ASSESSING THE SLOW-DOWN EFFECTS CAUSED BY ACTIVE DYNAMIC MESSAGE SIGNS AND EXPLORING MEANS TO EASE THE SLOW-DOWN

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ABSTRACT

As a critical component in Intelligent Transportation System (ITS) of modern traffic management, dynamic message signs (DMS) are widely used in many countries as an effective means to provide motorists with up to date information regarding road conditions, accidents, and congestion etc. However, it is often seen that motorists slow down when approaching active DMSs and speed up after passing these signs. The speed variations cause serious safety threats to other motorists on highways. To assess the slow-down effects, a human factors study was conducted to gain an understanding of the associated causes and risks. This study intends to improve the design and display of DMS messages in order to ease the slow-down effects. A questionnaire survey was first developed and conducted to identify possible causes and risks of slow-downs. Participants were further surveyed about their preferences on various DMS design and display features such as message category, message type, number of frames, message details, and use of graphics. To understand the effects of various DMS messages on the speed variations of traffic approaching and passing the signs, traffic data were gathered by several Mobility Technology Units (MTUs) near DMSs along I-95 in Rhode Island and analyzed. Drivers' responses to various DMS designs and formats were further assessed through a driving simulation. This study has provided updated knowledge regarding the causes and risks associated with the slow-down effects and it has identified measures to improve the design and display of DMS messages to help ease the slow-down effects.

Keywords: slow-down effect, dynamic message sign, questionnaire survey, traffic data analysis, driving simulation

INTRODUCTION

Objectives

This paper presents a human-factors study that investigated the causes of slow-downs and possible means to ease the slow-down effects. As a critical component in Rhode Island's Intelligent Transportation System, thirteen dynamic message signs are currently in service on Rhode Island major highways. While Dynamic Message Signs (DMSs) are considered as effective means to provide up to date traffic information and assistance for drivers concerning detours, road conditions, accidents, and congestion, it is observed on traffic surveillance cameras that drivers often slow down when approaching active DMSs and speed up after passing these signs. These speed variations could pose serious safety concerns on highways. This study intends to identify the causes of slow-downs and explore the means to ease the slow-down effects.

Scope

To understand the effects caused by DMSs, a questionnaire survey was developed and conducted to obtain drivers' understandings and preferences regarding DMS messages. The survey was intended to help better understand the effect of active dynamic message signs on traffic, identify causes of slow-downs, and improve the DMS message design and display. To assess the slow-downs on Rhode Island highways, and to understand the effects of various DMS messages on traffic speed, volume, and vehicle headway distance, the study next analyzed traffic data gathered by mobility technology units (MTUs) located near several DMSs along I-95 in Rhode Island. The traffic data analysis was expected to help understand the effects of various DMS messages on traffic speed, volume, and vehicle headway distance. With partial correlations found between certain DMS messages and traffic slow-downs, a video-based driving simulation was then developed and conducted to assess drivers' responses to active DMSs in a simulated environment. Drivers' preferences on various DMS messages obtained by the survey were compared with their responses to the same DMSs obtained from the simulation.

BACKGROUND

Reviews of literature and past studies regarding the impact of DMSs on drivers and the slow-down effects are summarized below.

Impact of DMSs

Many researchers have studied drivers' attentions and responses to DMSs. Ullman et al. (2005) evaluated DMS messages to determine which message displayed drivers found the most effective in an emergency situation. The study concluded that during emergencies, DMS messages should provide meaningful and straightforward messages that can be read and responded to quickly because their impact on drivers can be huge. In a questionnaire survey, Benson (1996) investigated whether drivers noticed and thus responded to DMSs. The author found that about 20% out of 500 subjects ignored active DMSs while driving. Interview surveys conducted by Bonsall (1993) in Paris revealed that 97% of the drivers knew that DMSs existed, 84% identified DMSs as providing very useful information and 46% had at least once detoured accordingly. Peng et al. (2004) conducted a similar study in Wisconsin. The results indicated that 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 due to the posted message. The most commonly used DMSs in the UK were used in the Midland Driver Information System (Tarry and Graham, 1995). These DMSs provided instructions to northbound drivers approaching a “key” decision point of whether to proceed westbound or eastbound around the city of Birmingham. The results showed 27-40 % of subjects diverted as instructed by these DMSs.

The Slow-down effects

In a study conducted by Harder et al. (2003), a computer based driving simulation was used to test various message types to see whether a slow-down effect was evident. The results showed that 21.7% of participants slowed their speed by 13.9 mph as “AMBER” alert DMS messages were approached. Alternatively, when a “Crash” alert DMS message was displayed, 13.3% of participants slowed their speed by 12.7 mph.

In another study, Boyle and Mannering (2004) used a driving simulation to determine the impact of DMSs on drivers’ speed. While it was found that drivers did slow down when approaching active DMSs, the study also showed that drivers sped up to compensate for their speed reduction after passing DMSs. Furthermore, the study demonstrated that when drivers encountered a new DMS message, they were more likely to have a larger deviation in speed. This can mean that when a new message is presented on a DMS, drivers tend to notice the change in message, and as a result more time is needed to process the information. Moreover, when a DMS is displaying the same message for a long period of time, drivers become familiar with it and thus less time is needed to read it.

Dudek (2004) added that the length of time in which a message display is shown is important to drivers as well as the credibility of a transportation agency. His report stated that the display time of a DMS should only cover the event or hazard in question. Advance showing of a message is appropriate, such as several hours or even days before, depending on the event’s effect for drivers. However, extending the display time of a DMS message, when it is no longer relevant, can cause confusion to drivers as well as the losing of public trust in the transportation system. As a result, everyday drivers who see the same message display and know that it is no longer important to them can eventually ignore them. Thus, in order for DMSs to be used effectively by transportation authorities, DMS messages should provide relevant information to drivers at all times.

Use of Graphics

It has been shown in several studies that the use of graphics to convey meaning on roadway signs provided many advantages over text-only messages. Graphic aided messages could be more easily and quickly identified compared to text-only messages from a further distance.

The fact that graphically presented information allowed faster responses than information presented by words was found by many studies (Bruce et al., 2000; Hanowski and Kantowitz, 1997; Staplin et al., 1990). Wang et al. (2007) conducted a study on the use of graphics on Dynamic Message Signs (DMS) and found that most drivers preferred graphics over text and responded faster to graphic-aided messages than text-only messages. The use of graphics or symbols on traffic signs has been widely employed in European countries such as Germany and Spain to influence derivers' route choices. All of these studies and practices indicated that by adding graphics, it might help enhance drivers' understanding of and responses to DMSs and ease the slow-downs.

To sum up, many studies indicated that DMSs have attracted drivers' attentions from their driving. Since drivers are expecting useful information from active DMSs, they are slowing down to gain extra time to read and comprehend the messages. To compensate for their speed reduction, drivers speed up after passing DMSs. Crashes are highly correlated to driving speed and this speed variation could pose a threat to other vehicles in the traffic and lead to crashes (Hauer, 1971; Lave, 1985; Rodriguez, 1990; Solomon, 1964; TRB, 1998). Adding graphics to DMS messages could help enhance drivers' understanding of and responses to those messages and reduce their speed variation while reading DMSs, and might help eventually ease the slow-downs.

DESCRIPTION OF THE STUDY

Three different approaches were employed in assessing the slow-downs on Rhode Island major highways, identifying the causes of slow-downs, and obtaining subjects' preferences and responses to different DMSs. These included a questionnaire survey, traffic data analysis, and a driving simulation. A description of each approach is given below.

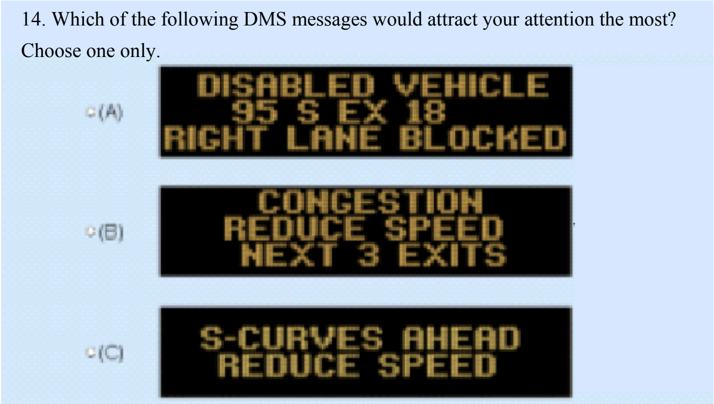
Questionnaire survey

A questionnaire survey was designed and conducted to help identify the causes of slow-downs on highway driving and also to gain insights about drivers' preferences on various message design and display features.

Design of the Questionnaire Survey

The questionnaire survey was designed using Microsoft PowerPoint with Visual Basic macros to record the subjects' answers. For each question, the subjects were required to choose either single or multiple answers.

The survey contained 24 questions. These questions were designed to collect drivers' opinions on two categories. The first six questions were used to identify the causes of slow-downs in general and those associated with DMS designs. Other questions were used to assess drivers' opinions and preferences regarding various DMS message display features. Each question was designed to assess a single design or display feature with multiple DMS displays as possible choices. Display features included message categories (danger warning, informative, and regulatory messages), message types (text-only, graphic-aided with full text, and graphic-aided with partial text message), and number of frames used to display the same message (single frame vs. two-frame). Figure 1 shows a sample question.



14. Which of the following DMS messages would attract your attention the most?
Choose one only.

○(A) DISABLED VEHICLE
95 S EX 18
RIGHT LANE BLOCKED

○(B) CONGESTION
REDUCE SPEED
NEXT 3 EXITS

○(C) S-CURVES AHEAD
REDUCE SPEED

Figure 1 A Sample Survey Question Regarding Message Categories

Survey Administration

The survey was conducted at multiple locations in Rhode Island in order to obtain a representative sample of the Rhode Island driving population. The University of Rhode Island, Pawtucket Department of Motor Vehicles, and Warwick Mall were among several sites where the survey took place. A total of 150 licensed subjects participated in the survey voluntarily. Among them, 75 were between 18 and 40 years old, 39 between 41 and 60, and 36 were older than 60, and there were 71 females and 79 males. Age and gender percentages of the survey resembled Rhode Island population. Prior to the survey, each participant was asked to read and sign a consent form, approved by the university's Institutional Review Board. The subject would then start taking the survey presented as PowerPoint slides on a laptop computer. Answer(s) could be made by using a clickable mouse or by telling the survey assistant.

Traffic Data Analysis

Wang et al. (2009) had previously conducted similar analysis in which slow-downs were assessed with measurements of mean volumes and speeds in 5-minute increments. Those traffic data were gathered by several mobility technology units (MTUs) near DMSs along I-95 in Rhode Island from June 1st through June 14th of 2007. To determine the extent of slow-downs caused by active DMSs, in this study, same traffic data were analyzed in longer periods of 30 minutes. Besides mean volume ($\mathrm{Vol}_{\mathrm{avg}}$) and speed ($\mathrm{Sp}_{\mathrm{avg}}$), vehicle headway distance ($\mathrm{Hdwy}_{\mathrm{avg}}$) was also analyzed in each of the four time periods (Figure 2) for each message display. It is believed that when slow-downs occur, both speed and headway distance will reduce while volume will increase. Mean volume (cars/5-minute duration), mean speed (mph), and mean vehicle headway distance (feet) were calculated using the following equations:

$$Vol_{avg} = \frac{\sum Vol_i}{n} \tag{1}$$

$$Sp_{avg} = \frac{\sum Sp_i Vol_i}{\sum Vol_i} \tag{2}$$

$$Hdway_{avg} = \frac{\dfrac{Sp_{avg} \times 5280}{12} - 15 \times \dfrac{Vol_{avg}}{N_{lane}}}{\dfrac{Vol_{avg}}{N_{lane}}} \tag{3}$$

where:

Vol_i: volume for the i^{th} 5-minute time increment

Sp_i: average speed for the i^{th} time increment

n: number of increments that are being summed up

12: number of 5-minute increments in an hour

15: average length of regular vehicle in feet

N_{lane}: number of total lanes where the data were collected

Two approaches were employed in this analysis, based on the length of DMS display and the time of day at which the DMS was displayed. In the first approach, data were divided into two groups according to the length of DMS display. The two groups were: DMS message displays that were active for less than 30 minutes at a time and DMS message displays that were active for greater than or equal to 30 minutes at a time. In the second approach, data were divided into two groups according to the time of display. They were message displays that were active during “rush hours” and message displays that were active during “non-rush hours.” In each approach, two hypotheses using paired t-test were employed to compare the before-during analysis and during-after analysis:

In the before-during analysis, the time periods of “Pre display” (30 minutes before the start of display) and “First during” (30 minutes after the start of display) were compared. And, in the during-after analysis, the time periods of "Last during" (last 30 minutes of the display) and "Post display" (30 minutes after the end of display) were considered (see Figure 2).

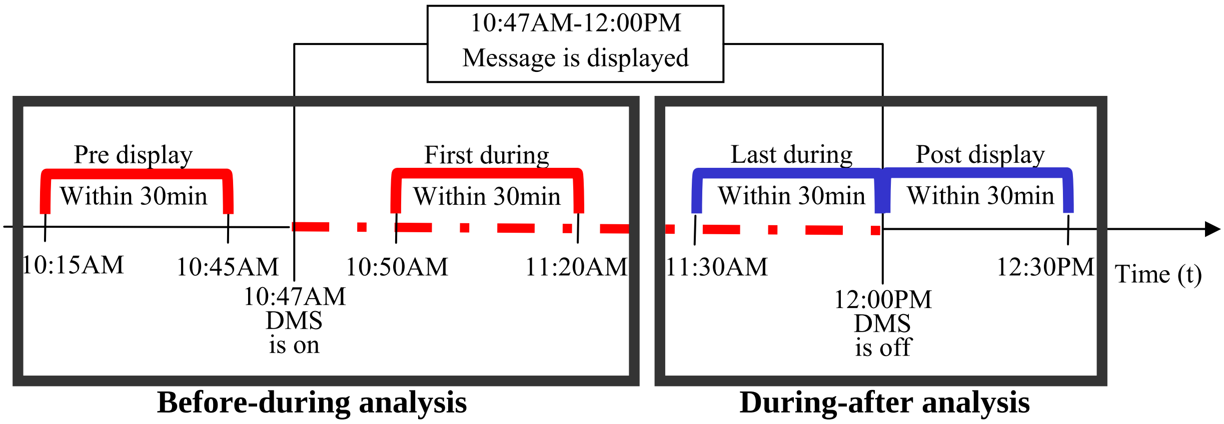


Figure 2 Before-during Analysis and During-after Analysis

Driving Simulation

To validate results from the questionnaire survey and further assess the impact of DMSs, a video-based driving simulation was developed and conducted to examine drivers' responses to various DMS messages in a simulated environment.

In the simulation, a video taken while driving southbound on RI Rte. 4 at approximately 50 mph was used. In this video, a blank DMS board was approached and passed. Test messages were created, resized and superimposed to fit onto the blank DMS board. Two main factors, message category and message type, and two blocking factors, age and gender were considered in a blocked factorial design experiment with 3 repetitions. Message category was categorized into three groups according to their contents: Danger Warning, Informative and Regulatory, per a previous study by Ridgeway (2003). Danger Warning messages consisted of "Disabled Vehicle," "Accident," and "Crash" messages. Informative messages contained messages such as "Roadwork" and "Delay." Regulatory messages were comprised of "S-curves," "Work Zone," and "Slippery Road" messages. Message type, the other main factor, governs how the message display was presented. There were three settings, graphic aided message with full text (GFT), graphic aided message with partial text (GPT), and a text message with no graphic (T). It should be noted that texts appeared in GFT and GPT messages were single stroke but appeared as double stroke in T messages. The blocking factors included age (three groups: 18- 40, 41- 60, and above 60) and gender (male, female).

There were 36 subjects with valid driver's licenses who participated in the driving simulation. Figure 3 shows a schematic view of the driving simulation laboratory. Participants sat in the fixed-base vehicle and were asked to respond by pressing one of the four response buttons which were mounted on the steering wheel. Participants were instructed to press "1" if a roadwork message was observed, "2" for a crash message, "3" for a slippery road message, and "4" if a fake message was observed. Driving simulation videos were projected onto the screen via a digital computer projector (see Figure 3). In each driving simulation trial, the

DMS message first appeared as a small image and gradually increased in size as the vehicle moved closer. A total of nine test messages were used in the experiment (see Figure 4). Each of three message categories (crash message for danger warning category, roadwork message for informative category, and slippery road message for regulatory message) was included with three message types (GFT, GPT, and T). Each message was presented three times in a random order totaling up to 27 separate trials (3 x 3 x 3 = 27). A few practice trials were given to subjects to ensure their readiness prior to the actual simulation. In this driving experiment, each trial's response time was measured from the moment a video started to the moment a response button was pushed.

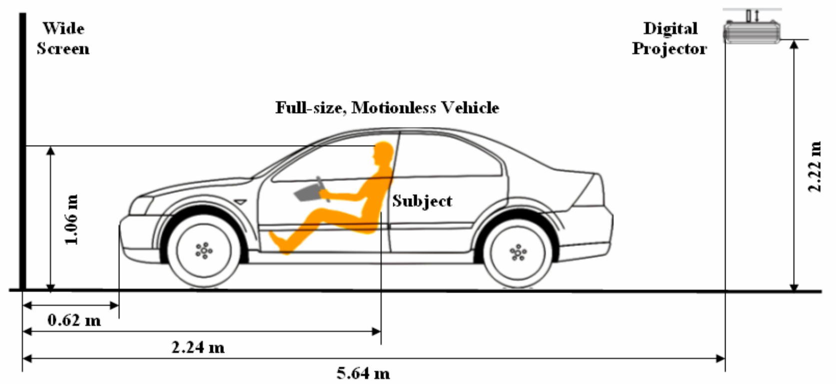


Figure 3 Schematic View of the Driver Performance Laboratory

Figure 4 Nine Test Messages in the Driving Simulation Experiment

RESULTS

Questionnaire Survey

When subjects were asked about the general causes of slow-downs on highways, most participants chose weather, poor visibility, roadwork, crash, police vehicles, congestion, and DMSs. When asked about which traffic signs were they likely to ignore while driving on highways, many indicated that they ignored static and temporary road signs but not active DMSs. When subjects were asked whether they would slow down when approaching an active DMS, 33% indicated that they always slowed down, 57% slowed down sometimes, and 10% never slowed down. When cross-examined by age and gender groups, it was found that elder drivers slowed down most of the time while the majority of young drivers slowed down occasionally. For those who slowed down, 65% indicated that they slowed down since they need more time to read the messages. For those who did not slow down, 77% indicated that they did not read the DMS messages because they were distracting. Answers obtained from the above questions indicated that most drivers paid attention to DMSs while driving and active DMSs did cause slow-downs.

When asked about the issues associated with DMS designs that could cause difficulty in their reading and understanding of the messages, the top choices were lengthy messages, complexly worded messages, abbreviated messages, and unfamiliar messages. They also indicated that poor visibility, poor weather conditions, distractions on the road, and driving at high speed could make it difficult to read and understand DMS messages. The majority of subjects (46%) indicated that danger warning messages received most of their attention, followed by informative (30%) and regulatory messages (24%).

When subjects were asked about their preferences on message types, text-only messages were preferred (44%) over graphic-aided messages (34%), and graphic-aided messages with partial text (22%) were preferred by the majority except the young subjects (18-40). Young subjects preferred graphic-aided messages (42%) over text-only messages (32%) and graphic-aided messages with partial text (26%). This finding is at odds with the common understanding that graphics are usually better than text since they can be identified easier and more quickly from a further distance.

The survey also indicated that subjects preferred a one-frame message (58%) over a two-frame message (42%) if the same contents were displayed. Most subjects would then prefer a two-frame message (59%) over a single-frame (41%) if a two-frame message gives more information and uses no abbreviations whereas a single-frame message gives less information and uses abbreviations.

To summarize, the majority of drivers indicated that they would reduce speed when approaching active DMSs. Furthermore, lengthy, complexly worded, and abbreviated messages could cause drivers to slow down. It was also found that drivers preferred text-only messages over graphic-aided messages and single frame over two-frame messages if they displayed the same content. Finally, two-frame messages with more information were preferred over single-frame messages with less information and abbreviations.

Traffic Data Analysis

Table 1 shows the results of the traffic data analysis in both approaches. Significant changes in average volume and vehicle headway distance were not observed when a DMS was on or off, whereas average speed significantly changed in most of the cases. It indicated that slow-downs in traffic were not presented when the DMS messages were displayed for less than 30 minutes as well as when DMS messages were displayed during rush hours in the “before and during analysis”. Slow-downs were observed during both cases in the “during and after analysis.” This was evidenced by a significant increase in the mean speed, a decrease in the mean volume, and an increase in the mean vehicle headway distance. As for DMS message displays that were active for greater than or equal to 30 minutes, drivers decreased their speed and vehicle headway distance as they approached active DMSs in the “before and during analysis” and increased their speeds and vehicle headway distances in the “during and after analysis.” This was also observed when DMS messages were active during non-rush hours. The decrease in both speeds and vehicle headway distances in the “before and during analysis” and the increase in both speeds and vehicle headway distances in the “during and after analysis” provided evidence of the slow-down effects caused by active DMSs.

Table 1 Summary of Paired t-tests for Before-during and During-after Analyses

	Approach	Length of display						Time of day					
	Group	<30 Min			≥30 Min			Rush Hours			Non-rush Hours		
	Statistics	Spd	Vol	Hdwy	Spd	Vol	Hdwy	Spd	Vol	Hdwy	Spd	Vol	Hdwy
	Sample size	N = 22			N = 23			N = 10			N = 32		
Before-during	Pre display	58.52	322	295.1	60.14	242	563.0	55.89	372	212.0	60.77	261	487.0
	First during	60.67	315	301.8	59.46	227	539.0	61.04	346	248.9	60.19	253	469.0
	P-value ($\alpha = 0.1$)	0.906	0.781	0.709	**0.078**	0.987	0.313	0.924	0.952	0.979	**0.060**	0.910	0.296
During-after	Last during	61.13	315	303.9	59.23	238	596.0	62.06	345	253.4	59.84	260	509.0
	Post display	61.91	311	307.6	60.24	242	658.0	63.11	339	266.9	60.78	265	544.0
	P-value ($\alpha = 0.1$)	**0.020**	0.358	0.386	**0.039**	0.767	0.135	**0.065**	0.286	0.131	**0.016**	0.829	0.193

Driving Simulation

Response times for 36 subjects were collected and analyzed. Through the analysis of variance (ANOVA), it was found that both main and blocking factors were significant (see Table 2) in affecting drivers’ response time. The interaction between age (A) and gender (G) was significant but not the interaction between message type (M) and message category (C).

Table 2 ANOVA Results

Source	DF	Seq SS	Adj SS	Adj MS	F	P
M	2	65.084	66.543	33.271	15.78	**0.000**
C	2	35.656	32.265	17.633	8.36	**0.000**
M*C	4	4.154	4.154	1.038	0.49	0.741
A	2	683.232	682.895	341.447	161.97	**0.000**
G	1	27.936	25.126	25.126	11.92	**0.001**
A*G	2	56.607	58.596	29.298	13.9	**0.000**
Error	855	1802.41	1802.41	2.108		
Total	868	2675.07				

Overall, young participants (age 18-40) and female participants responded the fastest among their peers. Participants responded faster to danger warning messages than to other message categories. Graphic aided messages with partial text (GPT) had similar response time when compared with text-only messages but was much shorter than that of graphic aided message with full text (GFT). This might be due to the fact that GFTs had more information on them and thus required longer response time. Figure 5 shows these results.

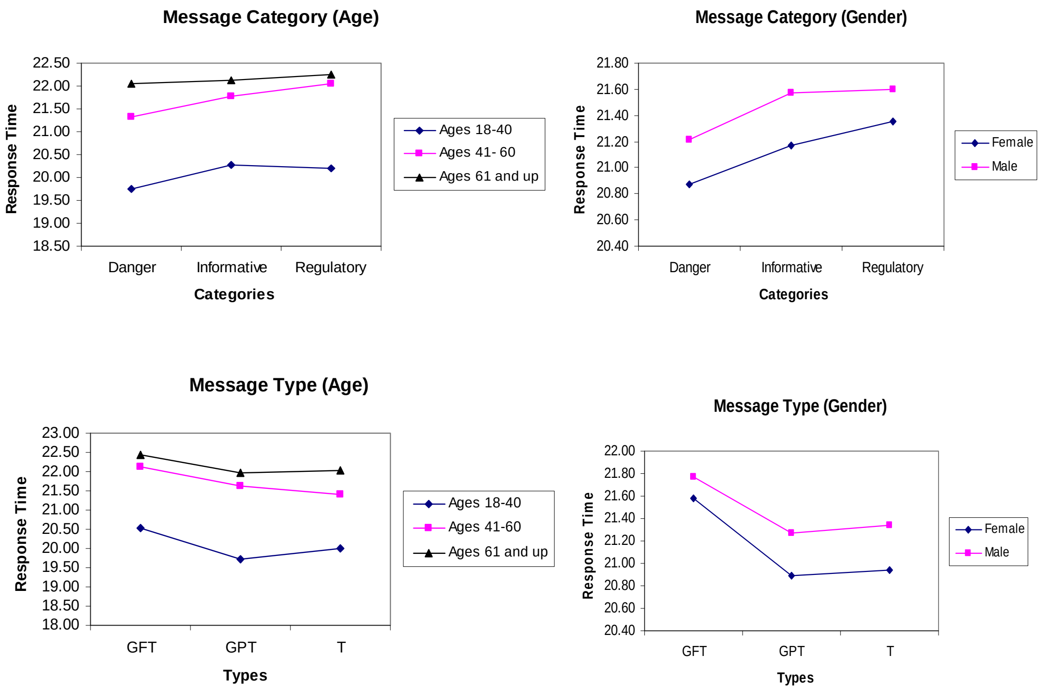


Figure 5 Interaction Plots among Age, Gender, Message Category, and Message Type

CONCLUSION

A questionnaire survey, a traffic data analysis, and a driving simulation were employed to assess the slow-downs on Rhode Island major highways, identify the causes of slow-downs, and obtain subjects' preferences on and responses to different DMSs, The findings of the survey indicated that the majority of drivers would reduce their speed when approaching active DMSs, especially elder drivers. Lengthy, complexly worded, and abbreviated messages could cause drivers to slow down. The survey also found that drivers preferred text-only messages over graphic-aided messages (GFTs and GPTs). Single frame messages were preferred over two-frame messages when their contents were the same. Through the traffic data analysis, traffic slow-downs were observed in most cases as speed changed significantly. This meant that drivers did slow down when DMSs were active and sped up when signs were off.

The results of the driving simulation indicated that participants responded faster to "danger warning" messages, followed by "informative," and "regulatory" messages. This compares favorably to the questionnaire survey where "danger warning" messages attracted most subjects' attention, followed by "informative," and "regulatory" messages. The results of the driving simulation however, found that participants responded faster to graphic aided messages with partial text (GPT), followed by full text (T) messages, and graphic aided messages with full text (GFT). This differs from the conclusions drawn from the survey when text only (T) messages were the most preferred, followed by graphic aided messages with full text (GFT), and graphic aided messages with partial text (GPT).

This study gathered results from both a static (survey) environment as well as dynamic (simulation, real traffic) environments. Slow-down effects were obvious in both environments. While the survey results showed that text only (T) messages were the most preferred by subjects, the study's driving simulation suggested a graphic aided DMS message with partial text (GPT) could shorten the response time the most and possibly help ease the slow-down effects. It is believed that the results gathered from the driving simulation could reflect a more accurate driver response in real driving. However, before implementing any means to ease the slow-down effects, a field study needs to be further employed to assess the influence of different message types (GFT, GPT, and T) on traffic, verify the findings found in this study, and make recommendations to the transportation authorities.

ACKNOWLEDGEMENTS

The authors wish to thank the University of Rhode Island Transportation Center (URITC) and the Rhode Island Department of Transportation (RIDOT) for their financial support and guidance in this study.

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