call
    End Sub

    'Form overrides dispose to clean up the component list.
    Protected Overloads Overrides Sub Dispose(ByVal disposing As Boolean)
        If disposing Then
            If Not (components Is Nothing) Then
                components.Dispose()
            End If
        End If
    End If
    MyBase.Dispose(disposing)

    'Required by the Windows Form Designer
    Private components As System.ComponentModel.IContainer

    'NOTE: The following procedure is required by the Windows Form Designer
    'It can be modified using the Windows Form Designer.
    'Do not modify it using the code editor.
    Friend WithEvents Button1 As System.Windows.Forms.Button
    <System.Diagnostics.DebuggerStepThrough()> Private Sub InitializeComponent()
        Me.SuspendLayout()

        'Button1
        Me.Button1.Location = New System.Drawing.Point(40, 48)
        Me.Button1.Name = "Button1"
        Me.Button1.TabIndex = 0
    End Sub

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Me.Button1.Text = "Button1"
'Form1
Me.AutoScaleBaseSize = New System.Drawing.Size(5, 13)
Me.Controls.Add(Me.Button1)
Me.Name = "Form1"
Me.Text = "Form1"
Me.ResumeLayout(False)
End Sub

Private Sub Button1_Click(ByVal sender As System.Object, ByVal e As System.EventArgs) Handles Button1.Click
Dim s() As String
Dim t, t1 As String
Dim n As Int32
Dim sr As New StreamReader("F:\Project files\newidea\mytext.txt")
    Do While sr.Peek <> -1
        's will be an array each element corresponds to a column
        s = sr.ReadLine().Split("","")
        'MessageBox.Show(s(0))
        t = Trim(Str(counter))
        n = Val(s(1))
        t1 = Trim(Str(n))
        Dim myBit1 As New Bitmap("F:\Project files\Video files\original frames marked\f" + t + "" + "copy.bmp")
        Dim myBit2 As New Bitmap("F:\Project files\DMS_Images\Images Fake\resized\F1_Work_Belt_R\F1_Work_Belt_R_S" + t1 + ".bmp")
        Dim i, j, x, y, sh, h, hh As Int32
        Dim myColor As Color
        sh = s(5) - s(3)
        If sh > myBit2.Height Then
            h = sh - myBit2.Height
            hh = Int(h / 2)
            For i = s(2) To s(4) - 1
                For j = (s(3) + hh) To (s(3) + hh + myBit2.Height - 1)
                    x = i - s(2)
                    y = j - (s(3) + hh)
                    myColor = myBit2.GetPixel(x, y)
                    myBit1.SetPixel(i, j, myColor)
                    Next j
                Next i
            Else
                hh = Int(((s(4) - s(2)) / 3.746) - myBit2.Height) / 2)
        End If
    Loop
End Sub
For i = s(2) To s(4) - 1
    For j = s(3) To (s(5) - hh - 1)
        x = i - s(2)
        y = j + myBit2.Height - (s(5) - hh)
        myColor = myBit2.GetPixel(x, y)
        myBit1.SetPixel(i, j, myColor)
    Next j
Next i
End If

myBit1.Save("G:\Video files\fake\F1_Work_Belt_R\f" + t + "copy.bmp")
counter = counter + 1
Loop
MessageBox.Show("finished")
End Sub

Private Sub Form1_Load(ByVal sender As System.Object, ByVal e As System.EventArgs) Handles MyBase.Load
    counter = 62
End Sub
End Class
APPENDIX E: EXPERIMENT ADMINISTRATOR PROGRAM

Source code of the experiment administrator program (courtesy of Siamak Ghanizadeh Hesar and the ISE department).

Form 1
*******************
Dim a(16) As Integer
Dim Key, order, number, number1, rnd_n, run As Integer
Dim pd1, pd2, pd3, pd4, pd5, pd6, pd7, pd8 As Integer
Dim pd9, pd10, pd11, pd12, pd13, pd14, pd15, pd16 As Integer
Dim pd17, pd18, pd19, pd20 As Integer
Dim pd21, pd22, pd23, pd24, pd25, pd26, pd27, pd28 As Integer
Dim pd29, pd30, pd31, pd32, pd33, pd34, pd35, pd36 As Integer
Dim pd37, pd38, pd39, pd40, pd41, pd42, pd43, pd44 As Integer
Dim pd45, pd46, pd47, pd48 As Integer
Dim start_time, End_time, RecTime As Single
Dim AccuracyRate1, AccuracyCounter1, AccuracyPercentage1 As Integer
' Dim start_time, End_time As Single
' Dim RecTime As Double '!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
' Dim RecTime As Double
Private Sub Command1_KeyPress(KeyAscii As Integer)
   Key = KeyAscii
   If Key = 42 Then 'Click * to initialize the test
      Speed.Visible = False
      Shape1.Visible = False
      Shape2(0).Visible = False
      Shape2(1).Visible = False
      Shape2(2).Visible = False
      Shape2(3).Visible = False
      Label1(0).Visible = False
      Label1(1).Visible = False
      Label1(2).Visible = False
      Label1(3).Visible = False
      Label2.Visible = False
      Image1.Visible = False
      Image2.Visible = False
      Image3.Visible = False
      Image4.Visible = False
      Command1.Visible = True
      Form1.BackColor = QBColor(7)
      Command1.Top = 0
      Command1.Left = 0
      Command1.Height = 1
      Command1.Width = 1
      Form1.Mediaplayer1.Visible = True
      Form1.Mediaplayer1.Top = 0
      Form1.Mediaplayer1.Left = 0
      Form1.Mediaplayer1.Width = Form1.Width
      Form1.Mediaplayer1.Height = Form1.Height
      number = 0
      run = 0
      AccuracyCounter1 = 0
      AccuracyRate1 = 0
      AccuracyPercentage1 = 0
      Do While (number < 3) '3 repetitions
         pd1 = 0: pd2 = 0: pd3 = 0: pd4 = 0: pd5 = 0: pd6 = 0: pd7 = 0: pd8 = 0
         pd9 = 0: pd10 = 0: pd11 = 0: pd12 = 0: pd13 = 0: pd14 = 0: pd15 = 0: pd16 = 0
         pd17 = 0: pd18 = 0: pd19 = 0: pd20 = 0
         pd21 = 0: pd22 = 0: pd23 = 0: pd24 = 0: pd25 = 0: pd26 = 0: pd27 = 0: pd28 = 0
         pd29 = 0: pd30 = 0: pd31 = 0: pd32 = 0: pd33 = 0: pd34 = 0: pd35 = 0: pd36 = 0
         pd37 = 0: pd38 = 0: pd39 = 0: pd40 = 0: pd41 = 0: pd42 = 0: pd43 = 0: pd44 = 0
   End While
Do While (number1 < 16)
    Command1.SetFocus
    'Beep
    PlayVideo1
    'start_time = Timer
    If (Form1MediaPlayer1.PlayState = mpStopped) Then
        'RecTime = Form1MediaPlayer1.Duration
        MsgBox "You did NOT make a choice in time! Please press
        message content!"
        RecordData
        run = run + 1
        number1 = number1 + 1
        delayy 'Added today
        If (number1 < 16) Then
            PlayVideo1
            'Beep
        End If
    End If
    If Key = 49 Or Key = 50 Or Key = 51 Then
        'MsgBox "It is TOO EARLY to make your choice!",
        vbExclamation + vbOKOnly, "It is TOO EARLY to make your choice!"
        Form1MediaPlayer1.Stop
        'Beep
        RecordData
        'To calculate accuracy rate
        AccuracyPert1 = AccuracyPert1 + AccuracyCounter1
        'MsgBox ("AccuracyPert1 = & AccuracyPert1)
        run = run + 1
        Command1.SetFocus
        Key = 33
        number1 = number1 + 1
        delayy 'Added today
        If (number1 < 16) Then
            PlayVideo1
            'Beep
        End If
    End If
    Delay
    Loop
End If

'Option to have a break after completing half of the experiments
loop
Dim i As Integer
i = 1
Do While i < 17
    a(i) = i
    i = i + 1
Loop

Form1.Visible = False
Form3.Visible = True 'After the tester finish the test, let him/her to exit.
End If
AccuracyPert1 'To calculate accuracy percentage
'Data1.DatabaseName = "C:\Documents and Settings\yong\Desktop\siamak\DMSData.mdb" 'Need to be the same name used in Data1
'Data1.RecordSource = "Table1" 'Need to be the same name used in Data1
'Data1.Refresh
'Data1.Recordset.AddNew
'Data1.Recordset("Accuracy Rate") = AccuracyPert1

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Sub PlayVideo1()
    playrnd  'A subroutine to generate random number
    order = ee.Caption
    Select Case order
        'Accident Message
        Case 1: Form1.MediaPlayer1.FileName = "C:\RIDOT_Projects\Video files\Videos\Accident_G.AVI"
        Case 2: Form1.MediaPlayer1.FileName = "C:\RIDOT_Projects\Video files\Videos\Accident_G_G1.AVI"
        Case 3: Form1.MediaPlayer1.FileName = "C:\RIDOT_Projects\Video files\Videos\Accident_Y.AVI"
        Case 4: Form1.MediaPlayer1.FileName = "C:\RIDOT_Projects\Video files\Videos\Accident_Y_G1.AVI"
        Case 5: Form1.MediaPlayer1.FileName = "C:\RIDOT_Projects\Video files\Videos\Accident_R.AVI"
        Case 6: Form1.MediaPlayer1.FileName = "C:\RIDOT_Projects\Video files\Videos\Accident_R_G1.AVI"
        'Road work Message
        Case 7: Form1.MediaPlayer1.FileName = "C:\RIDOT_Projects\Video files\Videos\Work_G.AVI"
        Case 8: Form1.MediaPlayer1.FileName = "C:\RIDOT_Projects\Video files\Videos\Work_G_G1.AVI"
        Case 9: Form1.MediaPlayer1.FileName = "C:\RIDOT_Projects\Video files\Videos\Work_Y.AVI"
        Case 10: Form1.MediaPlayer1.FileName = "C:\RIDOT_Projects\Video files\Videos\Work_Y_G1.AVI"
        Case 11: Form1.MediaPlayer1.FileName = "C:\RIDOT_Projects\Video files\Videos\Work_R.AVI"
        Case 12: Form1.MediaPlayer1.FileName = "C:\RIDOT_Projects\Video files\Videos\Work_R_G1.AVI"
        'Fake Message
        Case 13: Form1.MediaPlayer1.FileName = "C:\RIDOT_Projects\Video files\Videos\F_Congestion_Y_G1.AVI"
        Case 14: Form1.MediaPlayer1.FileName = "C:\RIDOT_Projects\Video files\Videos\F_Pavement_R.AVI"
        Case 15: Form1.MediaPlayer1.FileName = "C:\RIDOT_Projects\Video files\Videos\F_Slippery_Y_G1.AVI"
        Case Else: Form1.MediaPlayer1.FileName = "C:\RIDOT_Projects\Video files\Videos\F_Wind_G.AVI"
    End Select
    'MsgBox ("Case=") & order
    Form1.MediaPlayer1.Play
    start_time = Timer  '!!!!!!!!!!!!!!!!!!!!!!!
    ee.Caption = order
End Sub
Sub RecordData()
    End_time = Timer
    Data1.DatabaseName = "C:\RIDOT_Projects\Experiment results\DMSDATA.mdb"
    'Need to be the same name used in Data1 Data
    Data1.RecordSource = "Table1"  'Need to be the same name used in Data1 Data
    Data1.Refresh
    Data1.Recordset.AddNew
    Data1.Recordset("Name") = text1
    Data1.Recordset("Age") = age1(2)
    Data1.Recordset("Gender") = gender(3)
    Data1.Recordset("Language") = Language
    Data1.Recordset("Driving Ex") = Driving
    'End_time = Timer
    RecTime = End_time - start_time  'Record the response time
    'MsgBox ("Key=") & Key
End Sub
Select Case order
'Belows are accident messages
Case 1:
    Data1.Recordset("Message Name") = "Accident_G"
    If Key = 49 Then
        Data1.Recordset("Accuracy") = 1 'Correct response
        AccuracyCounter1 = 1
    Else
        Data1.Recordset("Accuracy") = 0
        AccuracyCounter1 = 0
    End If
Case 2:
    Data1.Recordset("Message Name") = "Accident_G_G1"
    If Key = 49 Then
        Data1.Recordset("Accuracy") = 1
        AccuracyCounter1 = 1
    Else
        Data1.Recordset("Accuracy") = 0
        AccuracyCounter1 = 0
    End If
Case 3:
    Data1.Recordset("Message Name") = "Accident_Y"
    If Key = 49 Then
        Data1.Recordset("Accuracy") = 1
        AccuracyCounter1 = 1
    Else
        Data1.Recordset("Accuracy") = 0
        AccuracyCounter1 = 0
    End If
Case 4:
    Data1.Recordset("Message Name") = "Accident_Y_G1"
    If Key = 49 Then
        Data1.Recordset("Accuracy") = 1 'Correct response
        AccuracyCounter1 = 1
    Else
        Data1.Recordset("Accuracy") = 0
        AccuracyCounter1 = 0
    End If
Case 5:
    Data1.Recordset("Message Name") = "Accident_R"
    If Key = 49 Then
        Data1.Recordset("Accuracy") = 1
        AccuracyCounter1 = 1
    Else
        Data1.Recordset("Accuracy") = 0
        AccuracyCounter1 = 0
    End If
Case 6:
    Data1.Recordset("Message Name") = "Accident_R_G1"
    If Key = 49 Then
        Data1.Recordset("Accuracy") = 1
        AccuracyCounter1 = 1
    Else
        Data1.Recordset("Accuracy") = 0
        AccuracyCounter1 = 0
    End If

''''''''''''''''''''''''''''''''''''''''''''''''''''''''
'Aboves are are accident messages' 
'Belows are seatbelt messages' 
''''''''''''''''''''''''''''''''''''''''''''''''''''''''
'Aboves are seatbelt messages' 
'Belows are Road Work messages' 
''''''''''''''''''''''''''''''''''''''''''''''''''''''''
Case 7:
Data1.Recordset("Message Name") = "Work_G"
If Key = 50 Then
  Data1.Recordset("Accuracy") = 1 'Correct response
  AccuracyCounter1 = 1
Else
  Data1.Recordset("Accuracy") = 0
  AccuracyCounter1 = 0
End If

Case 8:
Data1.Recordset("Message Name") = "Work_G_G1"
If Key = 50 Then
  Data1.Recordset("Accuracy") = 1
  AccuracyCounter1 = 1
Else
  Data1.Recordset("Accuracy") = 0
  AccuracyCounter1 = 0
End If

Case 9:
Data1.Recordset("Message Name") = "Work_Y"
If Key = 50 Then
  Data1.Recordset("Accuracy") = 1
  AccuracyCounter1 = 1
Else
  Data1.Recordset("Accuracy") = 0
  AccuracyCounter1 = 0
End If

Case 10:
Data1.Recordset("Message Name") = "Work_Y_G1"
If Key = 50 Then
  Data1.Recordset("Accuracy") = 1 'Correct response
  AccuracyCounter1 = 1
Else
  Data1.Recordset("Accuracy") = 0
  AccuracyCounter1 = 0
End If

Case 11:
Data1.Recordset("Message Name") = "Work_R"
If Key = 50 Then
  Data1.Recordset("Accuracy") = 1
  AccuracyCounter1 = 1
Else
  Data1.Recordset("Accuracy") = 0
  AccuracyCounter1 = 0
End If

Case 12:
Data1.Recordset("Message Name") = "Work_R_G1"
If Key = 50 Then
  Data1.Recordset("Accuracy") = 1
  AccuracyCounter1 = 1
Else
  Data1.Recordset("Accuracy") = 0
  AccuracyCounter1 = 0
End If

'Aboves are traffic messages
'Belows are fake messages

Case 13:
Data1.Recordset("Message Name") = "F_Congestion_Y_G1"
If Key = 51 Then
  Data1.Recordset("Accuracy") = 1
  AccuracyCounter1 = 1
Else
  Data1.Recordset("Accuracy") = 0

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AccuracyCounter1 = 0
End If

Case 14:
Data1.Recordset("Message Name") = "F_Pavement_R"
If Key = 51 Then
  Data1.Recordset("Accuracy") = 1
  AccuracyCounter1 = 1
Else
  Data1.Recordset("Accuracy") = 0
  AccuracyCounter1 = 0
End If

Case 15:
Data1.Recordset("Message Name") = "F_Slippery_Y_G1"
If Key = 51 Then
  Data1.Recordset("Accuracy") = 1
  AccuracyCounter1 = 1
Else
  Data1.Recordset("Accuracy") = 0
  AccuracyCounter1 = 0
End If

Case 16:
Data1.Recordset("Message Name") = "F_Wind_G"
If Key = 51 Then
  Data1.Recordset("Accuracy") = 1
  AccuracyCounter1 = 1
Else
  Data1.Recordset("Accuracy") = 0
  AccuracyCounter1 = 0
End If

'Aboves are fake messages
End Select

Data1.Recordset("Resp Key") = Key
Data1.Recordset("Resp Time") = RecTime '!!!!!!!
'Data1.Recordset("Resp Time") = Form1.MediaPlayer1.Duration '!!!!!!!
Data1.Recordset.Update
ee.Caption = order
End Sub

Sub AccuracyPert1() 'To calculate accuracy percentage
AccuracyPercentage1 = (AccuracyRate1 / 48) * 100
Form3.Label4.Caption = AccuracyRate1
Form3.Label5.Caption = AccuracyPercentage1
tempAccCount1 = AccuracyRate1
tempPercent1 = AccuracyPercentage1
End Sub

Sub delay()
Dim Start, Start2, delay
'Dim s As Single
's = 1
'delay = 0.05 + s / 100 ' Set the duration.
delay = 0.9 + s / 100
Start = Timer ' Set the start time.
Do While Start2 < Start + delay
  Start2 = Timer
  DoEvents ' Yield to other processes.
Loop
End Sub

Sub delayy()
Dim Start, Start2, delay
Dim s As Single
s = 2 * Rnd()
s = 0.01 + 2 * Rnd()
delay = s ' Set the duration.
Start = Timer ' Set the start time.
Do While Start2 < Start + delay

Start2 = Timer
DoEvents ' Yield to other processes.
Loop
End Sub
Private Sub Command2_Click() ' This sub show what happens if the tester click
' the "Begin" button.
Dim gender1 As String
If text1.Text = "" Then ' If the tester does not enter her/his name,
' a reminding message will appear.
MsgBox "Please input your Last Name!", vbExclamation,
"Please input your Last Name!"
name1(0).Visible = True
text1.Visible = True
age.Visible = True
age1(2).Visible = True
gender(3).Visible = True
gender.Visible = True
Native.Visible = True
Exper.Visible = True
Language.Visible = True
Driving.Visible = True
Command2.Visible = True
Label4.Visible = True
Label5.Visible = True
Label15.Visible = True
Else ' If the tester enter his/her name, just go ahead.
Form2.Visible = False
name1(0).Visible = False
text1.Visible = False
Speed.Visible = True
Shape1.Visible = True
Shape2(0).Visible = True
Shape2(1).Visible = True
Shape2(2).Visible = True
Shape2(3).Visible = True
Label1(0).Visible = True
Label1(1).Visible = True
Label1(2).Visible = True
Label1(9).Visible = True
Label2.Visible = True
Image1.Visible = True
Image2.Visible = True
Image3.Visible = True
Image4.Visible = True
age.Visible = False
age1(2).Visible = False
gender(3).Visible = False
Language.Visible = False
Driving.Visible = False
gender.Visible = False
Command1.Visible = True
Command2.Visible = False
Command3.Visible = False
Native.Visible = False
Exper.Visible = False
Label4.Visible = False
Label5.Visible = False
Label15.Visible = False
End If
End Sub
Private Sub Command3_Click() End
End Sub
Private Sub Form_Load()
Dim ii As Integer
ii = 1
Do While ii < 17
a(ii) = ii
iii = iii + 1
Loop
Form2.Show
End Sub
Sub playrnd()
Dim iii As Integer
Randomize
rnd_n = Int(Rnd * (16 - number1) + 1)
'number1 = numbwr1 - 1
ii = a(rnd_n)
Do While ii < 16
  a(ii) = a(ii + 1)
  ii = ii + 1
Loop
End Sub
*********************************
Form 2
Private Sub Command1_Click()
Form2.Visible = False
Form6.Visible = True
' Form4.Mediaplayer2.Visible = False
' Form4.Image1.Visible = False
' Form4.Image2.Visible = False
' Form4.Image3.Visible = False
' Form4.Image4.Visible = False
Form6.Show
Form6.Label1.Visible = True 'Show the instruction
' Form4.Label2(0).Visible = True
' Form4.Label3(0).Visible = True
' Form4.Label4(0).Visible = True
' Form4.Label4(3).Visible = True
' Form4.Label5.Visible = True
' Form4.Label14.Visible = True
' Image1.Visible = True
' Image2.Visible = True
' Image3.Visible = True
' Image4.Visible = True
Form6.Command1.Visible = True
' Form4.Command2.Visible = False
' Form4.Command3.Visible = False
End Sub
Private Sub Command2_Click()
End
End Sub
************************************
Form 4
Private Sub Command1_KeyPress(KeyAscii As Integer)
Key1 = KeyAscii
If Key1 = 42 Then 'Click * to start
  'Label1.Visible = False
  'Label2(0).Visible = False
  'Label3(0).Visible = False
  'Label4(0).Visible = False
  'Label4(3).Visible = False
  'Label5.Visible = False
  'Label14.Visible = False
  'Image1.Visible = False
  'Image2.Visible = False
  'Image3.Visible = False
  'Image4.Visible = False
Private Sub Command3_Click()
    Load Form2
    Form5.Visible = False
    Form2.Visible = True
    Form4.Visible = True
    Form4MediaPlayer2.Visible = False
    Form4Image1.Visible = False
    Form4Image2.Visible = False
    Form4Image3.Visible = False
    Dim frm As Form
    For Each frm In Forms
        Unload frm
    Next frm
    Form4MediaPlayer2.Visible = False
    Form4Image1.Visible = False
    Form4Image2.Visible = False
    Form4Image3.Visible = False
    Form6.Show
    Form6Label1.Visible = True 'Show the instruction
    Form4Label2(0).Visible = True
    Form4Label3(0).Visible = True
    Form4Label4(0).Visible = True
    Form4Label14.Visible = True
    Form4Image1.Visible = True
    Form4Image2.Visible = True
    Form4Image3.Visible = True
    Form4Image4.Visible = True
    Form6.Command1.Visible = True
    Form4.Command2.Visible = False
    Form4.Command3.Visible = False
    Form4.Label5.Visible = True
    Form4MediaPlayer2.Visible = False
End Sub

Private Sub Command1_Click()
    Form5.Visible = False
    Form1.Visible = True
    Form1MediaPlayer1.Visible = False
    Form1Image1.Visible = False
    Form1Image2.Visible = False
    Form1Image3.Visible = False
    Form1Image4.Visible = False
End Sub

Private Sub Command2_Click()
End

Private Sub Form_Load()
    Label5.Caption = tempAccCount
    Label6.Caption = tempPercent
End Sub

*****************************************************************************
Form 5
*****************************************************************************

Private Sub Command3_Click()
    Load Form2
    Form5.Visible = False
    Form2.Visible = True
    Form4.Visible = True
    Form4MediaPlayer2.Visible = False
    Form4Image1.Visible = False
    Form4Image2.Visible = False
    Form4Image3.Visible = False
    Form4Image4.Visible = False
    Dim frm As Form
    For Each frm In Forms
        Unload frm
    Next frm
    Form4MediaPlayer2.Visible = False
    Form4Image1.Visible = False
    Form4Image2.Visible = False
    Form4Image3.Visible = False
    Form6.Show
    Form6Label1.Visible = True 'Show the instruction
    Form4Label2(0).Visible = True
    Form4Label3(0).Visible = True
    Form4Label4(0).Visible = True
    Form4Label14.Visible = True
    Form4Image1.Visible = True
    Form4Image2.Visible = True
    Form4Image3.Visible = True
    Form4Image4.Visible = True
    Form6.Command1.Visible = True
    Form4.Command2.Visible = False
    Form4.Command3.Visible = False
    Form4.Label5.Visible = True
    Form4MediaPlayer2.Visible = False
End Sub

Private Sub Command1_Click()
    Form5.Visible = False
    Form1.Visible = True
    Form1MediaPlayer1.Visible = False
    Form1Image1.Visible = False
    Form1Image2.Visible = False
    Form1Image3.Visible = False
    Form1Image4.Visible = False
End Sub

Private Sub Command2_Click()
End

Private Sub Form_Load()
    Label5.Caption = tempAccCount
    Label6.Caption = tempPercent
End Sub

*****************************************************************************

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Form 6

Private Sub Command1_Click()
    Form6.Visible = False
    Form7.Visible = True
    Form7.Show
    Form7.Image1.Visible = True
    ' Form7.Image2.Visible = True
    ' Form7.Image3.Visible = True
    ' Form7.Image4.Visible = True
    Form7.Label1.Visible = True
    Form7.Command1.Visible = True
    Form7.Command2.Visible = True
End Sub

********************************

Form 7

Private Sub Command1_Click()
    Form7.Visible = False
    Form9.Visible = True
    Form9.Show
    Form9.Image1.Visible = True
    Form9.Image2.Visible = True
    ' Form9.Image3.Visible = True
    ' Form9.Image4.Visible = True
    Form9.Label1.Visible = True
    Form9.Command1.Visible = True
    Form9.Command2.Visible = True
End Sub

Private Sub Command2_Click()
    Form7.Visible = False
    Form6.Visible = True
    Form6.Show
    Form6.Label1.Visible = True
    Form6.Command1.Visible = True
End Sub

********************************

Form 8

Private Sub Command1_KeyPress(KeyAscii As Integer)
    Key1 = KeyAscii
    If Key1 = 49 Then
        Form8.Visible = False
        Form10.Visible = True
        Form10.Image1.Visible = True
        Form10.Label1.Visible = True
        Form10.Command1.SetFocus
    Else
        MsgBox "You did NOT make a correct choice! Press enter to continue.", _
            vbExclamation + vbOKOnly, "Make a choice when you see the message content!"
    End If
End Sub

********************************

Form 9

Private Sub Command1_Click()
Form9.Visible = False
Form4.Visible = True
Form4.Show
Form4.Command1.Visible = True
Form4.Command1.SetFocus
Form4.Label5.Visible = True
Form4.Label4(3).Visible = True
End Sub

Private Sub Command2_Click()
Form9.Visible = False
Form7.Visible = True
Form7.Show
Form7.Image1.Visible = True
Form7.Image2.Visible = True
Form7.Label1.Visible = True
Form7.Command1.Visible = True
Form7.Command2.Visible = True
End Sub

********************************
Form 10

Private Sub Command1_KeyPress(KeyAscii As Integer)
Key1 = KeyAscii
If Key1 = 49 Then
Form10.Visible = False
Form11.Visible = True
Form11.Image1.Visible = True
Form11.Label1.Visible = True
Form11.Command1.Visible = True
Form11.Command1.SetFocus
Else
MsgBox "You did NOT make a correct choice! Press enter to continue.", _
vbExclamation + vbOKOnly, "Make a choice when you see the message content!"
End If
End If
End Sub

********************************
Form 11

Private Sub Command1_KeyPress(KeyAscii As Integer)
Key1 = KeyAscii
If Key1 = 50 Then
Form11.Visible = False
Form12.Visible = True
Form12.Image1.Visible = True
Form12.Label1.Visible = True
Form12.Command1.Visible = True
Form12.Command1.SetFocus
Else
MsgBox "You did NOT make a correct choice! Press enter to continue.", _
vbExclamation + vbOKOnly, "Make a choice when you see the message content!"
End If
End If
End Sub

********************************
Form 12
Private Sub Command1_KeyPress(KeyAscii As Integer)
  Key1 = KeyAscii - 1
  If Key1 = 50 Then
    Form12.Visible = False
    Form13.Visible = True
    Form13.Image1.Visible = True
    Form13.Label1.Visible = True
    Form13.Command1.Visible = True
    Form13.Command1.SetFocus
  Else
    MsgBox "You did NOT make a correct choice! Press enter to continue.", _
    vbExclamation + vbOKOnly, "Make a choice when you see the message content!"
  End If
End Sub
********************************
Form 13
********************************
Private Sub Command1_KeyPress(KeyAscii As Integer)
  Key1 = KeyAscii - 1
  If Key1 = 51 Then
    Form13.Visible = False
    Form14.Visible = True
    Form14.Label1.Visible = True
    Form14.Command1.Visible = True
    Form14.Command1.SetFocus
  Else
    MsgBox "You did NOT make a correct choice! Press enter to continue.", _
    vbExclamation + vbOKOnly, "Make a choice when you see the message content!"
  End If
End Sub
********************************
Form 14
Dim Instructions As Integer
********************************
Private Sub Command1_KeyPress(KeyAscii As Integer)
  Key1 = KeyAscii
  Instructions = Instructions + 1
  If Instructions <= 3 Then
    If Key1 = 51 Then
      Form14.Visible = False
      Form8.Visible = True
      Form8.Image1.Visible = True
      Form8.Label1.Visible = True
      Form8.Command1.Visible = True
      Form8.Command1.SetFocus
    Else
      MsgBox "You did NOT make a correct choice! Press enter to continue.", _
      vbExclamation + vbOKOnly, "Make a choice when you see the message content!"
    End If
  End If
End Sub
ElseIf Instructions > 3 Then
    Form14.Visible = False
    Form1.Visible = True
    Form1MediaPlayer1.Visible = False
    Form1.Image1.Visible = False
    Form1.Image2.Visible = False
    Form1.Image3.Visible = False
End If
End Sub

*****************************************************************************
APPENDIX F: MALL CONFIGURATION DETAILS

Figure F1. Driving Simulation Administration Location: Warwick Mall

Figure F2. Driving Simulation Remote Location Experimental Configuration
Figure F3. Driving Simulation Customized Steering Wheel Input
Following is an example of the experiment database (courtesy of Siamak Ghanizadeh Hesar and the ISE department)

Table G1. Driving experiment data

<table>
<thead>
<tr>
<th>Record No.</th>
<th>Age</th>
<th>Gender</th>
<th>Message Name</th>
<th>Correct Key</th>
<th>Color</th>
<th>Graphic</th>
<th>Resp Key</th>
<th>Resp Time</th>
<th>Accuracy</th>
<th>Language</th>
<th>Driving Ex</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>41–60 Yr.</td>
<td>Female</td>
<td>Accident</td>
<td>49</td>
<td>Green</td>
<td>Text-only</td>
<td>49</td>
<td>21.73438</td>
<td>1</td>
<td>Spanish</td>
<td>more than 10 years</td>
</tr>
<tr>
<td>2</td>
<td>41–60 Yr.</td>
<td>Female</td>
<td>Accident</td>
<td>49</td>
<td>Amber</td>
<td>Text-only</td>
<td>49</td>
<td>21.3125</td>
<td>0</td>
<td>Spanish</td>
<td>more than 10 years</td>
</tr>
<tr>
<td>2736</td>
<td>20–40 Yr.</td>
<td>Male</td>
<td>Road Work</td>
<td>50</td>
<td>Green</td>
<td>Graphic-Aided</td>
<td>50</td>
<td>2.015625</td>
<td>1</td>
<td>English</td>
<td>5–10 years</td>
</tr>
</tbody>
</table>

Note:
1. In column “Response Key”, 49 stands for button “1”, 50 stands for button “2”, 51 stands for button “3”.
2. In column “Accuracy”, 0 stands for the incorrect response to a DMS message and 1 stands for the correct response to a DMS message.