Publication No. FHWA-HOP-05-069
August 2005

Impacts of Using Dynamic Features to Display Messages on Changeable Message Signs

U.S. Department of Transportation
Federal Highway Administration

Operations Office of Travel Management
Federal Highway Administration
400 Seventh Street, S.W.
Washington, D.C. 20590

Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
FHWA-HOP-05-069		

4. Title and Subtitle IMPACTS OF USING DYNAMIC FEATURES TO DISPLAY MESSAGES ON CHANGEABLE MESSAGE SIGNS	5. Report Date August 2005 6. Performing Organization Code
7. Author(s) Conrad L. Dudek, Steven D. Schrock, and Gerald L. Ullman	8. Performing Organization Report No.
9. Performing Organization Name and Address Texas Transportation Institute The Texas A&M University System College Station, Texas 77843-3135	10. Work Unit No. (TRAIS) 11. Contract or Grant No. Contract No. DTFH61-01-C-00049
12. Sponsoring Agency Name and Address Operations Office of Travel Management Federal Highway Administration 400 Seventh Street, S.W. Washington, D.C. 20590	13. Type of Report and Period Covered Final Report December 2003-August 2005 14. Sponsoring Agency Code HOTM

15. Supplementary Notes

Thomas Granda, FHWA Human-Center Systems Team, Office of Safety Research and Development, Contracting Officer's Technical Representative (COTR).

Performed through the University of Michigan Transportation Research Institute

16. Abstract Project

The objective of the research effort documented in this report was to conduct human factors driving simulator studies to determine the effects on motorists of the following three types of changeable message sign (CMS) dynamic display features: 1) flashing an entire one-phase message; 2) flashing one line of a one-phase message; and 3) alternating text on one line of a three-line CMS while keeping the other two lines of text constant on the second phase of the message thus displaying redundant information. Guidelines emanating from this research and recommendations for changes/additions to the existing sections of the Manual on Uniform Traffic Control Devices are documented in the White Paper that was prepared in response to Task 6.

Sixty-four subjects from the Bryan–College Station, Texas area participated in a driving simulator study. The measures of effectiveness were reading times, comprehension, and preference. In addition, driver performance measures of effectiveness were acceleration noise (an indication of the number and degree of speed changes), average lane position, standard deviation of lane position, average distance headway, and standard deviation of distance headway.

Average reading times for flashing messages were not higher than for static messages. However, the results indicate that flashing messages may have an adverse effect on message comprehension for unfamiliar drivers. Average reading times for flashing line messages and two-phase messages with alternating lines were significantly longer than the alternative messages. In addition, message comprehension was negatively affected by flashing line messages.

17. Key Words	18. Distribution Statement
Changeable Message Signs, Variable Message Signs, Dynamic Message Signs, Changeable Message Sign Operations, Changeable Message Sign Message Design, Flashing Messages, Dynamic Messages on Changeable Message Signs	No restrictions. This document is available to the public through NTIS: National Technical Information Service 5285 Port Royal Road Springfield, Virginia 22161

19. Security Classif.(of this report)	20. Security Classif.(of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	56	

Form DOT F 1700.7 **(8-72)** **Reproduction of completed page authorized**

ACKNOWLEDGMENTS

This study represents a Federal Highway Administration (FHWA) Traffic Management Center Pooled-Fund Study. Thomas Granda from the FHWA Human-Center Systems Team, Office of Safety Research and Development, served as the Contracting Officer's Technical Representative. Jeff Galas, Illinois DOT, was the project champion. URS Corporation, particularly Ming-Shiun Li, assisted the project team by providing technical guidance, project support, and review of project deliverables. The assistance of these individuals is both recognized and appreciated. The authors acknowledge the guidance from the Impacts of Using Dynamic Features to Display Messages on Changeable Message Signs Project Team members listed below.

- Manny Agah (Arizona DOT)
- Gary Thomas (Caltrans)
- Steve Balong (Caltrans)
- James Mona (Connecticut DOT)
- Raj Ghaman (FHWA)
- Linda Brown (FHWA)
- Fred Rank (FHWA)
- James Coylar (FHWA)
- Mark Demidovich (Georgia DOT)
- Mark Newland (Indiana DOT)
- Michael Floberg (Kansas DOT)
- Mia Silver (Michigan DOT)
- Will O'Reilly (Mississippi DOT)
- Lisa Vieth (Missouri DOT)
- Mark Hegerling (New York State DOT)
- John Bassett (New York State DOT)
- John Proctor (Ontario Ministry of Transportation)
- Michael DeGidio (Port Authority of New York and New Jersey)
- Cynthia Levesque (Rhode Island DOT)

The authors also acknowledge and thank the Texas Transportation Institute (TTI) employees who made significant contributions to the study reported herein. Susan Chrysler, manager of the TTI Driving Environment Simulator, provided expert advice throughout the study. Nada Trout, Brooke Ullman, and Alicia Williams conducted the driving simulator experiments. Shaw-Pin Miaou conducted the statistical analysis of the reading time data.

SUMMARY

A study was conducted using the Texas Transportation Institute's Driving Environment Simulator located in College Station, Texas to determine the effects of displaying changeable message sign (CMS) messages with dynamic features. Specifically, it was of interest to determine the effects of 1) flashing a one-phase, three-line message; 2) flashing one line of a one-phase, three-line message; and 3) alternating one line of a two-phase, three line sign while keeping the other two lines constant between the phases. Sixty-four subjects from the Bryan–College Station, Texas area participated in the study. The subject sample was representative of the drivers in Texas with respect to age, education, and gender. The measures of effectiveness were reading times, comprehension, and preference. In addition, driver performance measures of effectiveness were acceleration noise (an indication of the number and degree of speed changes), average lane position, standard deviation of lane position, average distance headway, maximum distance headway, minimum distance headway, and standard deviation of distance headway.

No difference in average reading time was found between the flashing and static one-phase, three-line messages. However, the results suggest that flashing a message may have adverse effects on message understanding for drivers who are unfamiliar with this dynamic mode of display. In this study, only 78 percent of the subjects understood the bottom line of the three-line message, and this percentage was significantly lower than that for the other two lines. A significant percent of the subjects (61 percent) preferred the static display. The most common reasons for preferring the static messages were that they give drivers more time to read the message and are easier to read.

The average reading time for one-phase, three-line messages with one flashing line (top line) was significantly longer than that for the static messages. The results also suggest that unfamiliar drivers will be adversely affected relative to comprehension of the entire message. Familiar drivers may also be adversely affected but to a lesser degree. The subjects in this study most often did not remember the information on the bottom line relative to the other two lines of the three-line message. The subjects liked the flashing line and static messages equally well.

The average reading time for the alternating line messages (with redundancy) was significantly longer than that for the messages that did not alternate (no redundancy). There was no significant difference in comprehension of each message line or for the number of message lines recalled. However, the percent of subjects that understood all four message lines was slightly less than 70 percent for both message modes. Even though the average reading time was significantly longer for the message with redundancy, a significantly higher percent (59 percent) preferred the message with redundancy.

No differences were found by age, education, and gender among the three dynamic message modes and their alternatives. In addition, no differences were noticed in the driver performance measures of effectiveness.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

1. INTRODUCTION

BACKGROUND

Several state departments of transportation (DOTs) currently operating changeable message signs (CMSs) are using dynamic features when displaying messages in the belief that the features attract the attention of drivers and emphasize the importance of the message. These dynamic features of displaying messages include:

- Flashing an entire one-phase message.
- Flashing one line of a one-phase message.
- Alternating one line of text of a two-phase message and keeping two lines constant.

It has been speculated by personnel from some state DOTs that continuously flashing certain one-phase messages (typically those that describe significant traffic disruptions downstream) or flashing one line of a one-phase message (typically the top problem statement line) emphasizes that the message is especially important to drivers and should be heeded. However, the extent to which such display practices actually increase the level of importance that a driver gives to a message has not been fully verified through objective research. Furthermore, it is not clear whether such practices have any adverse effects on message reading times and comprehension by drivers.

Another operating practice by some DOTs is to format a two-phase message in such a way that the top two lines of the message remain constant and a third (bottom) line is alternated between two separate message line phrases. In essence, the CMS operates as if it was a two-phase message, but the bottom line changes and the top two lines remain constant between the two phases. Thus the top two lines are redundant between the two phases. For this particular display practice, there was a need to determine whether drivers actually notice that the line changes. Also, it was not totally clear what effect the redundancy of information (top two lines repeated in each phase) has on driver reading times and comprehension of the entire message. For example, do the repeated lines cause drivers to read these lines more than once, thus increasing reading times?

Because of the various concerns associated with the dynamic message display practices in use in some jurisdictions, it was important to objectively determine whether such practices:

- Affect the amount of time it takes a driver to read the message.
- Affect a driver's ability to properly comprehend the message.
- Influence the importance drivers place on the message.
- Are preferred by drivers in comparison to static or non-redundant messages.
- Affect driver performance.

Only a limited amount of research has been conducted on these topics, and the effects that flashing or changing how a message is displayed on a CMS are not fully known. Initial human factors laboratory studies did suggest that dynamic features may have adverse effects on reading time and message recall. [1,2]

Whether these dynamic features of messages improve the effectiveness of their communication to drivers or detract from it is not fully understood. Further research was needed to determine their full effects and to provide guidance to state, regional, and local DOT agencies.

The Federal Highway Administration (FHWA), through the Traffic Management Center Pooled-Fund Study, sponsored the research project titled *Impacts of Using Dynamics Features to Display Messages on Changeable Message Signs*. The focus of this project was to conduct human factors studies that address the key issues related to dynamic message display features. The intended major products of this project were 1) a research report that includes detailed research results, provides guidance, and suggests recommended practices related to dynamically displaying messages on CMSs; and 2) a white paper that provides recommended practices, a set of proposed changes to the existing sections and/or recommended new sections in the Manual on Uniform Traffic Control Devices (MUTCD), as well as recommendations for further research. The intended audience of the project's products is personnel in state, regional, and local transportation agencies who are responsible for or are involved in the display of messages on permanent and portable CMSs. This report contains the documentation of the human factors research.

OBJECTIVES

The objectives of the research effort documented in this report were to:

- Conduct human factors driving simulator studies to determine the effects of the following dynamic display features on CMSs: a) flashing an entire one-phase message, b) flashing one line/word of a one-phase message, and c) alternating text on one line of a three-line CMS while keeping the other two lines of text constant on the second phase of the message.
- Develop guidance for practitioners on dynamically displaying messages on CMSs.

PREVIOUS RELATED WORK

Units of Information in Messages

Effective CMS message design includes an understanding of the reading and information processing limitations of drivers. The amount of information in a CMSs message is defined in terms of units of information. Dudek and Huchingson defined a *unit of information* as a simple answer to a question a driver might ask [3]. Stated another way, a unit of information is each data item in a message that a driver could use to make a decision. Each answer is one unit of information. A unit of information typically is one to three words but at times can be up to four words. The message in Table 1 has three units of information and serves to illustrate the concept of units of information.

Table 1. Defining "Units of Information."

UNITS OF INFORMATION		
Question	**Answer**	**Info Unit**
1. What happened?	**MAJOR ACCIDENT**	**1 unit**
2. Where?	**PAST ROWLAND ST**	**1 unit**
3. What is advised?	**USE OTHER ROUTES**	**1 unit**

Guidelines in CMS message design and display manuals include the following principles: [4,5,6]

- No more than four units of information should be displayed in a message when the operating speeds are 56 km/h (35 mi/h) or higher.
- No more than five units of information should be displayed in a message when the operating speeds are less than 56 km/h (35 mi/h).
- A message should not contain more than two phases.
- No more than three units of information should be displayed in any one phase.

Dynamic Features of Changeable Message Signs

The Texas Transportation Institute (TTI) researchers identified only one key reported study that was relevant to the issues in the current project. The study is summarized below.

Dudek et al. in 2000 and Dudek and Ullman in 2002 reported on research that was conducted for TxDOT as part of a study to improve CMS messages and operations in Texas [1,2]. Traffic management center managers in several Texas Department of Transportation (TxDOT) districts were interested in knowing more about the effectiveness of using some of the dynamic features of CMSs. The following three issues were examined: a) effect of flashing an entire one-phase message, b) effect of flashing one line of a one-phase message; and c) effect of alternating text on one line of a three-line message while keeping the other two lines of text the same.

Single-task human factors studies were conducted in five cities (Dallas, El Paso, Fort Worth, Houston, and San Antonio) using laptop computers. The laboratory instrument was administrated to 260 individuals, 52 from each of the 5 study locations, and matched as much as practical to the Texas driving population based on age, education, and gender. Although some important findings were reported, the study was a single-task experiment since subjects were not placed under heavy mental workload conditions simulating heavy driver workload while traveling on freeways. Thus, the transferability of the results to actual driving situations could not be fully ascertained in that study.

Flashing a one-phase, three line message with three units of information produced the following results:

- Flashing a one-phase three-unit message on a CMS had no significant effect upon driver comprehension of the information being presented.

- Driver preferences were fairly evenly split between flashing the message or not (i.e., a static message).
- Flashing the message increased the amount of time required to read and comprehend the message.

Flashing one line (top line) of a one-phase, three-line messages containing three units of information with one line flashing produced the following results:

- Flashing one line of a one-phase CMS message containing three units of information reduced the ability of drivers to remember parts of the message that were not flashing.
- Reading times were significantly increased when a line was flashed.
- Driver preferences were fairly evenly split between flashing the message line or not (i.e., a static message).

Alternating one line (bottom line) of text and keeping the other two lines constant on a two-phase, three-line message produced the following results:

- Three-line CMSs including redundant information by repeating the top two lines on both phases of a two-phase message while changing the bottom line did not reduce the ability of drivers to remember parts of the message.
- Total message reading times were significantly increased when redundant information was included.
- Driver preferences were fairly evenly split between having and not having redundant information in both phases.

2. STUDY APPROACH

DRIVING SIMULATOR

Characteristics

Upon the recommendation of FHWA, the studies were conducted using the TTI Driving Environment Simulator in College Station, Texas. The driving simulator is comprised of four components: vehicle, computers, projectors, and screens. The vehicle, a complete and full-size 1995 Saturn SL automobile, is outfitted with computers, potentiometers, and torque motors connected to the accelerator, brakes, and steering. The Saturn also features full stereo audio, full instrumentation, and fully interactive vehicle components, all of which provide a feel of driving. The Saturn is connected to a computer component that consists of one data collection computer and three image generation computers. Computer-generated driving scenes are sent to three high-resolution projectors and projected to three high-reflectance screens.

The driving simulator has the capability for projecting several different highway scenes and scenarios. The highway scenes and scenarios selected for this study were based on presenting the subject with the highest driving workload that is possible within the capability of TTI's simulator while minimizing the possibility of subject nausea. Experience by TTI researchers and results of presentations made during the 2004 annual meeting of the Transportation Research Board [(7)] regarding test subject nausea in driving simulators indicated that horizontal curves should be avoided as much as possible. The "driving" scene chosen for the study was a six-lane freeway with primarily tangent sections and slight horizontal curvature.

Display of Changeable Message Sign Messages

Presently, the ability to accurately represent the visual characteristics of a CMS within the TTI driving simulation environment is very limited. Furthermore, placing the CMS entirely within the simulation environment would not have allowed TTI researchers to systematically control and accurately measure required subject reading times. Therefore, CMS messages were displayed on a CMS that was projected via an add-on liquid crystal display (LCD) projector interfaced with a separate laptop computer. The messages were displayed on a large rectangle that replaced a portion of the simulated roadway scene on the left side of the "driving" scene. The rectangular area was 815 mm (32 in) wide by 450 mm (18 in) tall, with the center of the rectangle positioned 2.5 m (8.1 ft) from the subject and laterally offset from the roadway image by 16 degrees from the subject's "straight ahead" perspective. The CMS messages were displayed with nominal 40-mm (1.5-in) tall characters, which provided the visual angle as nominal 450-mm (18-in) characters of a full-size CMS viewed at 30 m (100 ft). This viewing angle was selected to prevent visual acuity of the subjects from being a factor in the reading times of the messages. See Appendix A for further discussions about the study controls taken to minimize subject nausea.

Driver Workload

In addition to "driving" the vehicle on the freeway, additional driver workload was introduced via a car-following approach. Each subject was placed in a "driving" workload situation by being required to follow a selected vehicle. The additional workload was simulated by having the speed of the lead vehicle vary significantly prior to, during, and immediately after the display of a CMS message. The speed of the lead vehicle varied significantly at other times during each study session to minimize the possibility that subjects would associate lead vehicle speed changes with the display of a CMS message. The time and degree of speed changes for the lead vehicle are shown in Figure 1.

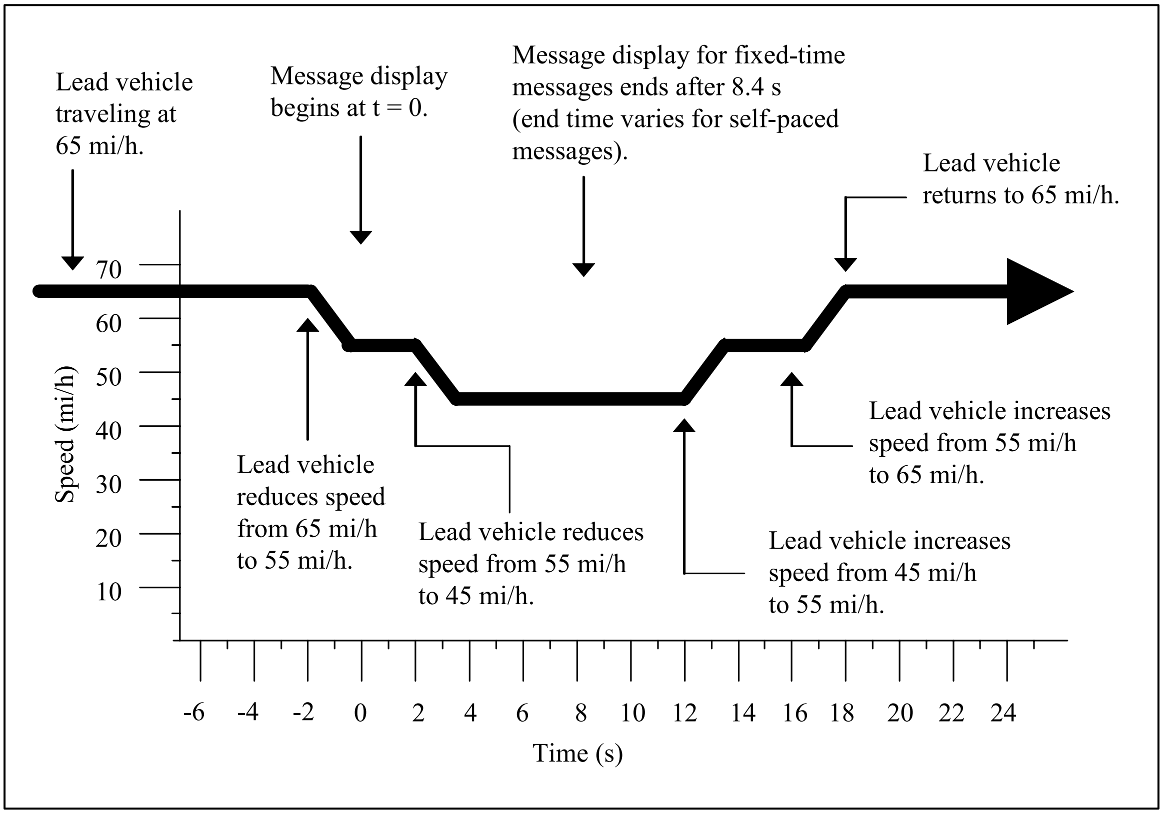

Figure 1. Illustration of the Time and Degree of Speed Changes for the Lead Vehicle.

In order to maintain a similar workload across all subjects and all instances of message display, the subjects were instructed to follow closely behind the lead vehicle. Generally the lead vehicle traveled straight, remained in the right-hand lane, and traveled at a constant 105 km/h (65 mi/h). Two seconds prior to the display of a message the lead vehicle would perform a series of speed changes, quickly slowing from 105 km/h to 70 km/h (65 mi/h to 45 mi/h), vary speed between 70 km/h and 90 km/h (45 mi/h and 55 mi/h) during the periods when the subjects would be viewing the messages, and then quickly speed back up to 105 km/h (65 mi/h) after the message was removed from the simulator screen. These speed change patterns were also performed at several other times when no CMS message was displayed in order to keep subjects from associating the lead vehicle speed changes as a cue that a CMS message was about to be displayed. The intention of the speed changes was to force the subjects to be more vigilant in the driving process by attending to the traffic situation in the simulated environment and to read the message at the same time, much like a real driving situation.

An acceptable car-following distance was left up to the subject with the following two instructions: the subject was to keep up with the lead vehicle but was to avoid running into the back of the lead vehicle. The second requirement was accomplished by displaying a visible warning on the simulator screen if the subject became more than 55 m (180 ft) behind the lead vehicle. The 55-m (180-ft) distance was selected based on researcher trial and error, and appeared to be the appropriate distance to use in the driving simulator to accomplish the objectives of driver loading. The warning was a bright red chevron that would appear on the simulator screen right in the center of the subject's visual field. This would also be a cue for the researchers to remind the subjects to close the distance to the lead vehicle. Generally subjects were able to follow both of these instructions after practicing the controls of the driving simulator during a preliminary practice session. Photographs of the driving simulator interior and scenes are shown in Figures 2 through 5

Control of Message Display Time

One of the primary measures of effectiveness used in this study was driver reading times of the CMS messages. To ensure that reading times were measured accurately and consistently, the TTI researchers developed a system to precisely control the presentation time of the stimulus (message). Two message time presentation formats were included in the study. The first format, referred to as *self paced*, allowed the subject to determine how long they needed (while performing the driving task) to view the message. In the second format, referred to as *fixed time*, the amount of time a message was presented to the subject was fixed (similar to having a limited amount of time available while approaching a CMS to read the message). In both presentation formats, the test administrator pushed a button at predetermined locations on the freeway whenever it was desirable to begin to display a CMS message. For the self-paced presentation format, a second push button was attached near the steering wheel of the simulator car and was depressed by the subject when he/she read and understood the message. Depressing the button removed the message from the scene and the message display times were automatically recorded on the laptop computer. In the fixed-time format, the CMS message simply went blank after it was displayed for the amount of time set by the researchers prior to the start of the subject driving trial. The amount of time a particular message was presented in the fixed-time format was identical for all subjects participating in the experiment.

Figure 2. View of Simulated Driving Scene with Lead Vehicle Prominent on the Screen.

Figure 3. Another Image of the Simulated Driving Scene. Note the Message Display and the "Fall-Behind" Warning on the Screen.

Figure 4. View of Interior of Driving Simulator Vehicle.

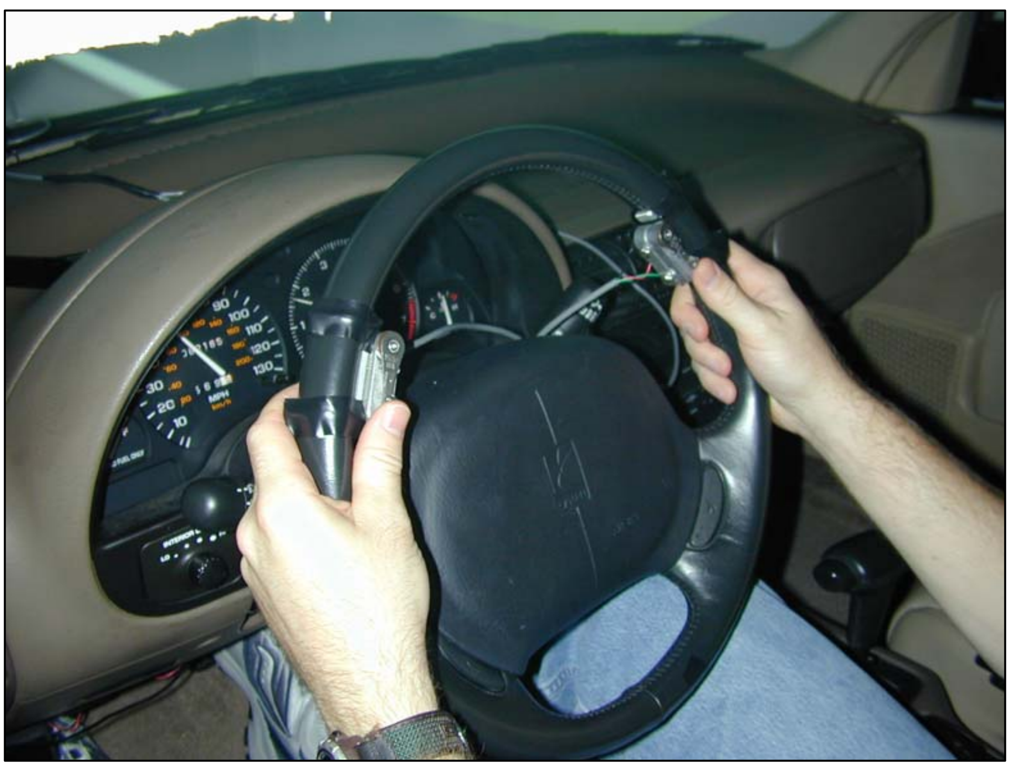

Figure 5. Image of the Steering Wheel Equipped with Buttons for the Subject to Turnoff the Messages during the Self-Paced Sessions.

EXPERIMENTAL DESIGN

Measures of Effectiveness

The primary measures of effectiveness (MOEs) for the experiment were message:

- Reading times,
- Comprehension, and
- Preferences.

In addition, the subjects' driving performance was monitored through the driving simulator software to determine if driving behavior was significantly affected when attempting to read the different CMS messages. One advantage to testing subjects in a driving simulator is the ability to collect continuous data on a wide variety of driving performance measures that would otherwise be difficult or impossible to collect in a real-world environment. TTI's driving simulator has the capability to collect several different attributes of driver performance. The seven MOEs that were determined to be most suitable for evaluating subject driving performance during the CMS message study were:

- Acceleration noise (the standard deviation of acceleration),
- Average lane position,
- The standard deviation of lane position,
- Maximum distance headway,
- Minimum distance headway,
- Average distance headway, and
- The standard deviation of distance headway.

Acceleration noise is the standard deviation of vehicle accelerations and gives an indication of the number and degree of driver speed changes. [(8)] Numerous and rapid decreases and increases in speed are reflected in high acceleration noise values and were assumed by the research team as an indication of whether driving ability was at all compromised systemically as a function of the different CMS display formats evaluated in this research.

Data for these later seven MOEs were automatically recorded every 0.33 s and saved as text files in the internal computer of the driving simulator. The files were later reduced by importing the text files into a spreadsheet program. Care was taken to identify the exact points in the data files when specific messages were displayed, to allow direct comparisons of subject driving performance when presented with a specific message. This approach was important because the experimental design employed in this study counterbalanced message location within the simulator environment so that not all subjects would see the messages in exactly the same order and location on the freeway throughout the study.

Subjects

A total of 64 subjects from the Bryan–College Station area participated in the study. All subjects were required to have a current state driver's license, drive at least 8000 miles per year, and travel on a freeway or highway at least 12 times per year. The demographic sample of subjects was based on age, education, and gender of drivers in Texas. This approach allowed researchers to develop a quantitative estimate of the average difference in reading times (if any) between the CMS display formats of interest in this study for the current driving population as a whole. The incremental influences of subject age and education levels were subsequently explored in the data analysis portion of the study (see below). However, the ability to completely and systematically evaluate their effect upon display type differences was not a part of the overall experimental study design and subject recruitment process. The demographic sample of subjects is shown in Table 2.

Table 2. Subject Demographics.

Age Group	No High School Diploma		High School Diploma		Some College		College Degree		Total
	Male	Female	Male	Female	Male	Female	Male	Female	
18-24	1	1	1	1	1	1	1	1	8
25-54	5	5	5	5	5	5	5	5	40
55-64	1	1	1	1	1	1	1	1	8
>64	1	1	1	1	1	1	1	1	8
Total	8	8	8	8	8	8	8	8	64

Changeable Message Sign Messages

The experimental stimulus material consisted of two messages for each of the three dynamic message modes of interest. One message formatted with a particular dynamic display feature was matched to a different but similar message presented in a static (or in the case of the alternating line display, a standard two-phase) format. Thus, results from each subject allowed direct comparisons of the MOEs for each display format, as shown below.

- Flashing a one-phase message (Messages 1 and 2).
- Flashing one line in a one-phase, three-line message (Messages 3 and 4).
- Alternating text on one line of a three-line CMS while keeping the other two lines of text constant on the second phase (Messages 5 and 6).

Because it was necessary for a subject to view each message twice, a set of eight additional messages that were not related to the specific objectives of the current study were intermixed with the primary test messages, and questions were asked of the subjects as a means of separating the primary messages in time and to avoid subjects from concentrating only on the messages with dynamic features. The study test messages for the dynamic features objectives are shown in Table 3. Note that for the study test messages, both the dynamic mode and static mode were used in the study.

Table 3. Test Messages for Driving Simulator Studies.

Message 1 (M1)		Message 2 (M2)	
Flash	**Static**	**Flash**	**Static**
MAJOR ACCIDENT **AT LITTLE YORK** **3 LANES CLOSED**	MAJOR ACCIDENT AT LITTLE YORK 3 LANES CLOSED	**FREEWAY BLOCKED** **AT TIDWELL** **USE OTHER ROUTES**	FREEWAY BLOCKED AT TIDWELL USE OTHER ROUTES

Message 3 (M3)		Message 4 (M4)	
Flash Line	**Static Line**	**Flash Line**	**Static Line**
FREEWAY CLOSED AT COLLEGE ST FOLLOW DETOUR	FREEWAY CLOSED AT COLLEGE ST FOLLOW DETOUR	**TRUCK ACCIDENT** AT AIRPORT RD USE SERVICE ROAD	TRUCK ACCIDENT AT AIRPORT RD USE SERVICE ROAD

Message 5 (M5)		Message 6 (M6)	
Alternating Line with Redundancy	**No Alternating Line without Redundancy**	**Alternating Line with Redundancy**	**No Alternating Line without Redundancy**
CONSTRUCTION AT BROADWAY RD **ALL LANES CLOSED**	CONSTRUCTION AT BROADWAY RD	MAJOR ACCIDENT AT WAYSIDE RD **ALL LANES BLOCKED**	MAJOR ACCIDENT AT WAYSIDE RD
CONSTRUCTION AT BROADWAY RD **USE OTHER ROUTES**	ALL LANES CLOSED USE OTHER ROUTES	MAJOR ACCIDENT AT WAYSIDE RD **USE OTHER ROUTES**	ALL LANES BLOCKED USE OTHER ROUTES

Note: Bold in the message indicates the portion of the message that flashed or alternated.

Method

The characteristics of the study design are shown in Table 4. The study was counterbalanced by dividing the subjects into two groups: Group A and Group B, with each group containing 50 percent of the subjects divided similarly according to age, education, and gender. The order of message presentation was further counterbalanced by dividing each group into two subgroups (i.e., A1 and A2 for Group A, B1 and B2 for Group B).

The study was divided into three types of experiments: 1) self paced, 2) fixed time, and 3) preference. The self-paced and fixed-time experiments were further divided into two sessions each in order to reduce the time that the subjects spent “driving” in the simulator for each research objective and to minimize the possibility of nausea.

Table 4. Characteristics of Study Design.

Dependent Variable	Session	Message Order	GROUPS (n=64)			
			A (#1-32)		B (#33-64)	
			A1 (#1-16)	A2 (#17-32)	B1 (#33-48)	B2 (#49-64)
Reading Time & Comprehension (Self-Paced)	1	1	M1 Static	M2 Flash	M2 Static	M1 Flash
		2	M2 Flash	M1 Static	M1 Flash	M2 Static
		3	M3 Static Line	M4 Flash Line	M3 Flash Line	M4 Static Line
	2	4	M4 Flash Line	M3 Static Line	M4 Static Line	M3 Flash Line
		5	M6 Alt Line	M5 No Alt Line	M6 No Alt Line	M5 Alt Line
		6	M5 No Alt Line	M6 Alt Line	M5 Alt Line	M6 No Alt Line
Comprehension (Fixed-Time)	3	7	M1 Flash	M2 Static	M1 Static	M2 Flash
		8	M2 Static	M1 Flash	M2 Flash	M1 Static
		9	M3 Flash Line	M4 Static Line	M4 Flash Line	M3 Static Line
	4	10	M4 Static Line	M3 Flash Line	M3 Static Line	M4 Flash Line
		11	M5 Alt Line	M6 No Alt Line	M6 Alt Line	M5 No Alt Line
		12	M6 No Alt Line	M5 Alt Line	M5 No Alt Line	M6 Alt Line
Preference (Fixed-Time)	5	13	M2 Static M2 Flash	M1 Flash M1 Static	M1 Static M1 Flash	M2 Flash M2 Static
		14	M4 Static Line M4 Flash Line	M3 Flash Line M3 Static Line	M3 Static Line M3 Flash Line	M4 Flash Line M4 Static Line
		15	M6 No Alt Line M6 Alt Line	M5 Alt Line M5 No Alt Line	M5 No Alt Line M5 Alt Line	M6 Alt Line M6 No Alt Line

Self-Paced Experiment

The self-paced experiment involved measurements of reading time and comprehension. Two one-phase messages with different text were displayed one at a time. Both the dynamic messages and the static messages were shown at different points within the larger experimental sessions. The messages were displayed until the subject read the message and felt that he/she understood the message at which point the subject pressed the button near the steering wheel to turn the sign off. The time that each message was visible to the subject was automatically recorded and provided data for reading times.

Following each message displayed, the study administrator asked questions relative to the content of the message on each line and recorded the responses on prepared forms. Examples of questions were “What is the traffic problem?”, “Where was the problem located?”, and “What are you to do?” The order of the questions was randomly changed for each message in order to minimize the possibility that subjects would anticipate the questions and thus memorize the message accordingly. However, the order of the questions was the same for the dynamic message and its alternative static message in order to minimize order effects when comprehension between the two modes was ascertained. In addition, it was sometimes necessary to ask follow-up questions as a way of getting an estimate of subject comprehension of the particular item of interest (as opposed to simply measuring subject memorization ability of the message).

Fixed-Time Experiment

The fixed-time experiment involved study of comprehension only. Two one-phase messages with different text were displayed one at a time. As noted previously, the messages were complements of the ones displayed in the self-paced experiment. That is, if a specific message was shown in a flashing mode in the self-paced experiment, it was shown in non-flashing mode in the fixed-time experiment, and vice versa. Each message was displayed for a total of 8.4 s. The flashing message was displayed alternately 1.5 s on and 0.5 s off, which is comparable to flash rates used by some state DOTs. This process continued automatically for a total of 8.4 s. The non-flashing message was displayed continuously for a total of 8.4 s. The time of 8.4 s was chosen because it is equivalent to the available reading time of typical current day light-emitting diode CMSs while drivers are traveling at 105 km/h (65 mi/h) under ideal environmental conditions. [(9)] Following each message displayed, the study administrator asked questions relative to the content of the message on each line and recorded the responses on prepared forms. The order of the questions varied among dynamic message types.

Preferences

The preference portion of the study involved showing the subject a flashing and non-flashing message style and asked the subjects to provide their preference and the reasons for selecting the specific message style. The order of the message presentation between the dynamic and static message style was counterbalanced such that the style presented last in the fixed-time experiment was shown first followed by its companion alternate. For example, if a flashing message was shown last in the fixed-time experiment, it was shown first in the preference experiment followed by the static version of the message.

3. ANALYSIS

EFFECT OF MESSAGE DISPLAY FORMATS ON READING TIMES

Statistical comparisons were performed of the differences in individual subject reading times of each of the dynamic display formats (flashing message, flashing line, and alternating line) with the comparable static message. The data were also examined to determine whether any differences in reading times appeared to be systemically related to differences in the actual messages used. Recall that two slightly different but presumed equivalent messages were used to compare each particular dynamic versus static display format in order to eliminate any potential learning effects upon reading times. That is, it was of interest to determine whether one of the messages had a longer average reading time than the other.

Secondary factors of age, education, and gender were also considered in the analysis. Specifically, the assessment of these secondary factors was performed within a driver sampling plan intended to replicate the current driving population of Texas motorists. It would not have been feasible to construct a fully randomized and counterbalanced study design to completely assess each of these secondary factors and their potential interactions within the time and funding available for this research. More importantly, the TTI researchers believe that the effort and time required to have fully evaluated these factors would not have provided significant additional value to the recommendations regarding dynamic displays that were generated from this research. Consequently, the results represent a general indication of the likely influences of these secondary factors, if any, upon reading time differences measured during the simulation studies.

In summary, given the study design and the measurements collected from the 64 sampled subjects, statistical analyses were conducted to:

1. Estimate the average response time differences between the dynamic message modes and the alternative modes.
2. Determine the quality, specifically, standard errors or confidence intervals, of the estimates for the above.
3. Conduct robustness tests to get a sense of how sensitive the estimates in (1) and (2) are with respect to the model distributional assumptions.
4. Gain some insights regarding the potential effects of age, education, and gender on the estimates in (1) and (2).

The basic statistical model used to achieve the first four estimation and inferential goals listed above is a simple linear regression model as follows:

$$t_{i,f,ma} - t_{i,s,mb} = \beta_0 + \beta_1 DE_i + \sum_j \beta_j x_{ij} + e_i \qquad i = 1,2,...64 \qquad (1)$$

Where:

$t_{i,f,ma}$ = response time of subject *i* on flash or alternating message which can be Message 1 or Message 2 (M1 or M2) for message the flashing message mode, Message 3 or Message 4 (M3 or M4) for the flashing line message mode, and Message 5 or Message 6 (M5 or M6) for the alternating line with redundancy message mode, depending on which study group the subject was assigned to.

$t_{i,s,mb}$ = corresponding response time for subject *i* on alternative (static) message mode "mb," which is different from "ma" by design to avoid the "memory effect."

DE = "design effect" which measures the effect of subjects being exposed to two different messages between flashing sign and static sign for the two study groups (a dummy variable of 0 if the subject is in study Group A and 1 if in Group B).

x_{ij}, $j = 1,2,..., J$, = set of 0-1 dummy variables, indicating which age, gender, and education category the subject *i* belongs to (with the first age, gender, and education categories used as reference categories).

e_i = the model residuals.

$\beta' s$ = unknown regression parameters to be estimated from the data.

The model residuals, e_i, are assumed to be normally distributed with zero mean and constant variance σ_e^2. To test the robustness of the normal assumption, an alternative "fat-tailed" t-distribution with 4 degrees of freedom was used. (10)

A Bayesian approach was used for estimating model parameters and for assessing model goodness-of-fit. To complete the full Bayesian specification, non-informative priors were used for all hyper-parameters involved. (11)

For all the models considered in this study, parameter estimates and associated inferences were obtained using programs coded in the WinBUGS language (version 1.4). (12) Typically, 20,000 simulation iterations were used with the first 5,000 iterations as burn-ins. In addition, Gelman-Rubin statistics available in WinBUGS were checked to ensure convergence. The deviance information criterion (DIC) is a Bayesian generalization of the Akaike Information Criterion (AIC) and Bayes Information Criterion (BIC). (13) It was employed by this study in assessing the overall goodness-of-fit of models at various levels of complexities—the smaller the DIC value, the better the overall model performance.

EFFECT OF MESSAGE DISPLAY FORMATS ON COMPREHENSION AND PREFERENCE

Differences in message comprehension and preference were evaluated. The Bernoulli Model was applied to all statistical tests that involved comprehension and preference proportions (percentages). (14)

EFFECT OF MESSAGE DISPLAY FORMATS ON DRIVER PERFORMANCE

As previously discussed, driving performance measure of acceleration noise (the standard deviation of acceleration), average lane position, standard deviation of lane position, maximum distance headway, minimum distance headway, average distance headway, and standard deviation of distance headway were also collected and evaluated.

It was decided that driving performance data would be analyzed for identical time periods for each message, regardless of how long the subjects actually viewed the message. The time period selected was 2 s prior to the display of the CMS message (the beginning of the erratic maneuvering by the lead vehicle) until 16 s after the beginning of the CMS message display (when the lead vehicle resumed normal driving). By keeping the analysis period the same, it was possible to compare subjects' reactions to exactly the same erratic maneuvers, eliminating the erratic maneuvering as a variable. Examples of the reduced data can be seen in Figures 6 and 7.

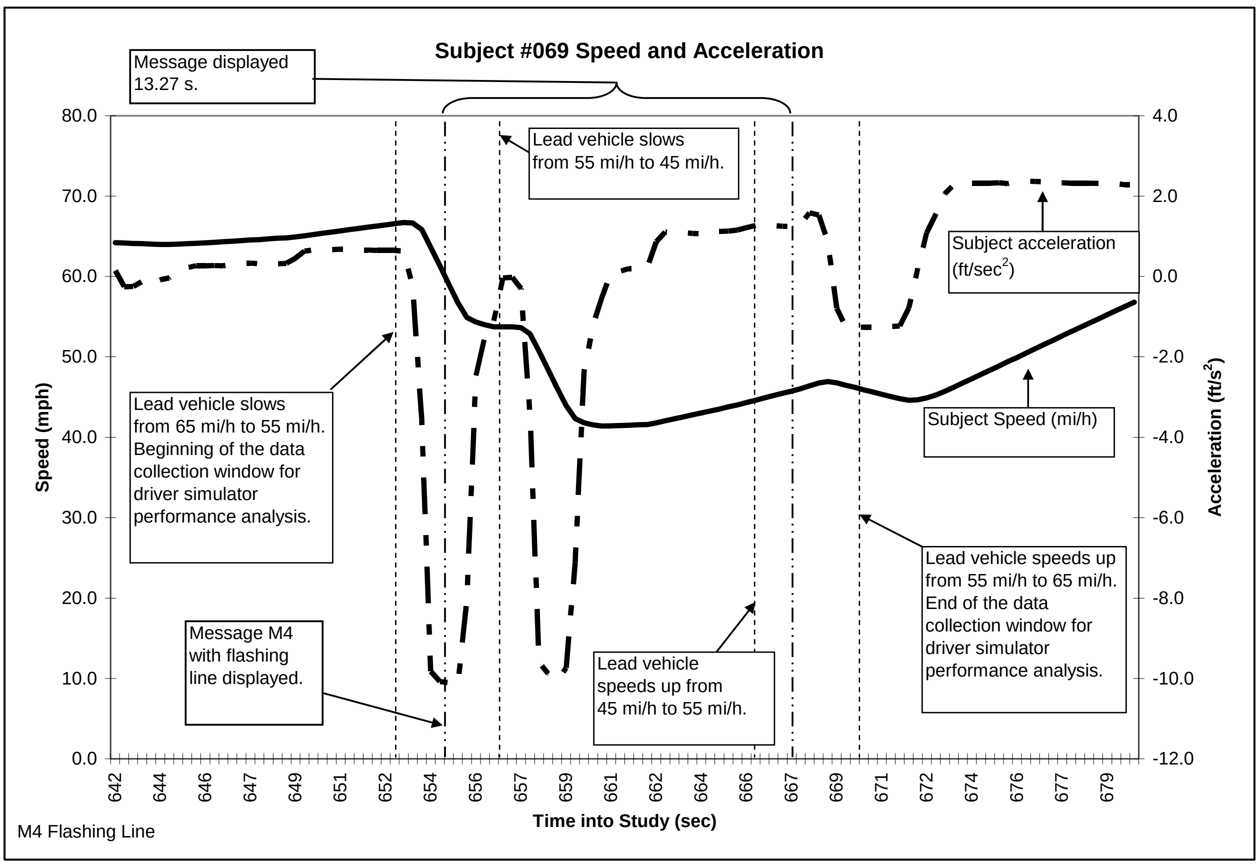

Figure 6. Example of Speed and Acceleration Data Collected During CMS Message Presentation.

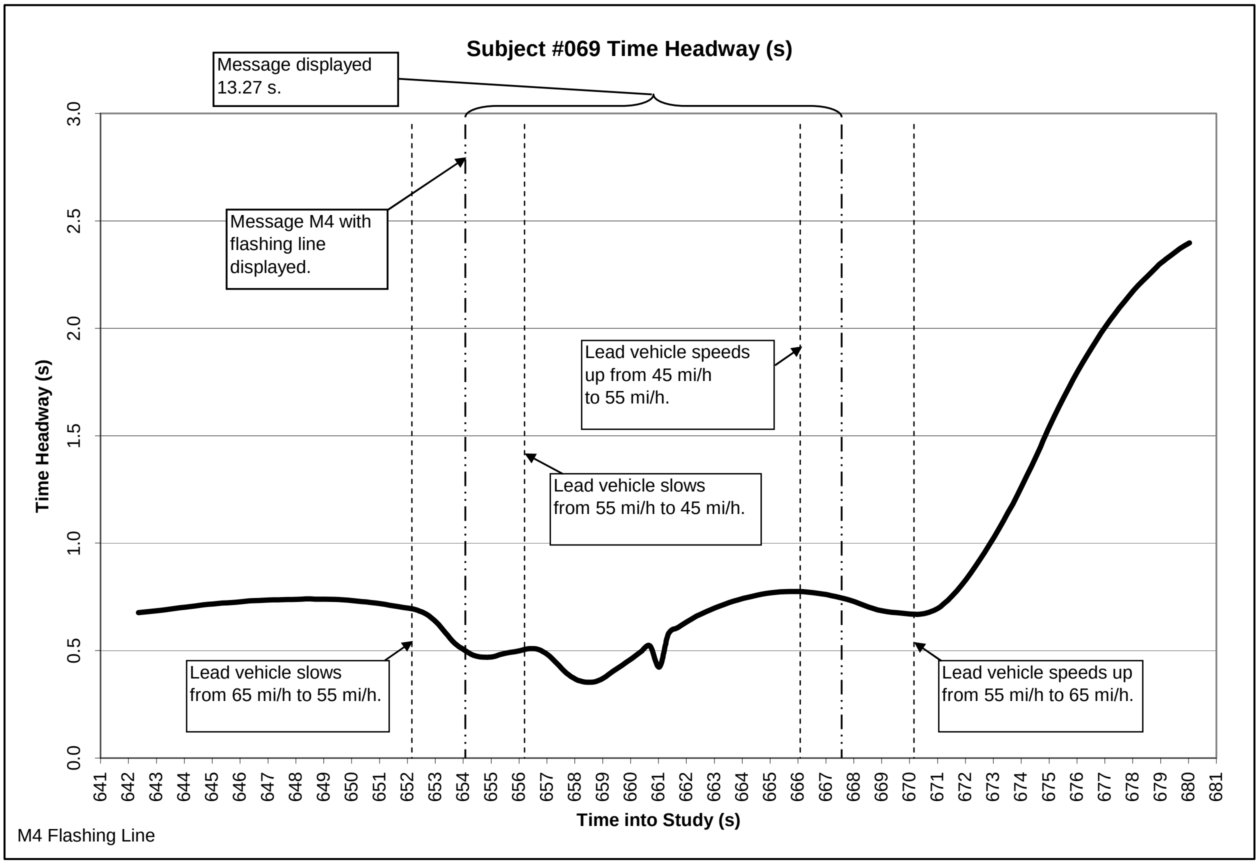

Figure 7. Example of Distance Headway Data Collected during CMS Message Presentation.

The data for the distributions for acceleration noise, the standard deviation of lane position, and the standard deviation of distance headway did not appear normally distributed. Histograms indicated that the data were more likely to follow Poisson distributions. As a result, these data were analyzed using the Chi-Square analysis with a level of significance of 0.05.

The data for the distributions of average lane positions and the average distance headway for all of the subjects appeared to follow a normal distribution. As a result, the Z-test for testing the population means was selected and tested at the 0.05 level of significance.

4. RESULTS

EFFECTS OF FLASHING ONE-PHASE, THREE-LINE MESSAGES

Reading Time

Overall, it was found that flashing three-unit, one-phase messages did not result in different average reading times than displaying the same messages in a non-flashing (static) mode. As shown in Table 5, there was no difference in average reading time between the flashing message and the static message using the more conservative statistical assumptions. The average reading time for both message modes was 7.2 s. The results differ from the laboratory studies conducted in five cities in Texas using laptop computers in which the average reading time was found to be significantly longer for the flashing message than for the static message. [1,2] It should again be noted that the data from the previous Texas study was done on laptop computers rather than in the driving simulator as was used in this current study. Also, the previous study relied completely on the subjects to guide and administer the experiment themselves (i.e., a researcher was not present at the computer to guide subjects through the study). Consequently, there tended to be a much greater variability in response times in the laptop study, some of which may have been more attributable to subject intimidation by computer operations rather than the CMS display formats that were the primary objective of the research.

Table 5. Reading Times: One-Phase, Three-Line Flashing Message versus Static Message (Three Units of Information).

Descriptive Statistics	Flash Message (s)	Static Message (s)	Difference (s)
Average Reading Time	7.2	7.2	0.0
Median Reading Time	6.7	6.1	0.3
Standard Deviation	2.8	3.4	2.6
Standard Error of Estimate	±0.6	±0.7	±0.3

The results of the analysis did not show any significant differences in average reading times among age groups, education levels, and gender, although there was a slight indication that the average reading time difference between the flashing and static messages was lower for the young age group (less than 25 years old) than that for the other age groups. There was also slight evidence that the average reading times between flashing and static messages for subjects without a high school diploma were longer than that for subjects with higher educational levels. A summary of the results of the secondary factors of age, education, and gender is given in Table 20 in Appendix B.

Comprehension

The results of the study upon motorist comprehension of the messages shown by message line are presented in Table 6. The table corresponds to each line on the CMS and the three questions that were asked after each message presentation. Each line represents one unit of information.

Generally speaking, the results indicate that flashing a one-phase, three-line message does not adversely affect motorist comprehension to a significant degree. This result is in agreement with the Texas study. (1,2) Furthermore the overall results (both display time types combined) show that the comprehension levels were above 87 percent for each message line.

Table 6. Comprehension of Messages by Message Line: One-Phase, Three-Line Flashing Message versus Static Message.

Responses	Self-Paced Experiment (%)		Fixed-Time Experiment (%)		Combined (%)	
	Flashing Message	Static Message	Flashing Message	Static Message	Flashing Message	Static Message
Top Line: *What is the traffic problem?*	89	95	97	100	93	98
Second Line: *Where is the traffic problem located?*	94	94	100	95	97	94
Bottom Line: *What are you to do?/What is told about the lanes?*	78*†	86	95	100	87	93

* Difference between 78 percent flashing self-paced and 95 percent flashing fixed-time is statistically significant at $\alpha = 0.05$.

† Difference between 78 percent flashing self-paced and 94 percent flashing self-paced is statistically significant at $\alpha = 0.05$.

As shown in Table 6, nearly equal percentages of the subjects correctly responded to the questions "What is the traffic problem?", "Where is the traffic problem located?", and "What are you told to do/What is told about the lanes?" regardless of whether the message was presented in a flashing or static mode. There were no significant differences between the flashing and static display modes for any of the message lines. The results are consistent with those from the Texas study, although the comprehension levels for the driving simulator studies were generally higher in comparison to the Texas study. (1,2)

Of interest is that for the self-paced experiment, only 78 percent of the subjects understood the bottom line in comparison to 94 percent for the middle line. The difference is statistically significant ($\alpha = 0.05$). In contrast, there was not a significant difference between comprehension of the bottom line and the other two lines for the static messages. As previously noted, since the self-paced experiment was performed prior to the fixed-time experiment, the results may be more reflective of unfamiliar drivers. Thus, results suggest that the flashing phenomenon may attract the attention of unfamiliar drivers to an extent that there is some delay in reading the message.

Also of interest is that there was a significant difference in comprehension of the bottom line between the self-paced and fixed-time displays and an indication of possible learning effects. Only 78 percent of the subjects understood the bottom line of the flashing message when viewing the self-paced messages in comparison to 95 percent for the fixed-time studies. The difference was statistically significant at $\alpha = 0.05$. As previously discussed, the subjects first viewed each message mode in a self-paced experiment prior to viewing messages for a fixed time. Thus, it was anticipated that there would be some degree of learning between the two experiments. The self-paced portion of the study may be reflective of unfamiliar drivers seeing the message for the first time, while the fixed-time study may be more indicative of familiar (commuter) drivers who have previously seen messages with similar styles and formats. Although attempts were made in the experimental design to counterbalance and control for learning effects with regards to the specific information being presented in the test messages, it was not possible to control for the fact that subjects became more comfortable and knowledgeable of the overall study process over time. More importantly, it is possible that subjects eventually developed their own learning aids or "tricks" over the course of the study to help them better respond to the administrators questions.

Another way to assess comprehension is to look at the number of lines (units of information) in a message that subjects understood. The results of this analysis are shown in Table 7. As seen in Table 7, overall (self-paced and fixed-time experiments combined) 80 percent of the subjects understood all three lines of the flashing message, while 88 percent understood all three lines of the static message. The difference was not statistically significant.

The results from the self-paced experiment show that only 67 percent of the subjects recalled all three lines (three units of information) in comparison to 80 percent for static messages. The difference between the flashing and the static messages was not statistically significant (α = 0.05).

The results also indicate that there were significant increases in comprehension levels between the self-paced and the fixed-time experiments. For the flashing messages, the percent of subjects who understood all three lines increased from 67 percent to 92 percent. The difference was statistically significant different ($\alpha = 0.05$). For the static messages, the percentage increased from 80 percent to 95 percent, which was significantly different ($\alpha = 0.05$). The results illustrate possible learning effects between the self-paced and fixed-time experiments.

Table 7. Comprehension by Message Lines for One-Phase, Three-Line Flashing Message or Static Message.

Number of Message Lines Recalled	Self-Paced Experiment (%)		Fixed-Time Experiment (%)		Combined (%)	
	Flashing Message	Static Message	Flashing Message	Static Message	Flashing Message	Static Message
3	67*	80*	92	95	80	88
2	27	17	8	5	17	11
1	6	3	0	0	3	1
	100	100	100	100	100	100

* Difference between 67 percent flashing self-paced and 92 percent flashing fixed-time is statistically significant at $\alpha = 0.05$. Difference between 80 percent static self-paced and 95 percent static fixed-time is statistically significant at $\alpha = 0.05$.

Preferences

Another measure of comparison was the subjects' preferences. After the subjects saw the message in both flashing and static modes, they were asked to indicate which mode they preferred and to provide some rationale for their preference. The preference data are summarized in Table 8.

As is illustrated in Table 8, the subjects preferred the one-phase static message format (61 percent) over the flashing message (39 percent). The difference is statistically different (α = 0.05). These results differ from the Texas study in which there was an even split relative to preference for the flashing and static message modes. [1,2]

Interesting in both the current and the previous Texas study, preference appears to be related to the order of the comparison presentation. The results showed a significant difference in preference depending upon whether the subjects viewed the static or flashing message last. In the driving simulator study, 72 percent of the subjects who viewed the static message after they saw the flashing message preferred the static message. There was a 50/50 split when the flashing message was shown after the static message. The results further amplify the importance of counterbalancing in the experiment.

Table 8. Subject Preferences for One-Phase, Three-Line Flashing Message or Static Message.

Preference	Static Message Presented Last (%)	Flashing Message Presented Last (%)	Both Presentation Orders Combined (%)
Flashing Message	28	50	39*
Static Message	72	50	61*
	100	100	100

* Difference between 39 percent and 61 percent statistically is significant at $\alpha = 0.05$.

A summary of the common responses received from the subjects as to why they preferred a flashing or static message is presented in Table 9. The most common reason for preferring the flashing message was that it gets the attention of drivers. The most common reasons for those who preferred a static message was that it gives the driver more time to read the message and it is easier to read.

Table 9. Common Reasons for Preferences of One-Phase , Three-Line Flashing Message or Static Message.

Preferred Flashing Message		Preferred Static Message	
% (n=25)	Reasons	% (n=38)	Reasons
84	Gets your attention	32	Gives more time to read
8	Helps to remember better	32	Easier to read
8	Easier to read	13	Flashing sign is distracting
		11	Might miss information on flashing sign
		5	Like all the information all at once
		5	Flashing is not necessary
		3	Easier to understand
100		100	

Note: One subject did not respond.

Driving Performance

In summary, there were no differences between the flashing messages and the static messages with respect to acceleration noise, lane position, standard deviation of lane position, average distance headway, or standard deviation of distance headway. The results of the subject driving performance analyses are shown in Tables 23 through 29 in Appendix C.

EFFECTS OF FLASHING ONE LINE OF ONE-PHASE, THREE-LINE MESSAGES

Reading Time

The results of the analysis of the effect of flashing one line (top line) of a one-phase, three-line message were somewhat more definitive as compared to flashing the entire message. As shown in Table 10, the average reading time for the flashing messages was 0.7 s longer than that for the static messages (7.8 versus 7.1 s). The difference is statistically significant ($\alpha = 0.05$). The findings are consistent with the Texas study in which flashing line messages resulted in significantly longer average reading times than comparable static messages. [1,2]

No significant difference in average reading time was found among age groups, education levels, and gender. There was a slight indication that one of the two messages used in the study resulted in average reading times higher than the other message. Further review of the data indicated that the slight difficulty subjects had in reading and understanding this one message did not adversely affect the ultimate conclusions of the study. The influence of the secondary factors of age, education, and gender is presented in Table 21 in Appendix B.

Table 10. Reading Times: Flashing One Line of a One-Phase, Three-Line Message versus Static Message (Three Units of Information).

Descriptive Statistics	Flash Line Message (s)	Static Message (s)	Difference (s)
Average Reading Time	7.8	7.1	0.7*
Median Reading Time	6.9	5.9	0.8
Standard Deviation	3.7	3.2	2.6
Standard Error of Estimate	±0.6	±0.6	±0.3

* Statistically significant at $\alpha = 0.05$.

Comprehension

The results of the analysis indicated no significant differences in understanding between the flashing line and static messages. This finding is consistent with that of the Texas study. [1,2] However, there was a significant difference in understanding the bottom line of the messages in comparison to the top two lines. Furthermore, there was a significant increase in understanding between the self-paced and fixed-time experiments.

A summary of the comprehension of the flashing line and static messages is presented in Table 11. The results apply to each of the three questions that were asked after each message presentation. As shown in the table, nearly equal percentages of subjects correctly responded to the questions "What is the traffic problem?", "Where was the problem located?", and "What are you to do?" between the flashing line and static messages.

Overall (self-paced and fixed-time combined), over 90 percent of the subjects recalled the top two lines in the messages for both the flashing line and static modes. Only 75 and 83 percent of the subjects recalled the bottom line for the flashing line and static messages, respectively. Although there was no significant difference between the flashing line and static messages, there was a significant difference ($\alpha = 0.05$) between the bottom line and the other two lines for the flashing line message. Similarly, the percent of subjects who understood the bottom line of the flashing line message was significantly lower than that for the other two lines in the message during both the self-paced and the fixed-time experiments. For the self-paced experiment, only 66 percent of the subjects understood the bottom line in comparison to 84 and 89 percent for the other two lines. For the fixed-time experiment, 84 percent of the subjects understood the bottom line in comparison to 98 and 94 percent for the other two lines. Thus, in addition to a higher reading time it appears that the flashing line adversely affects the drivers' ability to read the entire message.

Table 11. Comprehension of Messages by Message Line: One-Phase, Three-Line Flashing Line Message versus Static Message.

Responses	Self-Paced Experiment (%)		Fixed-Time Experiment (%)		Combined (%)	
	Flashing Line Message	Static Message	Flashing Line Message	Static Message	Flashing Line Message	Static Message
Top Line: *What is the traffic problem?*	84*	84*	98	97	91	91
Second Line: *Where is the traffic problem located?*	89	89	94	95	91	92
Bottom Line: *What are you to do?*	66*†	73*	84†	92	75†	83

* Difference between 84 percent top line flashing line self-paced and 98 percent flashing line fixed-time presentations is statistically significant at α = 0.05. Difference between 84 percent top line static self-paced and 97 percent fixed-time presentations is statistically significant at α = 0.05. Difference between 66 percent bottom line flashing line self-paced and 84 percent flashing line fixed-time presentations are statistically significant at " = 0.05. Difference between 73 percent bottom line static self-paced and 84 percent fixed-time presentations is statistically significant at α = 0.05.

† Difference between bottom line and top two lines is statistically significant at α = 0.05.

The data were further analyzed to evaluate the number of lines (units of information) in the messages that the subjects recalled. The results are shown in Table 12.

No significant difference was found between the flashing line and static messages. As seen in Table 12, overall only 62 percent of the subjects understood the information on all three lines of the flashing messages, and only 71 percent understood all three lines of the static message. Interestingly, comprehension was much lower than for the full flashing and static messages discussed in the previous section of the report. Although it cannot be stated with certainty, a reason may be due to the slight difficulty subjects had in understanding one of the two messages used in the flashing line message comparisons.

For the self-paced presentation, only 47 percent of the subjects understood the information on all three lines of the flashing messages, and only 56 percent of the subjects understood all three lines for the static messages. The difference in percentages was not statistically significant. Furthermore, a high percentage of subjects understood information on only two lines (45 percent for the flashing line message and 34 percent for the static messages) and thus did not get the full context of the message.

There was a significant increase (α = 0.05) in the percentage of subjects who understood all three lines for both the flashing line and static messages for the fixed-time presentation. Seventy-seven percent of the subjects understood all three lines of the flashing messages, and 86 percent understood all three lines of the static presentation. These results again illustrate possible learning effects.

Interestingly, comprehension was much lower than for the full flashing and static messages discussed in the previous section of the report. Although it cannot be stated with certainty, a reason may be due to the fact that the messages used in the flashing line comparisons may have been slight more complex than the messages used in the flashing message comparisons.

Table 12. Comprehension by Message Lines for One-Phase, Three-Line Flashing Line Message or Static Message.

Number of Message Lines Recalled	Self-Paced Experiment (%)		Fixed-Time Experiment (%)		Combined (%)	
	Flashing Line Message	Static Message	Flashing Line Message	Static Message	Flashing Line Message	Static Message
3	47*	56*	77	86	62	71
2	45	34	23	13	34	34
1	8	9	0	2	4	5
	100	100	100	100	100	100

* Difference between 47 percent for self-paced and 77 percent for fixed-time presentations is statistically significant at $\alpha = 0.05$. Difference between 56 percent for self-paced and 86 percent for fixed-time presentations is statistically significant at $\alpha = 0.05$.

Preferences

Preference data for the flashing line message and static formats are presented in Table 13. The results revealed that there was a 50/50 split relative to the preference for the two message modes. Interestingly, more subjects (66 percent) who viewed the static message after viewing the flashing line message preferred the static format. In contrast, more subjects (66 percent) who viewed the flashing line message after viewing the static message preferred the flashing line message.

Table 13. Subject Preferences for One-Phase Flashing Line Message or Static Message.

Preference	Static Message Presented Last (%)	Flashing Line Message Presented Last (%)	Both Presentation Orders Combined (%)
Flashing Line Message	34	66	50
Static Message	66	34	50
	100	100	100

Common responses to the reasons for the preference selections are summarized in Table 14. As expected, those who preferred the flashing line message did so because they felt it was better able to get their attention or emphasized the importance of the information. Conversely, those who preferred the static message indicated that the flashing was distracting and the static message gave them more time to read the message and was easier to read.

Table 14. Common Reasons for Preferences of One-Phase Flashing Line Message or Static Message.

Preferred Flashing Line Message		Preferred Static Message	
% (n=29)	Reasons	% (n=34)	Reasons
76	Gets your attention	32	Gives more time to read
24	Emphasizes importance of information	32	Flashing is distracting
		13	Might miss information on flashing sign
		11	Easier to read
		5	Do not like flashing
		5	Like all the information all at once
		2	Flashing is not necessary
100		100	

Note: One subject did not respond.

Driving Performance

The results of the subject driving performance data are shown in Tables 23 through 29 in Appendix C. In summary, there were no differences between the flashing messages and the static messages with respect to acceleration noise, lane position, standard deviation of lane position, average distance headway or standard deviation of distance headway.

EFFECTS OF THREE-LINE, TWO-PHASE MESSAGES WITH AN ALTERNATING LINE AND INFORMATION REDUNDANCY BETWEEN PHASES

In this part of the study, three-line, two-phase messages in which the third line alternated between phases while the top two lines remained constant were evaluated. This message format resulted in the same (thus redundant) information presented on the top two lines of the message. The alternative message had the same information presented on two phases but without repetition of lines and thus no redundancy.

Reading Time

Descriptive statistics results of the comparison of two-phase alternating line messages with redundancy and messages without redundancy are presented in Table 15. The average reading time of the alternating line messages with redundancy was found to be 1.8 s longer than that of messages without redundancy. The difference is statistically significant ($\alpha = 0.05$). This result is consistent with the Texas study in which the average reading time of the message with redundancy was significantly longer than that of the message without redundancy. [1,2]

Table 15. Reading Times: Alternating One Line of a Two-Phase, Three Line Message with Redundancy versus a Two-Phase Message without Redundancy.

Descriptive Statistics	With Redundancy (s)	No Redundancy (s)	Difference (s)
Average Reading Time	15.9	14.1	1.8*
Median Reading Time	14.8	14.7	0.8
Standard Deviation	6.8	4.8	5.8
Standard Error of Estimate	±1.2	±1.0	±0.7

* Statistically significant at $\alpha = 0.05$.

Evaluations of the secondary factors revealed that there were no significant differences among age groups, education levels, and gender. However, there were indications of some trends. Specifically, the less than 25-years old age group had smaller differences in reading times for the two formats than the other subjects, while the no high school diploma group had higher reading time differences than the other education levels for the two message display formats. Again, though, the large standard errors associated with these estimates preclude any type of statistical significance being attached to them for the driving population as a whole. The results of the secondary factors are summarized in Table 22 in Appendix B.

Comprehension

The response results to the questions "What is the traffic problem?", "Where was the problem located?", "What is told about the lanes?", and "What are you to do?" are summarized in Table 16. No statistically significant differences were found between the messages with and without redundancy. The results were also consistent between the self-paced and fixed-time message presentations. In addition, no significant differences were found between the self-paced and fixed-time experiments. Overall, the percent of subjects who understood each message line ranged between 84 and 91 percent.

In contrast with the flashing messages and flashing line messages, the percent of subjects who understood each message line during the self-paced experiment was very high, ranging between 83 and 91 percent. One possible reason is that subjects took an average of between 14 and 16 s to read the messages during the self-paced experiment, about twice the amount of time they would have had available to read messages displayed on a highway. Messages were displayed for 8.4 s during the fixed-time studies.

Analysis of comprehension levels by the number of message lines revealed no significant differences in the percent of subjects who understood all four message lines between the messages with redundancy and the non-redundant messages (see Table 16). However, only about two-thirds of subjects understood all four lines of the message regardless of the message mode.

A summary of the number of message lines that were recalled by the subjects is shown in Table 17. No differences were found between messages with redundancy and those without redundancy. Overall, only about two-thirds of the subjects recalled all four message lines.

Table 16. Comprehension of Messages by Message Line: Alternating One Line of a Two-Phase, Three-Line Message with Redundancy versus a Two-Phase Message without Redundancy.

Responses	Self-Paced Experiment (%)		Fixed-Time Experiment (%)		Combined (%)	
	With Redundancy	No Redundancy	With Redundancy	No Redundancy	With Redundancy	No Redundancy
Top Line: *What is the traffic problem?*	89	91	95	92	91	91
Second Line: *Where is the traffic problem located?*	86	91	89	91	87	91
Bottom Line (first phase): *What is told about the lanes?*	94	88	92	92	88	90
Bottom Line (second phase): *What are you to do?*	83	86	86	84	84	84

Table 17. Comprehension by Message Lines for Alternating One Line of a Two-Phase, Three Line Message with Redundancy versus a Two-Phase Message without Redundancy.

Number of Message Lines Recalled	Self-Paced Experiment (%)		Fixed-Time Experiment (%)		Combined (%)	
	With Redundancy	No Redundancy	With Redundancy	No Redundancy	With Redundancy	No Redundancy
4	59	66	70	66	65	68
3	33	23	22	27	27	25
2	8	11	6	6	7	6
1	0	0	2	2	1	1
	100	100	100	100	100	100

Preferences

A summary of the subject preferences for the two message modes is shown in Table 18. Again, the preference selection was influenced by the order in which the two message modes were presented during the preference portion of the study. Overall, more subjects preferred the message with redundancy (59 percent) than without redundancy (41 percent). The difference is significant ($\alpha = 0.05$). In contrast, the subjects in the Texas study were evenly split in preference between the two modes. [1,2]

Table 18. Subject Preferences for Alternating One Line of a Two-Phase, Three-Line Message with Redundancy versus a Two-Phase Message without Redundancy.

Preference	Non-Redundant Message Presented Last (%)	Redundant Message Presented Last (%)	Both Presentation Orders Combined (%)
With Redundancy	44	75	59*
Without Redundancy	56	25	41
	100	100	100

* Statistically significant at $\alpha = 0.05$.

A summary of the common reasons received from the subjects as to why they preferred to have or not have redundancy in the message is presented in Table 19. Some of the subjects who preferred the message with redundancy felt that it provided more information at one time, the critical (to them) information remained static, and it was easier to process the information. On the other hand, some subjects who preferred the message without redundancy felt it was easier to read and process and was easier to notice the message change between phases.

Table 19. Common Reasons for Preferences for Alternating One Line of a Two-Phase, Three-Line Message with Redundancy versus a Two-Phase Message without Redundancy.

Preferred Redundant Message		Preferred Non-Redundant Message	
% (n=37)	Reasons	% (n=25)	Reasons
24	Provides more information at one time	44	Easier to read
22	Easier to read	36	Easier to process the information
19	Critical information remained static	12	Easier to notice when sign changes
18	Easier to process information	8	Just like it better
5	Just liked it better		
15	Other (5 subjects with different reasons)		
100		100	

Note: Two subjects did not respond.

Driving Performance

There were no differences detected between the messages with redundancy and the messages without redundancy with respect to acceleration noise, lane position, standard deviation of lane position, average distance headway, or standard deviation of distance headway. The results of the subject driving performance data are shown in Tables 23 through 29 in Appendix C.

5. SUMMARY OF FINDINGS AND RECOMMENDATIONS FOR FURTHER STUDY

Studies were conducted using TTI's driving simulator to evaluate the effects of:

- Flashing an entire one-phase, three-line message containing three units of information.
- Flashing one line (top line) of a one-phase, three line message containing three units of information.
- Alternating one line (bottom line) of text of a two-phase, three-line message and keeping two lines (top two lines) constant.

A total of 64 subjects from the Bryan–College Station, Texas area participated. The sample matched the driving population of Texas. The study was divided into three main experiments. The order of the experiments was as follows:

- Self-paced,
- Fixed-time, and
- Preference.

The subjects viewed the CMS messages for as long as they needed during the self-paced experiment. For the fixed-time experiment, the subjects viewed the messages for 8.4 s which is equivalent to the available message exposure time of the newer LED CMSs when drivers are traveling at 105 km/h (65 mi/h).

The results indicate some learning effects between the self-paced and fixed-time experiments. Because the self-paced experiment was conducted first, the results may be more reflective of drivers who are unfamiliar with the dynamic message modes. In contrast, since similar CMS message modes were used in the fixed-time experiment, the results may be more reflective of familiar drivers (commuters).

The findings from the study are summarized below. In addition, the findings are compared to the human factors laboratory studies that were conducted by TTI in five Texas cities using laptop computers.

EFFECTS OF FLASHING ONE-PHASE, THREE LINE MESSAGES

The findings relative to flashing a one-phase, three-line message containing three units of information are as follows:

1. No significant differences were found in average reading time between flashing messages and static messages. The average reading time for both was 7.2 s. The results differ from the Texas study in which the average reading time for the flashing messages was found to be significantly longer than for the static messages. [1,2]

2. No significant differences were found in average reading times among age groups, education levels, or gender.

3. The results suggest that flashing messages will have adverse affects on message understanding for drivers who are unfamiliar with this mode of CMS display. The problem is reflected by the significantly lower understanding of the information displayed on the bottom line of the message. Only 78 percent of the subjects understood the bottom line of the flashing messages during the self-paced experiment in comparison to 95 percent during the fixed-time experiment. The percent difference was statistically significant ($\alpha = 0.05$).

4. Overall (self-paced and fixed-time experiments combined), comprehension of each message line was at very acceptable levels of 87 percent or higher for both the flashing and the static messages. There were no significant differences between the flashing and static messages. These results are consistent with those from the Texas study; however, the comprehension levels for the driving simulator studies were generally higher in comparison to the Texas study. [1,2]

5. Overall, 80 percent of the subjects understood all three lines of the flashing messages, and 88 percent understood all three lines of the static messages. However for the self-paced studies, only 67 percent of the subjects recalled all three lines of the flashing message in comparison to 80 percent for the static messages. The difference between the flashing and static messages was not statistically significant ($\alpha = 0.05$). For the fixed-time studies, the percentages increased to 92 and 95 percent. These latter results further indicate possible learning effects between the experiments and further support the notion that unfamiliar drivers will have some difficulty in reading all three lines of flashing messages while driving at typical freeway speeds.

6. Only 39 percent of the subjects preferred the flashing message, while 61 percent preferred the static message mode. The difference was statistically significant ($\alpha = 0.05$). In contrast to the driving simulator results, there was a 50/50 split in preference in the Texas study. [1,2]

7. The most common reason cited by the subjects who preferred the flashing message mode was that it gets the attention of drivers. The most common reasons for those who preferred a static message was that it gives the driver more time to read the message and is easier to read.

8. No differences were found between the flashing messages and the static messages with respect to the driver performance measures of acceleration noise, lane position, standard deviation of lane position, average distance headway, or standard deviation of distance headway.

EFFECTS OF FLASHING ONE LINE OF ONE-PHASE, THREE-LINE MESSAGES

The findings relative to flashing the top line of a one-phase, three-line message containing three units of information are listed below.

1. The average reading time for the flashing line message was found to be 0.7 s longer for the flashing line messages than the static messages (7.8 versus. 7.1 s). The difference is statistically significant ($\alpha = 0.05$). This result suggests that reading time may increase by

nearly 10 percent when a message line is flashed in a one-phase message. Average reading time was found to be significantly longer for the flashing line messages in the Texas study as well. [1,2]

2. No significant differences were found in average reading times among age groups, education levels, or gender.

3. The results suggest that flashing a message line will have adverse affects on message understanding for unfamiliar drivers. It may also adversely affect familiar drivers but to a lesser degree. The problem is reflected in the significantly lower understanding of the information displayed on the bottom line. The result is similar to the difficulty indicated for the flashing message. Only 66 percent of the subjects understood the bottom line during the self-paced experiment, which was significantly lower than that for the other two lines ($\alpha = 0.05$). Similarly, 84 percent understood the bottom line during the fixed-time experiment, which was significantly lower than that for the other two lines ($\alpha = 0.05$). Overall, the percent of subjects that understood the bottom line (75 percent) was significantly ($\alpha = 0.05$) lower than for the top and middle message lines.

4. Overall (self-paced and fixed-time experiment combined), no significant differences were found in comprehension of each message line between the flashing line and static messages. However, similar to the flashing message experiment, there was indication of learning effects because comprehension percentages of the top and bottom lines of the messages for the fixed-time experiment were significantly ($\alpha = 0.05$) higher than for the self-paced experiment.

5. Overall, only 75 percent recalled the bottom line of the flashing line messages in comparison to 91 percent for the other two lines. The differences were significant ($\alpha = 0.05$). For the static messages, 83 percent recalled the information in the bottom line in comparison to 91 and 92 percent for the other two lines. The differences, however, were not statistically significant.

6. From the perspective of the number of message lines (units of information) that the subjects understood, overall, only 62 percent of the subjects recalled all three lines of the flashing line message, and only 71 percent recalled all three lines of the static messages. There was a significant increase in the percent of subjects that understood all three message lines between the self-paced and fixed-time experiments, again indicating learning between the two experiments and the effects that flashing line messages may have on unfamiliar drivers.

7. The subjects were evenly split (50/50) relative to their preference between the flashing line and static message modes. The result is consistent with the Texas study. [1,2]

8. Subjects who preferred the flashing line message did so because they felt it was better able to get their attention or emphasized the importance of the information. Conversely, those who preferred the static message indicated that the flashing line was distracting and the static message gave them more time to read the message and was easier to read.

9. No differences were found between the flashing messages and the static messages with respect to acceleration noise, lane position, standard deviation of lane position, average distance headway, or standard deviation of distance headway.

EFFECTS OF THREE-LINE, TWO-PHASE MESSAGES WITH AN ALTERNATING LINE AND INFORMATION REDUNDANCY BETWEEN PHASES

The findings relative to alternating one line of two-phase, three-line messages are listed below.

1. The average reading time for the alternating line message with redundancy and non-alternating line message without redundancy were 15.9 and 14.1 s, respectively—a difference of 1.8 s. The difference is significant ($\alpha = 0.05$). As with the flashing line message results, this increase suggests that alternating the third line in the message requires 13 percent more reading time than presenting the same information without redundancy. The average reading time was also found to be significantly longer for the alternating line messages in the Texas study. [1,2]

2. No significant differences were found in average reading times among age groups, education levels, or gender.

3 No difference in comprehension was found between the messages with redundancy and the messages without redundancy. Also, there were there significant differences between the self-paced and fixed-time experiments. Overall comprehension percentages were high for each message line ranging from 84 to 91 percent.

4. In contrast to the flashing and flashing line messages, the percent of subjects who understood the information on each message line was very high during the self-paced experiment, ranging between 83 and 91 percent. This was most likely due to the fact that the subjects took an average of between 14 and 16 s to read the messages. No differences in comprehension were found between the self-paced and fixed-time experiments.

5. No differences were found in the number of message lines recalled by the subjects between the messages with redundancy and messages without redundancy. However, only 65 percent of subjects recalled all four message lines for the message with redundancy, and only 68 percent recalled all four lines for the messages without redundancy.

6. Fifty-nine percent of the subjects preferred the message with redundancy and 41 percent preferred the message without redundancy. The difference was statistically different ($\alpha = 0.05$). Interestingly, the average reading time for the message with redundancy was almost 2 s longer than that for the messages without redundancy.

7. Some of the subjects who preferred the message with redundancy felt that it provided more information at one time, the critical (to them) information remained static, and it was easier to process the information. On the other hand, some subjects who preferred the message

without redundancy felt it was easier to read and process and was easier to notice the message change between phases.

8. No differences were found between the flashing and static messages with respect to acceleration noise, lane position, standard deviation of lane position, average distance headway, or standard deviation of distance headway.

RECOMMENDATIONS FOR FURTHER STUDY

The results of the computer laptop laboratory study and driving simulator study for the flashing line and alternating line message modes were consistent. However, there were differences for the messages in which all three lines flashed, particularly with respect to reading time. In the laboratory study, the flashing messages resulted in a significantly longer reading time than for the static messages. In contrast, no differences in reading time were found in the driving simulator study. This latter result suggests that further research should be conducted to better resolve the disagreement in reading time for the flashing message. In addition, the studies to date have focused exclusively on the potential adverse effects of dynamic displays. No attempts have been made to assess whether the perception by some subjects and state DOT personnel that the dynamic features increase the attention-getting value of the message above and beyond that possible with the use of static messages actually occurs. The authors of this report recommend that FHWA initiate proving ground studies to further the knowledge on the effects of the flashing three lines of a one-phase, three line messages. It is also recommended that, although there was consistency between the laboratory and diving simulator studies for the flashing line and alternating line message modes, added value can be gained at a low cost to further evaluate these modes in proving ground studies. The rationale for conducting proving ground studies is addressed in the following paragraphs.

The current study was conducted using the TTI Driving Simulator in College Station, Texas. No differences were found in driving performance between each of the dynamic display features and its comparable static display. The reading time, comprehension, and preference results of the driving simulator study with respect to all three dynamic feature evaluated compare favorably to those from the computer laptop study, with only a few exceptions that were associated with the flashing three-line, one phase messages. Although average reading times for the flashing messages were found to be significantly longer than for the static messages in the computer laptop study, the results of this driving simulator study showed reading times to be nearly identical. Also, in contrast to the driving simulator results which show a significant preference for static (non-flashing messages), subjects in the Texas study were evenly split as to which display format they preferred.

An important feature of driving simulators is that they provide an environment in which the actions taken by the subjects (i.e., steering, braking, etc.) replicate the typical actions taken by drivers in the real world. They also provide opportunities to introduce secondary task-loading into the studies. After evaluating several alternative approaches for secondary task loading in the current study, the decision was made in concert with FHWA that the best approach within the capabilities of the TTI Driving Simulator was to use the car-following technique discussed earlier in the report.

One factor that may have influenced the results of the driving simulator study was the very high attention that subjects devoted to the vehicle that they were following. Because of the high mental and visual concentration on the lead vehicle so that the subject would maintain a safe driving distance, most subjects totally ignored the roadside features in the surrounding simulated environment. In addition, the operational responses were highly constrained because the subjects did not have to change lanes and follow curves during the experiments. In essence, the study design eliminated potential operational MOEs that could have been measured.

The level of agreement shown between the computer laptop and the driving simulator studies has shown that subject visual and mental concentration similar to the current driving simulator study can be achieved with laboratory studies using laptop computers with secondary workload activities. This gives rise to speculation that laptop studies with secondary task loading features may be an effective means of conducting similar studies in different locations in the U.S.

For any study, it is important to understand how well the results represent the real world. Depending on the question of interest to be answered through research, there is a hierarchy of human factors studies that can be performed with each level resulting in different levels of knowledge with respect to translation of the results to the real world. The hierarchy of human factors studies with respect to CMS signing issues is as follows:

1. Surveys and focus group studies.
2. Basic laboratory studies.
3. Single-task laptop laboratory studies.
4. Driving simulator and secondary task-loading laptop studies.
5. Proving ground studies.
6. Controlled field studies.
7. Real world event studies.

Surveys and focus group studies provide basic subjective information about information that might be considered in CMS messages. Basic laboratory studies can provide useful information to separate the "worst" cases or designs from further consideration but do not have the resolution to compare all alternatives. Single-task laptop laboratory studies allow the researchers to make comparisons among alternative designs. However, specific values (e.g., reading times) may differ from the real world.

In the next order in the hierarchy of studies are driving simulator and laptop studies with secondary task loading of subjects. Both types of studies introduce secondary loading and provide opportunities to compare alternatives during higher subject work load with greater resolution. However, specific values (e.g., reading times) may still differ from the real world. Thus, the reading time values found in the current driving simulator study allow one to compare the differences between the alternatives, but in no way indicate that the same values (e.g., reading times) would be the same in the real world. One limitation of a driving simulator study is that residents from only one location are generally used in the sample. Regional differences cannot be measured unless driving simulators from other locations are used. Because each driving simulator has different features and software, the cost of replicating the experiment becomes very high. In contrast, regional differences can be easily and cost-effectively measured using laptop computers with secondary loading tasks. One limitation of laptop studies is that the specific actions that the subjects need to take (e.g., steering, braking, etc.) are not the same as would be required in a driving situation.

The next order in the hierarchy and thus capable of higher resolution with respect to translation to the real world are proving ground studies. Subjects actually drive a vehicle in a closed course and are asked to respond to certain situations or questions. The nature of the proving ground studies forces the subject to pay attention to the surrounding environment in contrast to what was experienced in the current driving simulator study. Eye-tracking can be included in the experiment so that differences in the amount of time subjects look at each CMS message and each line of the message. Missing from the proving ground environment is other traffic. Thus the subject's work load is less than the real world. However, this study approach allows the test administrators to control outside variables that might bias the results. Comparable to driving simulator studies, there is a high cost to replicate the experiment at other locations to measure regional differences.

Still higher on the hierarchy are controlled field studies in which each subject drives a vehicle on a highway. The subject responds to stimulus material (e.g., highway signs, CMS messages, etc.) by driving actions, or the subject answers questions asked by a test administrator after the subject passes the signs. In some studies the stimulus material can be introduced within the vehicle. The problem with this study method is that the environment changes frequently. That is, traffic may vary at the sign locations, or there may be traffic factors (e.g., lane changing, vehicles slowing, etc.) that constantly change. These outside influencing factors can adversely affect the results when alternative messages are being evaluated. Thus, the sample size has to be extremely large in order to collect sufficient data to account for the variances associated with the external influencing factors. Another factor to consider is that when the fictitious messages are displayed external to the vehicle they must be displayed on CMSs—an undesirable situation for most highway agencies.

The highest level is conducting studies on a highway and measuring the change in traffic characteristics in response to messages posted on CMSs. Similar to controlled field studies, the high variability of traffic during the course of the study would require very large samples. Also, fictitious messages must be displayed if direct comparisons and analyses are to be made. The cost of real world event studies would be prohibitively high. In addition, it would not be possible to gain insight on important characteristics such as reading times, comprehension, and preferences to compare the alternatives.

6. REFERENCES

1. Dudek, C.L., N. Trout, B. Durkop, S. Booth, and G.L. Ullman. *Improving Dynamic Message Sign Operations.* Report FHWA/TX-01/1882-2. Texas Transportation Institute, College Station, Texas, October 2000.

2. Dudek, C.L., and G.L. Ullman. Flashing Messages, Flashing Lines, and Alternating One Line on Changeable Message Signs. In *Highway Research Record 1803*, TRB, National Research Council, Washington, D.C., 2002, pp. 94-101.

3. Dudek C.L., and R.D. Huchingson. *Manual on Real-Time Motorist Information Displays*. Report FHWA-IP-86-16. FHWA, U.S. Department of Transportation, Washington, D.C., August 1986.

4. Dudek, C.L. *Dynamic Message Sign Message Design and Display Manual*. Report FHWA/TX-04/-4023-P1. Texas Transportation Institute, College Station, Texas, March 2004.

5. Dudek, C.L. *Variable Message Sign Operations Manual.* Report FHWA-NJ-2001-10. New Jersey Department of Transportation, Trenton, New Jersey, November 2001.

6. Dudek, C.L. *Changeable Message Sign Operation and Messaging Handbook*. Report FHWA-OP-03-070. FHWA, U.S. Department of Transportation, Washington, D.C., August 2004.

7. *Driver Simulator Sickness and Usability*. Conference session held at the Annual Meeting of TRB, National Research Council, Washington, D.C., January 2004.

8. Drew, D.R., C.L. Dudek, and C.J. Keese. Freeway Level of Service as Described by an Energy-Acceleration Noise Model. In *Highway Research Record 162*, TRB, National Research Council, Washington, D.C., 1967, pp. 30-85.

9 Ullman, G.L., and C.L. Dudek. Legibility Distance of Light-Emitting Diode (LED) Variable Message Signs. *CD-ROM Compendium*, 6th World Congress on Intelligent Transport Systems, Toronto, Ontario, November 1999.

10. Carlin, B.P., and T.A. Louis. *Bayes and Empirical Bayes Methods for Data Analysis*. Chapman and Hall/CRC, London, 1996.

11. Lange, K.L., R.J.A. Little, and J.M.G. Taylor. Robust Statistical Modeling Using the t Distribution. *Journal of the American Statistical Association*, Vol. 84, No. 408, Dec. 1989, pp. 881-896.

12. Spiegelhalter, D.J., N. Best, B.P. Carlin, and A. Linde. Bayesian Measure of Model Complexity and Fit. *Journal of Royal Statistical Society*, Vol. 64, Part 3, 2002, pp. 1-34.

13. Spiegelhalter, D.J., A. Thomas, and N.G. Best. *WinBUGS Version 1.4 User Manual*. Imperial College and Medical Research Council, UK, 2003.

14. Lindgren, B.W. *Statistical Theory.* Third Edition. Macmillan Publishing Co., Inc., New York, 1968.

APPENDIX A – CONTROLS FOR SUBJECT NAUSEA

Based on anecdotal experiences from previous TTI driving simulator studies and presentations made at the 2004 annual meeting of the Transportation Research Board, the TTI researchers were concerned about the possibility of subjects experiencing simulator-induced discomfort (SID) and being forced to prematurely end their participation. Anecdotal evidence exists that older subjects and female subjects may be more likely to suffer from SID, and that events such as sharp turns could rapidly induce SID. The procedures shown below were introduced into the study to minimize the likelihood of SID occurrences.

- During subject recruitment the researchers asked the potential subjects if they had ever experienced motion sickness, and anyone who said they had was excluded from the study.
- The subjects were fully briefed on SID prior to the beginning of the study, and it was explained to them that if they felt any uncomfortable symptoms, they were to notify the researchers and the study would end.
- A practice session was used to acclimate subjects to the driving simulator and served as an opportunity to closely observe the subjects for adverse reactions.
- A rest break was provided at four points during the study to get the subjects out of the driving simulator.
- The subjects were frequently asked how they were feeling in an attempt to detect SID early.
- One of the two researchers in the study observed the subjects through a closed-circuit television camera and watched for visual signs of subject discomfort.
- The presence of horizontal curvature was eliminated in the simulated driving environment.
- The presence of vertical curvature was minimized in the simulated driving environment.
- Lane changes or other maneuvers that required turning the steering wheel left or right were minimized.

Of the 64 original subjects that were tested, 2 subjects complained of SID despite the precautions taken. In those cases the subjects were removed from the simulator, monitored until they stated that they felt well enough to drive home, and were released. These subjects were then replaced with other subjects.

APPENDIX B - EFFECTS OF AGE, EDUCATION, AND GENDER DIFFERENCES

Table 20. Effect of Age, Education, Gender, and Different Messages upon Difference in Reading Times: One-Phase, Three-Line Flashing versus Static Message Display (Three Units of Information).

Factor Effect	Assuming Differences in Response Time Follow a Normal Distribution		Assuming Differences in Response Time Follow a t-Distribution	
	Parameter[A] Estimate (s)	Standard Error of Estimate (s)	Parameter[A] Estimate (s)	Standard Error of Estimate (s)
Flashing minus Static	0.0	±1.2	0.3	±1.3
Age:				
< 25	---	---	---	---
25-39	0.4	±1.1	0.4	±1.2
40-54	1.0	±1.1	1.2	±1.2
55-64	1.0	±1.4	1.7	±1.7
> 64	0.8	±1.4	1.3	±1.3
Gender	-0.2	±1.7	-0.6	±0.7
Education:				
No HS Diploma	---	---	---	---
HS Diploma	-0.5	±1.0	-0.6	±0.9
Some College	-0.6	±1.0	-1.0	±0.9
College Degree	-1.1	±1.1	-0.7	±0.9

[A] Difference between the average reading times for the flashing message versus the static message.

--- Value against which other parameters in that category are compared. For example, the average reading time differences between the flashing messages and the static messages for subjects in the 25-39 year-old group was 0.4 s longer than for subjects younger than 25 years old.

Table 21. Effect of Age, Education, Gender, and Different Messages upon Difference in Reading Times: One Line Flashing versus Static Message Display (Three Units of Information).

Factor Effect	Assuming Differences in Response Time Follow a Normal Distribution		Assuming Differences in Response Time Follow a t-Distribution	
	Parameter[A] Estimate (s)	Standard Error of Estimate (s)	Parameter[A] Estimate (s)	Standard Error of Estimate (s)
One Line Flashing minus Static	1.3	±1.2	1.7	±1.2
Age: < 25	---	---	---	---
25-39	-1.9**	±1.1	-2.2*	±1.1
40-54	-0.8	±1.1	-1.2	±1.1
55-64	-0.1	±1.3	-0.5	±1.3
> 64	-0.5	±1.3	-0.7	±1.3
Gender	-0.1	±0.7	-0.2	±0.6
Education: No HS Diploma	---	---	---	---
HS Diploma	2.1*	±0.9	2.1*	±1.0
Some College	0.5	±0.9	0.5	±0.9
College Degree	0.7	±0.9	0.6	±0.8

[A] Difference between the average reading times for the flashing line message versus the static message.

--- Value against which other parameters in that category are compared. For example, subjects between 25 and 39 years old had differences in reading times that were 1.9 s shorter for the one-line flashing display than for the static display for subjects younger than 25 years old.

* Statistically significant at $\alpha = 0.05$.

** Statistically significant at $\alpha = 0.10$.

Table 22. Effect of Age, Education, Gender, and Different Messages upon Difference in Reading Times: Alternating Third Line versus Two-Phase Message Display.

Factor Effect	Assuming Differences in Response Time Follow a Normal Distribution		Assuming Differences in Response Time Follow a t-Distribution	
	Parameter Estimate (s)	Standard Error of Estimate (s)	Parameter Estimate (s)	Standard Error of Estimate (s)
Alternating Line minus Non-alternating Line	-0.9	±2.7	-1.5	±2.2
Age: < 25	---	---	---	---
25-39	2.4	±2.5	2.5	±1.9
40-54	4.3**	±2.4	2.9	±2.0
55-64	5.4**	±3.0	4.8*	±2.5
> 64	4.0	±3.0	4.7**	±2.6
Gender	1.6	±1.5	0.4	±1.3
Education: No HS Diploma	---	---	---	---
HS Diploma	-2.7	±2.1	-0.9	±1.9
Some College	-1.9	±2.1	-0.8	±2.0
College Degree	-2.7	±2.1	-1.3	±2.0

[A] Difference between the average reading times for the message with redundancy versus the message without redundancy.

--- Value against which other parameters in that category are compared. For example, subjects between 25 and 39 years old had differences in reading times that were 2.4 s longer for the alternating line display than for the non-alternating line display for subjects younger than 25 years old.

* Statistically significant at $\alpha = 0.05$.

** Statistically significant at $\alpha = 0.10$.

APPENDIX C – DRIVER PERFORMANCE RESULTS

Table 23. Statistical Testing of Acceleration Noise.

		Flash Message vs. Static Message		Flash Line Message vs. Static Message		Redundant Message vs. Non-Redundant Message	
		Flash	Static	Flash Line	Static	Redundancy: With	Redundancy: No
Acceleration Noise (ft/sec^2)	Self-Paced Experiment	5.5	5.1	5.4	5.3	5.5	5.3
	Statistically Significant ($\alpha = 0.05$)?	No		No		No	
	Fixed-Time Experiment	5.1	5.1	5.0	5.1	5.2	5.4
	Statistically Significant ($\alpha = 0.05$)?	No		No		No	

Table 24. Statistical Testing of Average Lateral Lane Position.

		Flash Message vs. Static Message		Flash Line Message vs. Static Message		Redundant Message vs. Non-redundant Message	
		Flash	Static	Flash Line	Static	Redundancy: With	Redundancy: No
Average Lane Position (ft)	Self-Paced Experiment	-0.8	-0.7	-0.7	-0.7	-0.8	-0.8
	Statistically Significant ($\alpha = 0.05$)?	No		No		No	
	Fixed-Time Experiment	-0.7	-0.7	-0.7	-0.7	-0.7	-0.7
	Statistically Significant ($\alpha = 0.05$)?	No		No		No	

Table 25. Statistical Testing of the Standard Deviation of Lateral Lane Position.

		Flash Message vs. Static Message		Flash Line Message vs. Static Message		Redundant Message vs. Non-redundant Message	
		Flash	Static	Flash Line	Static	Redundancy: With	Redundancy: No
Standard Deviation of Lane Position (ft)	Self-Paced Experiment	0.2	0.2	0.2	0.2	0.2	0.2
	Statistically Significant ($\alpha = 0.05$)?	No		No		No	
	Fixed-Time Experiment	0.2	0.2	0.2	0.2	0.1	0.2
	Statistically Significant ($\alpha = 0.05$)?	No		No		No	

Table 26. Statistical Testing of Average Distance Headway.

		Flash Message vs. Static Message		Flash Line Message vs. Static Message		Redundant Message vs. Non-redundant Message	
		Flash	Static	Flash Line	Static	Redundancy: With	Redundancy: No
Average Distance Headway (ft)	Self-Paced Experiment	70	68	69	66	77	81
	Statistically Significant ($\alpha = 0.05$)?	No		No		No	
	Fixed-Time Experiment	83	83	81	86	88	83
	Statistically Significant ($\alpha = 0.05$)?	No		No		No	

Table 27. Statistical Testing of the Standard Deviation of Distance Headway.

<table>
<tr><th colspan="2" rowspan="3"></th><th colspan="2">Flash Message vs. Static Message</th><th colspan="2">Flash Line Message vs. Static Message</th><th colspan="2">Redundant Message vs. Non-redundant Message</th></tr>
<tr><th rowspan="2">Flash</th><th rowspan="2">Static</th><th rowspan="2">Flash Line</th><th rowspan="2">Static</th><th colspan="2">Redundancy</th></tr>
<tr><th>With</th><th>No</th></tr>
<tr><td rowspan="4">Standard Deviation of Average Distance Headway (ft)</td><td>Self-Paced Experiment</td><td>20.2</td><td>19.0</td><td>18.4</td><td>17.6</td><td>21.3</td><td>21.9</td></tr>
<tr><td>Statistically Significant (α = 0.05)?</td><td colspan="2">No</td><td colspan="2">No</td><td colspan="2">No</td></tr>
<tr><td>Fixed-Time Experiment</td><td>23.5</td><td>22.7</td><td>22.1</td><td>15.4</td><td>24.8</td><td>19.8</td></tr>
<tr><td>Statistically Significant (α = 0.05)?</td><td colspan="2">No</td><td colspan="2">No</td><td colspan="2">No</td></tr>
</table>

Table 28. Statistical Testing of Average Maximum Distance Headway.

<table>
<tr><th colspan="2" rowspan="3"></th><th colspan="2">Flash Message vs. Static Message</th><th colspan="2">Flash Line Message vs. Static Message</th><th colspan="2">Redundant Message vs. Non-redundant Message</th></tr>
<tr><th rowspan="2">Flash</th><th rowspan="2">Static</th><th rowspan="2">Flash Line</th><th rowspan="2">Static</th><th colspan="2">Redundancy</th></tr>
<tr><th>With</th><th>No</th></tr>
<tr><td rowspan="4">Average Maximum Distance Headway (ft)</td><td>Self-Paced Reading Time Sessions</td><td>114.6</td><td>108.1</td><td>107.6</td><td>105.6</td><td>119.5</td><td>121.4</td></tr>
<tr><td>Statistically Significant (α = 0.05)?</td><td colspan="2">No</td><td colspan="2">No</td><td colspan="2">No</td></tr>
<tr><td>Fixed Reading Time Sessions</td><td>127.2</td><td>124.7</td><td>117.9</td><td>115.4</td><td>129.8</td><td>125.2</td></tr>
<tr><td>Statistically Significant (α = 0.05)?</td><td colspan="2">No</td><td colspan="2">No</td><td colspan="2">No</td></tr>
</table>

Table 29. Statistical Testing of Average Minimum Distance Headway.

		Flash Message vs. Static Message		Flash Line Message vs. Static Message		Redundant Message vs. Non-redundant Message	
						Redundancy	
		Flash	Static	Flash Line	Static	With	No
Average Minimum Distance Headway (ft)	Self-Paced Reading Time Sessions	47.2	45.6	45.2	44.9	50.6	56.2
	Statistically Significant (α = 0.05)?	No		No		No	
	Fixed Reading Time Sessions	56.3	56.6	55.7	62.8	59.7	56.7
	Statistically Significant (α = 0.05)?	No		No		No	