Disseminating Information with Variable Message Signs during Natural or Human-Caused Disasters

Valerie Maier-Speredelozzi[1*], Jyh-Hone Wang[1], Charles Collyer[2], Natacha Thomas[3], Aaron Clark[1], Jeff Severson[1], Kelvin Santiago Chaparro[1]
[1]Department of Industrial and Manufacturing Engineering
[2]Department of Psychology
[3]Department of Civil and Environmental Engineering
*Corresponding Author: vms@egr.uri.edu or 401-874-5187
University of Rhode Island, Kingston, RI 02881

Abstract
Recent natural and human caused disasters present new challenges for transportation systems. The actions taken prior to and following a disaster are of critical to ensuring minimal impact on infrastructure and to minimizing the loss of human life. One of the most significant problems is a lack of clear and efficient communication. The public requires timely information and guidance during and after a catastrophic event. The decisions and responses made by transportation system officials must be promptly disseminated to the general public especially during mass evacuation. This study examined the state of Rhode Island's emergency response capability in disseminating information to motorists during times of crisis to improve public safety. A methodology is described for developing a library of messages for deployment on Variable Message Signs (VMS), to enhance the preparedness of Rhode Island's transportation system for a potential natural or human-caused disaster, based on three specific scenarios. A public opinion survey was conducted to gauge receptiveness to the new expansion of VMS capabilities, and provide inputs for subsequent driving simulation tests for message formats and content.
Keywords: Variable Message Sign, Emergency, Evacuation

Introduction

Recent natural and human-caused catastrophes provide compelling motivation to enhance the communication capabilities of transportation systems so that they are more robust, prepared, and responsive in emergency situations. Authorities around the country have made great strides in preparing action plans and protocols to help the public in time of crisis, but they have lagged behind in creating timely and effective means to communicate with the public at those times. This paper examines the use of Variable Message Signs as an alternative to inform and coordinate motorists and emergency responders to minimize incidents and maximize safety.

An Intelligent Transportation System (ITS) has many components that help agencies manage traffic and distribute information, such as Variable Message Signs (VMS) and Dynamic Message Signs (DMS). The distinction between these two types of electronic bulletin boards is that DMS are in fixed positions while VMS are portable, as seen in Figure 1. Another difference is that DMSs can display three lines of twenty characters in amber, red, or green, whereas VMSs only have three lines of eight amber characters. Both sign types can display sequenced message loops and allow transportation authorities to inform motorists of changing conditions in real time.

At this time, there is a message library that the Rhode Island Transportation Management Center uses for road closures, road work, congestion, or adverse weather conditions. Unfortunately,

Figure 1: VMS (Left) & DMS (Right)

there is no message library for emergency scenarios. In some cases, VMS operators type custom messages when standard messages do not suffice, but this requires time and effort, and operators can not be sure that the intent is adequately conveyed or helpful to motorists. This is a serious problem during emergencies when timely, accurate information is critical to public safety.

A review of relevant literature is made to improve and expand the role of VMS in disasters. In order to assess the preparedness of Rhode Island's transportation system, several disaster scenarios were created to describe high probability events with potential high impact on the area. Each scenario provides a description, timelines, secondary hazards, and implications. In particular, these scenarios explore the impact that each event would have on the transportation system, such as evacuations and emergency response. Finally, a survey was conducted to gauge the receptiveness of the public to expanding the role of VMS to communicate not only traffic and roadwork information, but also critical safety advisories during times of emergency.

Present State of Knowledge

The main influences on the current condition of Rhode Island's transportation emergency communication infrastructure were reviewed. Also, guidelines governing present message usage, established emergency plans and procedures, and different state organizations' roles.

Current Emergency Communication Capabilities

Rhode Island's current means of disseminating emergency information to motorists are: local television news and a cable traffic channel, radio advisories on local channels and on the 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 the use of these media forms during emergencies, because the majority of motorists have no access while driving. The 511 call-in traveler information system provides timely information, but relies on cellular telephones and may not be familiar to all motorists. Motorists are not likely to listen to radio messages if they are not prompted to find the proper station. Fixed signs can deliver helpful information, but can only communicate permanent pre-existing messages which do not help much with dynamic emergency conditions. For example, approved shelter lists change over time, and extreme situations may make it necessary to designate emergency shelters on short notice, which means it is impossible for state agencies to maintain up to date evacuation route markers. VMS and DMS can communicate a near limitless variety of messages to motorists effectively in real time, and can be moved to critical locations if necessary. VMS flexibility also allows them to direct motorists to other emergency communication media (Levesque, 2006).

Review of Studies Related to VMS and DMS

Much of the research on optimizing the use of VMS and DMS focuses on how to best present the signs (visibility, location, etc), rather than on the message content. Colomb et al. (1991) tested favorable conditions for VMS legibility. Guerrier and Wachtel (2001) found that single frame messages produced better response times than alternating two frame messages, and Durkop and Dudek (2001) studied the use of abbreviations. Wang et al. (2006) revealed that single frame messages with minimum flashing, specific wording, no abbreviation, and amber-green color combinations were preferred and resulted in faster response times. Wardman et al. (1997) surveyed the effect of VMS information on motorists' route choices. Peeta et al. (2000) found that the level of detail in VMS content significantly affects drivers' willingness to divert.

Review of Studies Related to Emergency Procedures

There has been an abundance of recent research on disaster preparation and emergency procedures, including intelligent transportation systems (ITS) issues such as modeling transportation systems, directing evacuation traffic, mobilizing resources, and distributing information. Wolshon et al. (2005) published a two part review of policies and practices for hurricane evacuation. Buck (2004) and Levesque (2002) detailed successful inter-agency cooperation to improve incident response in Maryland and Rhode Island, respectively. Liu et al. (2006) presented a framework for real time traffic management under emergency conditions and Yuan et al. (2006) presented a framework for simultaneous optimization of evacuation traffic destination and route assignment. Some research exists on applying existing ITS elements during emergencies, such as Jiang et al. (2002) and Kodali et al. (2005). To date, there has not been a significant focus on developing effective methods of disseminating information during emergencies using VMS. One common theme in recent disaster preparation research is that most systems suffer from a "lack of communication between agencies in charge" (Church et al., 2002) and that "working partnerships were a key" (Buck 2004) to successful emergency plans.

Review of the Emergency Management Plan in RI

The federal government requires states to have a comprehensive emergency operations plan (Wolshon 2005). Various disaster drills have occurred in RI for port or train station evacuations, plane crashes, bioterrorism attacks, and explosions. Such drills address inter-agency cooperation, but are mostly localized in scope and do not tax the transportation system, communication lines, and mass displacement of individuals and resources. The impracticality of drilling for large scale events underscores the need for robust communications systems that can withstand emergencies that exceed the capacities of standard procedures. Recent studies show that one third of possible evacuees will resist leaving their homes, which presents a challenge of persuasion for state officials (Hitti, 2006). VMS becomes a plausible and effective alternative for communicating real dangers and unusual situations. The State of Rhode Island Emergency Operations Plan (RIEMA, 2006) is composed of four stages that are classified by timeframe: Awareness, 72-48 hours before; Preparedness, 48-24; Response, 24-0; and Recovery, after a hurricane arrival.

Review of TMC's Role in Emergency Communication

The majority of information communicated to Rhode Island motorists is coordinated by the Transportation Management Center (TMC) which operates 24 hours per day. This entity is responsible for monitoring and managing traffic on major roadways, controlling VMS and DMS, and coordinating incident response with an intelligent transportation system of closed circuit video, VMS and DMS, detection equipment, information systems, and the accompanying software and networking. There are, however, a number of constraints on TMC effectiveness. Present monitoring is only along major traffic arteries. The TMC has an inventory of about 30 DMSs and 15 VMSs that are centrally controlled, but other VMSs are operated by road construction contractors and have no integration with the TMC in times of emergency. The TMC also relies on outside agencies to approve many of its operations.

During emergencies, TMC personnel should be managing dynamic transportation system conditions and coordinating with other agencies, rather than composing custom VMS messages. The TMC has four standard libraries of environmental, accident, roadwork, and congestion messages for DMSs, but no emergency message library. Some useful emergency messages exist in the other libraries, but they are insufficient and are not always suitable for the smaller display parameters of VMSs. A nearly unlimited library of messages that have been prepared, tested, and approved in advance can be stored to save critical time during natural or human-caused disasters.

There are many guidelines for VMS messages used in the state that arise from documents such as the Manual on Uniform Traffic Control Devices (MUTCD), the I-95 Corridor Coalition, TMC protocols, and government statutes. Expanding the use of electronic messaging for 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" (FHWA, 2003). The use of VMS in emergencies also fits with both the MUTCD's guidelines for portable electronic message signs, and TMC usage which allows for "…special public safety messages" (Levesque, 2006), although this is not typical current practice.

The MUTCD recommendations for VMS message design include no more than one or two phases using capital letters and display times of at least 5 seconds. For one phase messages, MUTCD's recommendation is for the three lines to present the problem, the location or distance ahead, and the recommended driver action, respectively. The TMC prioritizes message types starting with road closures, safety messages, lane closures, weather advisories, and general advisories (Levesque, 2006), but 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. 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.

Methodologies

Figure 2 shows the proposed emergency message development process, starting with assessing the messages in available libraries for situations such as congestion, road closures, or weather conditions. When a scenario description is incomplete, assumptions about the emergency must be made, such as the existing infrastructure, emergency plans and other information. Once a scenario is complete, the specific user needs during that type of emergency can be evaluated, and relevant message sets can be generated which fit the constraints of the available signs. In the agency survey step, consideration must be given to the specific agency needs, the role of that agency during an emergency, and any existing plans. If the messages pass through the agency

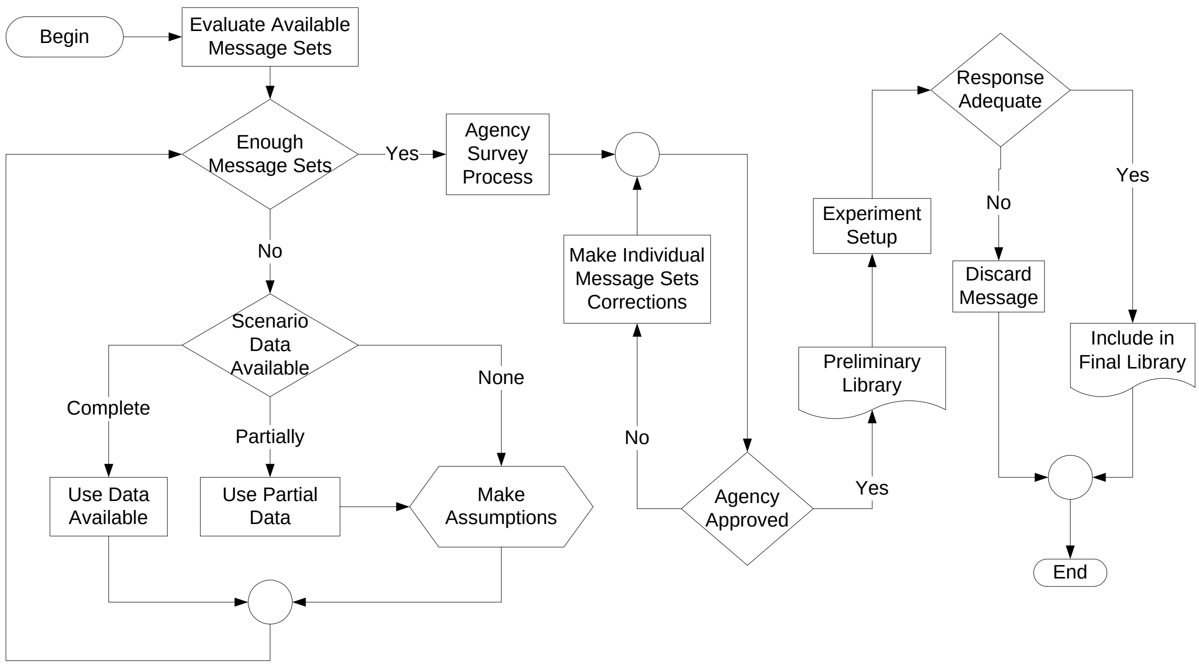

Figure 2: Message Development Process

survey process then they can be included into the preliminary message library, which can then be tested through driving simulation experiments and surveys, to ensure adequate and appropriate responses result, prior to inclusion in a final message library for the agency.

Potential Disaster Scenarios

A key part of an effective emergency response plan is a synopsis of possible disaster scenarios including a description of the event and details of the consequential effects on the transportation system and emergency response agencies. Three scenarios specific to Rhode Island are provided.

Hurricane Scenario

In the past 50 years, only a handful of hurricanes have been powerful enough to cause loss of human life and significant infrastructure damage to Rhode Island. Among these were Carol (1954), Gloria (1985), and Bob (1991) which were all category 3 storms or less when they made landfall. Data from these events were used to create a possible worst case scenario of a category 4 hurricane with a forward speed of 40 mph, sustained winds of 120 mph and gusts of up to 150 mph. Storm surges could be 10-20 feet with 35 foot swells. Such a storm could cause over 500,000 homes in the area to lose power for more than 24 hours and require months of recovery with more than $1 billion in property damage. Evacuations could number 200,000, with 100 fatalities and 2,000 hospitalizations, or worse during the height of tourist season. This is an order of magnitude less than Katrina, but New Orleans had great vulnerability of areas below sea level.

After developing off the African Coast, a tropical storm is upgraded to a hurricane following four days in open water. The category 4 storm is predicted to directly hit on the state within 2 days. After making landfall, the hurricane decreases in speed and intensity and moves out of the area the following day. Based on previous storms, areas near the coast and large bodies of water would sustain the most damage due to flooding, high winds, and flying debris. At best, these areas would have 1-3 days to prepare, so evacuation and contingency plans need to be made ahead of time and implemented on short notice. Due to massive congestion of evacuation routes, not all residents would be able to leave, causing the limited number of shelters to be filled to capacity, including emergency designations. The massive amounts of debris would cause some residents to be trapped in their homes or on the roads and would hinder rescue attempts. Electrical power would be disrupted for the majority of residents, impacting the communication of instructions to affected residents and emergency personnel, as well as supplies of food, water, and medicine. Extensive structural damage and resulting debris would create thousands of homeless individuals who would require food and medical care for longer periods of time. Emergency response teams would also be hindered by the lack of clear roadways to transport the injured to medical facilities. Structural damage to fuel storage tanks, power plants and factories could cause leaks that would contaminate drinking water. Local companies would have extensive damage to their facilities and surrounding infrastructure, and displaced employees.

LNG Tank Explosion Scenario

Liquefied Natural Gas and oil storage tanks in Providence harbor are susceptible to terrorist attacks or natural disasters that could cause them to suddenly explode or leak. An explosion would be highly destructive to neighboring structures and cause many fatalities and injuries. Emergency response agencies and local medical facilities would be overwhelmed by the high volume of patients in a short amount of time with burn and hazardous fume inhalation injuries. Fires from the explosion could cause surrounding buildings to ignite, requiring the assistance of many fire departments. Areas further away from the impact would be affected by smoke and debris for several hours after initial impact. Infrastructure damage would be less extensive in these areas but injuries, environmental contamination, and traffic congestion would still occur.

Damage would be immediate with little or no warning occurring prior to an explosion, while a leak would possibly have some warning. The possibilities for short-term preventative measures to mitigate damage, as with the case of hurricanes, are limited or nonexistent in LNG explosions, as with chemical leaks or fires. Terrorist related events might be prevented by closely monitoring land, air, and water activity surrounding the LNG tank. Traffic would increase due to individuals attempting to leave the impact area, also hindering the efforts of responding emergency personnel. Demand for telephone communications would increase. This can be expected to hinder efforts of emergency response personnel responding to calls in the area. Since the large LNG tank in Providence harbor is very close to Rhode Island Hospital, coordination of planning between RI state agencies and the hospital is strongly recommended. Temporary shelters would be needed in the areas immediately surrounding the impact site and in some remote areas for longer term response, which would take weeks to months and cost millions of dollars.

Bridge Destruction/Collapse Scenario

Bridges represent a significant part of the transportation network in Rhode Island, where bridges connect the mainland with several islands in Narragansett Bay and span rivers entering the Bay. Any destruction or collapse of one or more of these bridges due to damage from a severe storm or terrorist attack could prove especially damaging to the highway infrastructure, in addition to the loss of human life. Aftereffects from a bridge closure could last months and cost millions of dollars while the bridge is replaced or repaired, which would significantly impact traffic flows and the local economy, especially during the summer tourist season. As a result of bridge destruction due to a terrorist attack, debris would fall into the water below, affecting boat traffic and possibly causing environmental contamination. Local hospitals would also be impacted by the sudden high volume of injured persons and fatalities.

A terrorist attack on a major bridge would have little or no warning, and its effects would be immediate. Traffic would accumulate on both sides of the bridge, with hours of delays and no chance to divert traffic until after the event. This congestion would affect arriving emergency crews and would spread to surrounding communities. Shortly after bridge closure the public would lack information and instructions regarding evacuation of the area and recommended routes. There would be a delay between the event occurrence and when instructions would be transmitted via radio and VMS boards placed around the site. During this time the public would rely on information spread by word of mouth and panic or confusion could occur.

Preliminary Message Libraries

The following tables contain the results of the methodologies described above, as applied to the Rhode Island Emergency Management Agency (RIEMA) tasks during the hurricane scenario, which must also be approval by the TMC. The state already has message library elements for adverse weather conditions such as snow and ice, and traffic accidents. The state had partial data regarding the hurricane scenario, including flood maps, shelter information and evacuation zones. Unfortunately, there is no plan for how to design or arrange messages for a hurricane.

Table 1a shows potential VMS messages for the 24 hours immediately preceding hurricane arrival. Table 1b has messages that can be displayed prior to and after the hurricane arrival to appeal to public consciousness. This set of preliminary messages provides a stating point for user response testing with surveys and driving simulation experiments. The library elements in tables 1a and 1b can be combined into relevant messages for each of the four stages of the state's emergency operations plan (RIEMA, 2006). For example, during stage 1, Awareness, which is more than 48 hours before, a message could be "FILL GAS TANKS." During stage 2, Preparedness, within 24-48 hours before, messages could be "HURRICANE WATCH" or "EVACUATE RTE 1N." In stage 3, Response, on the day of the event, a sample message is "SHELTER NEXT EXIT." And during stage 4, after the event, messages such as "BEACHES AND PARKS CLOSED" may be used. 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" (Wolshon, 2005). In such cases, as in an explosion, the stages are truncated and authorities need very effective communication plans.

Survey Design

To aid proper construction and evaluation of potential emergency communication solutions and improvements, including the viability of increasing the use of VMS, informal interviews with transportation and emergency agencies were conducted. A public opinion survey was used as a preliminary assessment tool 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 communication systems; assess drivers' approval of expanding the role of VMS in emergencies; and test driver's preferences and comprehension of several emergency messages to assess basic design elements. The questionnaire posed 12 distinct questions where the first 7 questions were used to collect participants' level of agreement with a given statement on a scale of "1" to "5", where "1" indicates "strongly agree" and "5" indicates "strongly disagree." The

LINE1	LINE2	LINE3
EVACUATE	AHEAD	1610 AM
ROADWORK	BEAR	AHEAD
SHELTER	EXIT	AT EXIT X
TUNE	NEXT EXIT	EXIT XX
	RADIO	LEFT
	STRAIGHT	RIGHT
	TURN	RTE XX
	TURN LEFT	
	TURN RIGHT	
	USE	
	VIA	

LINE1	LINE2	LINE3
ONTO	NORTH TO	RTE XX
RIGHT	ON RTE XX	XX RD
RTE XX	ONTO	
THEN	RTE XX	
THEN EXIT	SCHOOL	
TO HIGH	SOUTH TO	
TO MIDDLE	XXX	
USE		

Table 1a: Messages for 24 hours before hurricane arrival (Portable Signs)

LINE1	LINE2	LINE3
BEACHES	AND PARKS	CLOSED
FILL	CLOSED	AHEAD
FLOOD	FOR POWER	ITEMS
HURRICANE	GAS TANKS	OUTAGES
PREPARE	HAZARDS	SUPPLIES
ROAD	LOOSE	YET
SECURE	NOT OPEN	
SHELTER	OPEN	
STORM	WARNING	
	WATCH	
	WATER	

LINE1	LINE2	LINE3
OFFICIAL	USE ONLY	
DRIVE	CAREFULLY	

Table 1b: Messages for 76-24 hours before and after hurricane arrival (Portable Signs)

remaining questions surveyed participants' experience with and interpretation of VMS messages in emergency scenarios, as well as demographic information that might influence survey results.

Several factors were considered in designing the public opinion survey, including message wording based on current standard practice and recent research for VMS, and accessibility for a broad demographic of backgrounds, education levels, and physical conditions. To facilitate an acceptable level of returns, the survey had to be concise, with wording that was understandable, clear, 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. The survey focused on portable VMSs, since they can be of great use in diverse emergency situations and because messages on these signs can also be implemented on larger, fixed DMS, but the reverse is not possible.

Survey Results and Discussion

The survey was presented to volunteers with valid drivers' licenses at three locations by Institutional Review Board certified researchers. Based on the demographics of the 233 participants, the group was found to be representative of the area's driving population, with sufficiently diverse ages, genders, native languages, education levels, and driving experience.

The survey responses are shown in table 2. Responses of "1" and "2" were combined for agreement, while responses of "4" and "5" indicated disagreement. It can be seen that 46.1% of

Table 2: Public Opinion Survey Questions 1-7 and 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:

		Strongly Agree				Strongly Disagree	
		1	2	3	4	5	Total
Question		%	%	%	%	%	#
Q1		18.7	13.3	21.7	17.3	28.8	*225*
Q2	Radio	26.3	16.4	24.9	16.0	17.4	*213*
	Television	26.2	25.7	19.3	14.4	14.4	*202*
	511 Call-in	12.0	5.8	19.9	21.5	40.8	*191*
	VMS	30.0	27.1	21.3	11.6	10.6	*207*
	Internet	14.7	16.2	21.8	20.8	26.4	*197*
	Fixed Sign	44.3	21.0	14.8	10.5	9.5	*210*
Q3	Radio	25.9	9.4	22.6	13.7	28.3	*212*
	Television	27.0	14.2	23.5	14.7	20.6	*204*
	511 Call-in	7.7	4.1	17.0	18.0	53.1	*194*
	VMS	28.9	24.0	23.0	10.3	13.7	*204*
	Internet	10.8	12.8	20.5	18.5	37.4	*195*
	Fixed Sign	47.4	19.6	18.2	7.2	7.7	*209*
Q4		45.0	25.5	16.4	6.8	6.4	*220*
Q5		47.2	29.4	12.4	4.6	6.4	*218*
Q6		68.7	20.3	4.6	1.8	4.6	*217*
Q7	fill gas tanks	38.6	19.0	22.9	7.6	11.9	*210*
	blizzard	48.6	24.3	16.2	3.3	7.6	*210*
	secure water supplies	33.0	18.9	28.2	7.3	12.6	*206*
	prepare for outages	36.7	24.2	23.7	6.3	9.2	*207*
	icy road ahead	62.7	20.1	10.0	2.9	4.3	*209*
	expect high winds	47.6	23.6	17.3	6.3	5.3	*208*
	secure loose objects	36.6	20.0	20.5	10.7	12.2	*205*

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 that the 511 traffic information phone 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 surveyed were fixed signs and to a slightly lesser extent, VMS, with 65.3% and 57.1% agreement, respectively.

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% 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). Respondents found the 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).

In question 8, when given the choice of four sign designs for an emergency detour, 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 state transportation department’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. Questions 10-12 were more qualitative, with free response content that will guide future research studies and driving simulation experiments for developing and refining effective emergency VMS messages. The quantitative results from questions 1-9 were statistically analyzed to assess the potential effects of demographic characteristics on responses.

Conclusions and Recommendations

In order to minimize the impact of a natural disaster or terrorist attack, it is essential to have an emergency response plan with necessary procedures for all agencies based on potential disaster scenarios. This plan needs to address methods of communication, evacuation, deployment of emergency response vehicles, and guidelines for shelters. An effective emergency response plan helps to mitigate the effects of a disaster on the transportation system. This paper has presented three disaster scenarios for the state of Rhode Island, with the goal of enhancing preparedness for various agencies (police, fire, emergency rescue, and transportation management center) would have to provide during such an emergency. A transportation management center using ITS can contribute to response efforts on many levels, including public communication and administering effective alternate routes to minimize congestion and chaos near the disaster area.

Message design, library development, and testing are critical to the success of VMS and DMS communication, particular for use during natural and human caused disasters. The methodology described herein should be implemented on multiple levels with all cooperating emergency response and government agencies. Survey results show that this application of VMS can be a suitable alternative for providing information and guidance to motorists regarding the dynamic circumstances of disaster events. To do so, time and effort should be dedicated in advance to develop, design, and test potential messages for effectiveness in terms of content and features, including the use of different colors, fonts, graphics, or abbreviations. Next, the messages that are selected for emergency use should be integrated into a library with easy access for situations with little or no warning. The deployment plan for implementing such messages through VMS and DMS signs should be integrated into the emergency response plans of government agencies.

The overall survey results indicated that people in general desire more information than 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 such as radio, television, the internet, and the 511 call-in system. Such findings are in agreement with the positive attitudes expressed toward VMS/DMS in previous public opinion polls by Benson (1996), Chatterjee et al. (2002), and Peng et al. (2004) at different U.S. locations. The results further demonstrated that drivers are willing to follow VMS instructions in emergencies, and follow other VMS directives to a high degree. In testing the adequacy of various emergency messages, it was found that motorists could process a considerable amount of abbreviated material and fill in missing terms 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, indicating. a potential benefit for such emergency signs but further refinement must be done. It may also be true that motorists' familiarity with existing signs positively influenced their reactions.

The practical constraints of survey administration, such as the very small probability of getting certain combinations of factor levels means that the data could be sparse and not as easy to statistically analyze as a well designed laboratory experiment. For instance, it is difficult to find a representative sub-population of English speakers who are older than 40 and have only a few years of driving experience. Some interpretation was necessary even for questions that provided clear alternatives, since participant marking conventions were not uniform. 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.

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. State agencies and residents could benefit from having a special message library for emergency situations, linked to evacuation and emergency vehicle routes and monitoring capabilities of an ITS. This would lead to better information for the public using well tested messages, and also alleviate the strain on agency resources during emergencies. Time that would otherwise be spent constructing signs can instead be used to manage the dynamic situation of natural or human-caused disasters.

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