DEVELOPMENT OF A PERSONAL COMPUTER-BASED SECONDARY TASK PROCEDURE AS A SURROGATE FOR A DRIVING SIMULATOR

A Dissertation

by

STEVEN DALE SCHROCK

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

DOCTOR OF PHILOSOPHY

August 2007

Major Subject: Civil Engineering

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Chair of Committee,	Conrad L. Dudek
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ABSTRACT

Development of a Personal Computer-Based Secondary Task Procedure as a Surrogate for a Driving Simulator.
(August 2007)
Steven Dale Schrock, B.S., Iowa State University;
M.S., Iowa State University
Chair of Advisory Committee: Dr. Conrad L. Dudek

This research was conducted to develop and test a personal computer-based study procedure (PCSP) with secondary task loading for use in human factors laboratory experiments in lieu of a driving simulator to test reading time and understanding of traffic control devices such as changeable message sign (CMS) messages. Using Microsoft® Visual C#®, a PCSP was developed where subjects were shown CMS messages while simultaneously deactivating randomly displayed buttons in an on-screen control panel which served as a secondary loading task. The subject secondary task workload could be varied by increasing or decreasing the rate the buttons appeared in the control panel. The PCSP was designed to:

- Display a wide variety of CMS messages including two phase and/or flashing messages,
- Provide a push-button secondary task that could be varied in button display rate, and
- Automatically store subject performance data such as reading time and button-pressing time for later retrieval and analysis.

One-hundred-twenty-six subjects were tested within the PCSP and in the Texas Transportation Institute's (TTI's) Driving Environment Simulator. The subjects were

subdivided into three subgroups to compare performance between the driving simulator and the PCSP with respect to differences in reading times, comprehension, and preference for alternative CMS messages. The study consisted of comparing reading times, comprehension, and preferences for each of five types of CMS messages with an alternative message. Three different levels of secondary task loading were selected for the PCSP: no secondary task, buttons displayed at a rate of 0.625 button/second, and buttons displayed at 0.909 button/second.

Data analysis revealed that only three instances of statistically significant results were found between the PCSP with no secondary task and the driving simulator out of 41 hypotheses tested. Additionally, only three differences were found for the PSCP with 0.625 button/second secondary task display rate and six for the PCSP at the 0.909 button/second secondary task display rate. The few differences between the three display rates revealed no trends, and indicated that all three of the versions of the PCSP seem acceptable for use in studying CMS messages in order to find comparable results to TTI's driving simulator.

DEDICATION

I dedicate this work to my beautiful bride; your support made all this possible. When I was busy working on this you took care of our boys and twenty thousand other details. When I was stressed you comforted me. When I wondered if I would ever be done you encouraged me. I love you now and forever.

ACKNOWLEDGEMENTS

The successful completion of this dissertation was not a solitary task; while my name is on the cover, it would never have been completed if not for the efforts of many highly-motivating people. Each of these people comprised a team whose mission was to motivate, push, and pull me toward completion. These wonderful people are:

- My bride Andrea: You helped me in every stage of my graduate work. You supported me both financially and emotionally while I struggled as a full-time student. Later, you helped me balance full-time employment, raising a family, and finishing this research. I could not have done this without your support, but more importantly not without your love.
- Mom and Stuart: You always believed in me, always encouraging me to reach my goals.
- Dad: I always knew you were in my corner. Whenever I needed an encouraging word I knew I could turn to you.
- Conrad Dudek: You always pushed me to think of the ultimate contribution of my research and to improve the quality of my efforts.
- Daniel and Pam Fambro: Dr. Fambro helped make me realize that a doctorate was not an impossible dream. He encouraged me while I was finishing my Master's thesis at Iowa State University. Together, the Fambros showed me how wonderful Texas A&M University is; they started me on the right path. I often wonder what form my dissertation would have taken had Dr. Fambro been here to help craft it. May he rest in peace.
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CHAPTER I

INTRODUCTION

There are many areas of transportation engineering where gaining an increased understanding of how drivers react to a new or innovative traffic control device would be beneficial. Traditional studies of this type have relied on implementing a device in limited field situations and measuring driver reactions (1-3). This is clearly an unattractive strategy in situations where the safety of drivers may be degraded. To combat potential negative safety impacts, researchers have expended resources developing high-fidelity driving simulators to mimic normal driving situations. In a driving simulator, a subject's understanding and reaction to a new traffic control device, plan, or message can be measured with minimal risks (4-6).

However, in spite of the potential safety advantages inherent in driving simulators, there are drawbacks to simulator-centered studies. There are only a limited number of driving simulators available for use nationwide, and as these are generally immobile systems, obtaining a sample of human participants with a wide geographic distribution would be difficult. Also, the cost of programming and operating a driving simulator is high relative to other study methods, and may be cost-prohibitive for many types of studies. In addition, subject vertigo and nausea are increasingly recognized as drawbacks to collecting data in a driving simulator.

Other less-costly options may be used to answer specific research questions. For example, in recent years researchers have used personal computer (PC) -based research studies to determine reading time and comprehension of alternative changeable message sign (CMS) messages (7). Some researchers believe that a driving simulator is

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This dissertation follows the style of the *Transportation Research Record*.

superior to PC computer methods because of the inherent similarities between "driving" in a simulator and actual driving on a highway. Also, there is occasional skepticism of PC-based research studies that do not include a secondary mental task to occupy a portion of subjects' attention, just as would driving a vehicle or operating a driving simulator. Without the secondary task workload it could be argued that these subjects are less like drivers of a vehicle and more like passengers, as they can devote all of their attention to reading messages. However, others believe that results obtained from a PC-based approach are valid. To reconcile the different opinions, there was a need to compare conclusions reached and results obtained from driver simulator and PC-based studies. In addition, a proven task-loading technique for application to PC studies was needed.

PROBLEM STATEMENT

A new PC study procedure (PCSP) was needed for use in traffic sign message-reading human factors experiments that includes a secondary task that would produce results similar to that from fixed-base driving simulators. Ideally, a PCSP that provided the same research findings as a driving simulator would allow additional options for future research that attempt to take driving workload effects upon driver reading time and comprehension into account.

Previous PC-based studies can be used as a starting point in terms of programming and visual characteristics. For example, studies by Dudek, et al. were conducted without a secondary task, but were still useful in determining the level of reading time and comprehension of various CMS messages (7). These studies were also useful in determining subject preferences between various ways of displaying information. Other PC-based studies of CMS messages included secondary tasks to increase the mental workload of the participants, but in general these tasks appear to have been arbitrarily selected, and did not reflect the type of mental and physical task loading representative with normal driving conditions (8). In fact, there exists a large variety and type of secondary tasks that have been used in human factors studies in general, not specific just to PC-based message-reading studies; determining which are appropriate to replicate the mental workload associated with a driving simulator is not intuitive (9).

RESEARCH OBJECTIVE

The primary goals of this research was to develop and test a PCSP and to determine levels of subject workload during which the same research findings would be reached regarding differences in reading time and comprehension of alternative CMS messages to those reached from driving simulator studies. The specific objectives for this research were to:

- Develop a task-specific computer program to measure subject reading time and comprehension of CMS messages. The computer program needed to be able to test subjects under a base secondary task, vary the workload associated with the secondary task, and automatically record the time that subjects viewed the CMS messages;
- Identify levels of subject workload that the PCSP can provide, and select a range for further testing;
- Collect reading time and comprehension data from subjects tested within the PCSP and also in a driving simulator, with equal portions of subjects tested at each level of workload selected for testing within the PCSP;
- Conduct statistical analyses on the difference in reading time and comprehension data between the driving simulator and the PCSP to determine which PCSP level of subject workload had the least difference from the driving simulator;

- Determine the research conclusions that were reached using a driving simulator and compare these results with the research conclusions that were reached using the PCSP at each of the selected levels of subject workload; and
- Provide detailed results of the performance of the PCSP and recommendations for future PCSP sign message-reading time and comprehension studies.

The steps followed to complete this research are shown graphically in Figure 1. By developing and demonstrating that the PCSP can provide similar CMS message reading time and comprehension results as a driving simulator, the PCSP could be used as a low-cost proxy for the more expensive driving simulator study method.

ACKNOWLEDGEMENTS

The research described herein was funded in part by two different research projects conducted by the Texas Transportation Institute (TTI). The first was a Federal Highway Administration (FHWA) Traffic Management Center Pooled-Fund Study entitled "Impacts of Using Dynamic Features to Display Messages on Changeable Message Signs." The emphasis during the driving simulator data collection activities focused on comparing CMS messages presented both in static mode and various types of flashing presentations to determine whether the flashing feature could improve the message transmission and retention to the driving public. Therefore, the sign presentation focused primarily on specific formats of CMS messages, and did not run the entire gamut of sign formats. It is through this project that funding was available to pay for 50 percent of the subject participation in the driving simulator.

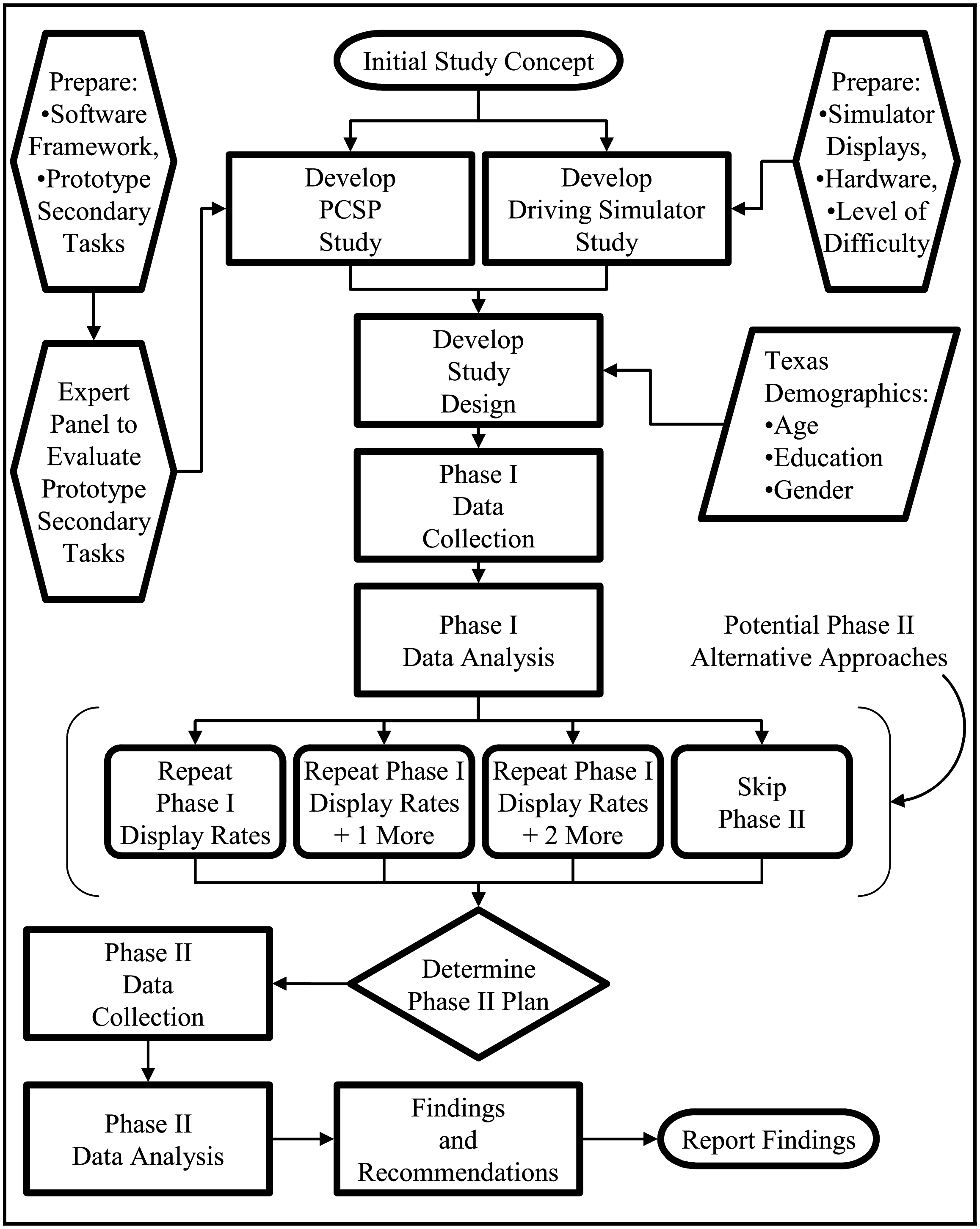


Figure 1. Flowchart of Research Plan Showing Alternate Plans for Phase II of Data Collection

The second research project was a Southwest University Transportation Center study entitled "Development of Secondary Task Tools for Laptop Computer-Based Driver Surveys to Correlate Results with the Driving Simulator," which primarily focused on the development as part of this dissertation of a PCSP for future research studies. It is through this project that funding was available to pay for 50 percent of the subject participation payments for the driving simulator sessions and 100 percent of the subject participation payments for the PCSP sessions.

CONTRIBUTION OF RESEARCH

A laboratory approach was utilized to test the comparison between a driving simulator and a new PC-based system to collect subjects' reading times, comprehension, and preferences of CMS messages. By developing a computer-based study alternative to a driving simulator study, the potential exists to collect data on reading times and comprehension of CMS messages more quickly, more efficiently, and over a wider geographic area than can be done with a driving simulator alone. Perhaps more importantly, lowering the time and cost of CMS message research will allow for more rapid answers to a wider variety of future CMS-related research questions, which in turn can lead to improved signs on the roadside. The procedure can be used to improve the state-of-the-practice in traffic management through the development of improved signing, including such sign formats as traffic incident management messages, AMBER (America's Missing Broadcast Emergency Response) alert messages, and special event signing.

ORGANIZATION OF DISSERTATION

This dissertation is organized into six chapters. In Chapter I, the issues related to collecting human factors data related to CMS messages are introduced, and the ultimate goals of conducting this research are discussed. In Chapter II, a review of the pertinent literature is provided and is used to summarize the salient points that were found. The development of the PCSP, as well as the driving simulator hardware, software, and configuration for this research are presented in Chapter III. The experimental design, documentation of the techniques used in the data collection process, and research hypotheses used to analyze the data collected for the study are presented in Chapter IV. In Chapter V the results of the statistical analysis and the hypothesis tests are shown. Finally, the results of this research, conclusions, and recommendations from these findings are presented in Chapter VI.

CHAPTER II

LITERATURE REVIEW

The first step in this research was to conduct a literature review to determine the findings of previous related studies. Previous research was reviewed to provide a better understanding of the history of human factors research, CMS message development research, and driving simulator-related research. The review also served to determine the extent of the gap that exists in the literature that can be filled with the research reported herein.

The review of the literature was divided by subject. First, a review regarding human factors theory is presented. Second, research into potential confounding factors that can affect human factors-related research is presented. Third, human factors research that relates directly to driving is presented. Fourth, a discussion of research that utilized driving simulators is detailed. The chapter ends with a summary of the salient points discovered during this review.

This literature review was not intended to encompass all human factors-related research, but rather, was intended to provide a summary of the prominent research that can contribute directly to the research objectives of this dissertation. References were identified by searching online library databases such as WorldCat FirstSearch and Transport, as well as the Texas A&M University Evans Library and TTI Library Services.

HUMAN FACTORS ISSUES

Human factors is the study of how human beings interact with the environment, especially with engineered devices. Early work in human factors work was conducted to understand human limitations when using complex engineering systems such as radar displays and aircraft cockpit controls. An understanding of how individuals function in their environment in response to various stimuli can lead to the improved design of engineered systems (10). Studying how humans accomplish multiple tasks such as driving and simultaneously reading CMS messages can provide insight into the development of more appropriate messages that can be more easily detected, read, and understood by drivers.

Secondary Task Use in Human Factors Studies

Early work in secondary task techniques was based on the belief that using secondary tasks to determine spare mental capacity were fairly straightforward. Senders summarized the underlying theory in 1970, stating that:

- The operator's mental processing is a single-channel system,
- That channel has fixed capacity,
- There is a way of measuring the amount of this capacity that is taken up with the mental demands of any task, and
- The mental processing workload of multiple tasks conducted simultaneously is linearly additive (11).

Later researchers found that mental task capacity is more complex. Based on theoretical constructs by Wickens, the human brain can be thought to have three basic processing areas: auditory, visual, and spatial (12). The vast majority of the driving task requires only the visual and spatial portions of the mental workload structure. Under normal driving conditions, a driver has merely to scan the roadway ahead to gather enough information to safely operate the vehicle (13-15). A secondary task that is used to mimic this condition should provide similar kinds of mental loading as that experienced by actual driving, or driving in a simulator.

Wickens suggested in a 1985 publication that drivers have a finite capacity for their mental processing resources. Mental processing resources can be allocated to several tasks only at the cost of increased error or decreased efficiency in the performance of the tasks being performed (16). Wickens also stated that mental processing errors or inefficiencies were most significant when the competing tasks use the same sense modality. For example, when asked to attend to two simultaneous tasks involving hearing, a subject would need to focus more attention to successfully complete both tasks. If the subject cannot devote enough resources to complete both tasks, degraded performance can be expected in one or both tasks. Conversely, two tasks that access different sense modalities – such as hearing and visual scanning – are less likely to conflict because they are processed using different portions of available mental capabilities. Wickens' mental resource theory is shown in Figure 2. In this theory, mental processing resources are subdivided into several smaller regions, each reserved for specific uses. The mental processing resources that are available in one region of the model cannot be used to process information of another type.

Wickens' model is divided in three ways: codes, modalities, and stages. The two types of codes are spatial and verbal. Spatial information is non-language-based information relating to distances and direction, such a lane position or headway distances between vehicles. Verbal information is communication-based information including verbal or written language or symbols. Modalities are simply the manner in which the information is conveyed, either as visual communication or as auditory communication, and would relate directly to whether a person would receive the information from the eyes or ears. Stages indicate how a person's mental resources are structured to process the information, and recognizes that some resources are reserved for receiving information (encoding), processing the information (central processing), and acting on the information (response).

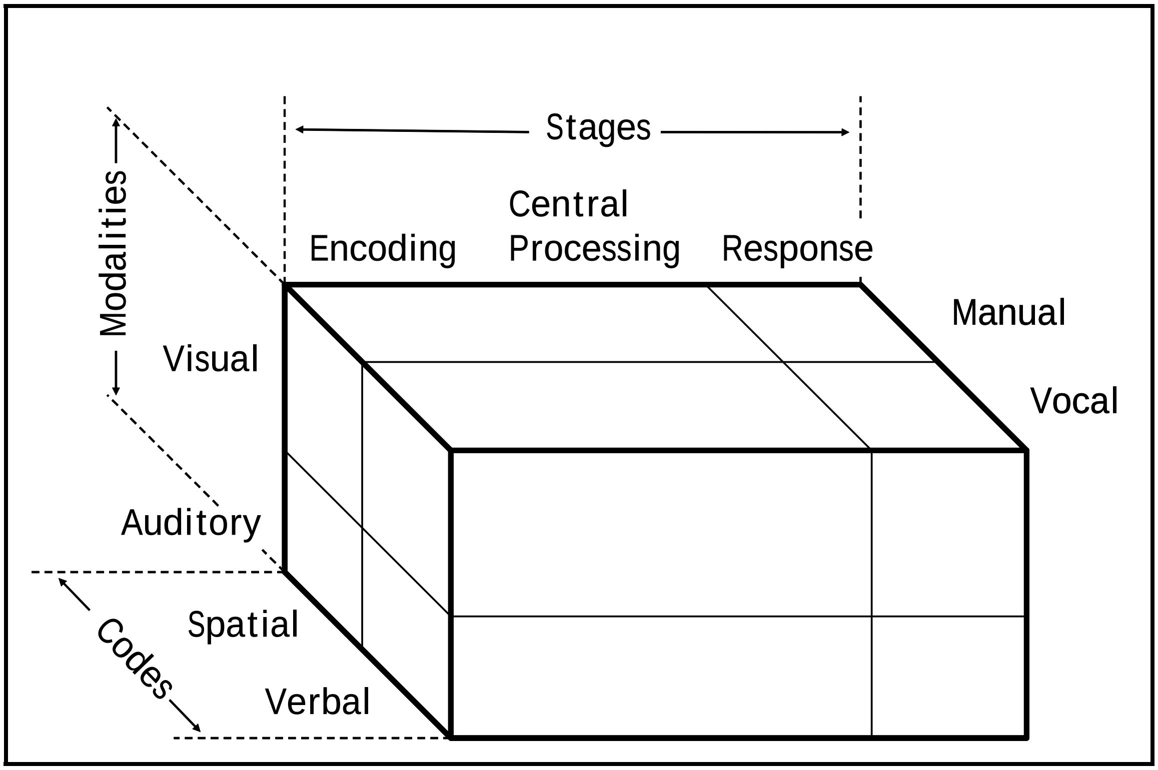


Figure 2. Wickens' Proposed Structure of Processing Resources (16)

Wickens explained that if tasks use different regions of mental processing resources then these tasks can be successfully performed simultaneously, but if they access the same resources then they conflict and are likely to cause interference (16).

The very definitions of mental workload are not universally accepted by experts. Even among psychologists, mental workload is presented as a multifaceted concept, with several definitions. Several common definitions of mental workload include:

- The discrepancy between system input and the system's capability of handling that input (17),
- The subjective state of the subject's stress level (17),
- The demand on a subject's attention by performing a set of tasks (17),

- The level of busyness of the subject (18), and
- The aggregate of the task demands placed on an operator from the system of which he or she is a part (19).

Additionally, the methods used to measure mental workload are not consistent throughout the literature. In 1979, Ogden, Levine, and Eisner synthesized human factors literature that included secondary task studies, and found that there were twelve identifiable classes of secondary tasks (20). These classes were:

1. Choice reaction time - the amount of time taken to make a choice;
2. Classification (or identification) - the time taken to categorize some unit of presented information;
3. Detection (or monitoring) - the time needed to spot some change in the visual environment;
4. Memory - retaining some bit(s) of information in short-term memory;
5. Mental math (or problem solving) - performance of math or logic problems;
6. Piano playing;
7. Reaction time - the time to respond to some stimulus;
8. Shadowing - making an object controlled by the subject match a changing stimulus;
9. Tapping - maintaining a constant unvarying rhythm;
10. Task battery - performance of a wide variety of tasks in a short time;
11. Time estimation - estimating the amount of time that has passed, such as performing a task at regular intervals; and
12. Tracking - following some moving stimulus.

Their synthesis did not suggest a single best task or class of tasks for the measurement of workload, however.

Secondary Task Studies as a Tool to Measure Subject Workload

One of the definitions of mental workload given previously is, "the relationship between workload capacity and task demands" (21). When subjects attend to a single task, they are able to focus almost all of their total supply of attention to the task. As a result, performance should be high, as long as the demand is less than the subject's mental workload capacity. However, with the addition of a second task, the workload increases somewhat. Even at levels below workload capacity, performing multiple tasks can result in inefficiencies in performing each task, which can result in errors and/or degraded performance.

However, it is difficult to quantify workload. Mental workload capacity is linked to the abilities of the individual subject, and the specific task or tasks being studied (22). In spite of this, researchers have successfully used the presence or absence of a secondary task as a way of measuring the workload required for a primary task (20).

In 1973, Kahneman, Ben-Ishai, and Lotan reported on testing of professional bus drivers for their ability to perform multiple tasks, and compared that with their accident history (23). They found that a subject's ability to deal with divided attention tasks had a negative relationship with the likelihood of having vehicular crashes on their driving record. The researchers concluded that bus driver applicants that could successfully perform two or more tasks simultaneously had the potential for better safety records if hired.

Literature also exists where researchers have compared the complexity of tasks rather than the number of tasks that are performed. McDowd and Craik found in 1980 that successful task performance decreased as the complexity of the task increased (24). Similarly, Walker, et al. found in 1990 that simpler secondary tasks were more successfully performed than complicated ones during a study on in-vehicle navigation systems (25). McFarland, Tune, and Welford found in 1964 that a trade-off existed between time and errors made while performing multiple attention tasks (26). Specifically, if time was held constant, the error rate was found to increase with increasing task complexity. Conversely, if the allowable error rate was held constant, it generally took subjects longer to complete more complex tasks.

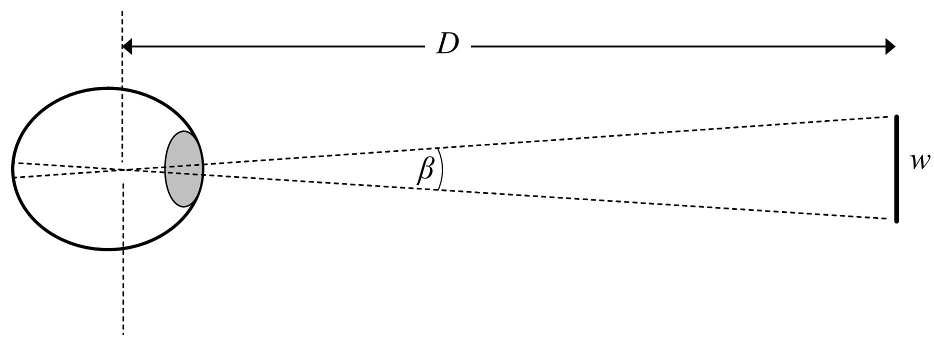
Vision Limitations as a Human Factors Concept

Several interrelated issues are present in dealing with subject's detection, reading, and comprehension of traffic signs in general and CMS messages in particular. These issues include visual acuity, change blindness, information processing, and communication theory. In addition, there are several age-related and gender-related issues that have been researched to determine if a subject's ability to perform multiple simultaneous tasks is affected. These issues are summarized below.

Visual Acuity

Visual acuity is the capacity to differentiate the fine details presented in one's field of view (27). The minimum dimension of an object that can be correctly viewed by a subject is normally used to determine visual acuity. Dimensions used to quantify visual acuity normally are units of length of the minimum object and the visual angle that is subtended at the eye by the object. A graphical example of visual acuity measurements is shown in Figure 3.

Several factors affect the visual acuity of an object. These can be divided into two basic categories: 1) properties of the object being viewed, and 2) properties of the human eye. Properties of the object being viewed include: contrast of the object to its background, intensity of the stimulating light, and stimulus duration. These factors are all applicable to the basic premise of target search and detection. Bryam found in 1944



D = Distance to Object
w = Minimum Dimension of Object
β = Angle Subtended by Object on Eye

Figure 3. How Visual Acuity Is Measured (27)

that thin lines displayed against a high-contrast background were detected as easily as a thicker line displayed against a low-contrast background (28). In instances where the object was viewed for a short time, the detectibility of the object was directly related to quantity of light that arrived in the eye over the detection time (29,30). Bryam indicated that if observation of an object is the desired goal, then adequate viewing time should be provided and the object should have a high visual contrast with its background.

Properties of the human eye that effect acuity include: clarity of vision, location on the retina where object image is displayed, size of the pupil, state of adaptation of the eye to dark (in reduced-light conditions), and eye movements. The size of the pupil, eye movements, and, eye adaptation are clearly related to the amount of light reflected off the object that is displayed upon the appropriate receptors in the eye. Helmholtz first described acuity in terms of the concentration of cones and rods in the fovea of the eye in 1925, and postulated that this was the reason that visual acuity is increased in the fovea compared to the visual periphery (31).

Another important issue is the detection of an object moving through a subject's visual field. This would be manifested if the subject were at rest and the object moving, or if the object were still and the subject were in motion. The latter case would be true in most driving situations where a driver must detect a traffic sign or other roadside feature. In 1966, Burg tested the visual acuity of 17,500 subjects between the ages of 16 and 92 to determine how dynamic visual acuity - the ability to detect fine detail on objects that are in motion relative to the subject - changed throughout the test population (32). He determined that dynamic visual acuity declined as the relative speed of target increased. He also found that the ability of subjects to discern targets degraded with age.

In a 2004 study, Atchley and Dressel examined the functional field of view to determine how it changed while performing a secondary task (33). The researchers found that when occupied with two complex tasks of cell-phone conversations while looking at driving video, subjects took three times as long to identify a particular target than subjects that were not using cell phones. This is an indication of reduced functional field of view when occupied with a secondary task. In other research from 1998, Owsley, et al. found a 230 percent increase in crash risk with a 40 percent reduction in functional visual field (34).

Change Blindness

Another of the limitations of human visual processing is the phenomenon of change blindness. Rensink defined change blindness as an apparent inability to recognize changes in the visual scene in a subject's field of view "even when [the changes] are large, repeatedly made, and anticipated (35)." While this may seem contrary to what humans perceive as the way they view the world, extensive research has shown that humans often miss large changes in their visual field even when at or near the area of foveal view (36-38). When a change happens in one's peripheral vision, or happens when one blinks, glances away, or is otherwise distracted, detection of the change are even more difficult (39-43).

Looking Time and Familiarization

Studies have been conducted to better determine the relationship between the amount of time a subject looks at an object or text and the extent to which that subject is familiar with that object or text. Research on looking time and familiarization is related to the current research topic as it addresses how looking time changes as a subject is exposed to the same sign multiple times.

In 1957 Berlyne tested subjects exposed to simple line drawings for short exposures of 0.14 second (44). The subject could control the number of times that they could see the picture, and the researchers were interested in the number of times the subject chose to view a glimpse of the picture. Researchers found that subjects were more likely to view a picture an increased number of times if it:

- Was novel (an odd or unexpected combination of images, for example);
- Was part of a meaningful sequence, defined as the gradual development of a meaningful figure by successive addition of parts;
- Was a complex image; or
- Was asymmetrical.

Berlyne investigated this concept further and found that consistently repeating one visual stimulus when two stimuli were presented at a time side-by-side would lead subjects to spend less and less time looking at the repeated stimulus.

McReynolds also conducted early work in this area by studying schizophrenics in 1956 (45). He had subjects review color slides of animals for ten seconds each. After a ten minute rest they were shown another set of slides, with one-third being repeats from the first set. McReynolds found that subjects spent more time looking at unfamiliar pictures than they were for the repeated pictures.

Leckart conducted a similar study in 1965 by showing a series of color slides of landscapes to 240 college students (46). The students were subdivided into eight groups of 30 subjects each. Two groups were used as controls, and the other six were used to determine changes in looking time when provided various levels of familiarization with the initial slides. Subjects were presented with initial slides and were then either shown a second set of slides (containing some repeats from the first set) immediately or were shown the second set after a 48 hour rest. Leckart showed that when subjects had ample time to familiarize themselves with the images in the first portion of the experiment, there was a reduction in looking time for those images that were repeated 48 hours later. However, when familiarization time in the first portion was limited to less than 10 seconds, looking time in the second portion for repeated images was not significantly different from previously unseen images. Leckart determined that 48 hours was insufficient time to completely erase the effects on looking time of previously viewing an image. This relationship for a 48-hour rest was also found in a study by Cantor and Cantor from 1964 (47).

COMMUNICATION AND PROCESSING OF VISUAL INFORMATION

At the most basic level, modern communication can be divided into three phases, each with potential obstacles that must be overcome (48). First, there are the technical issues dealing with communication, including the equipment that is used to convey the information, such as the specifications of a CMS, radio, television, or however the message is being broadcast. Second, there are the semantic issues of how to properly structure the message so that the intended meaning is discerned by the receiver of the message. Third, there is the issue of how effective the message is at getting the person or people who receive the message to act on the information they receive. The study of communication processing involves communication theory and information theory.

Communication Theory

Communication in its most basic sense is successful information transmission from a source to a destination. This most general model was presented by Shannon and Weaver in 1963 (48). Their conceptual model consisted of the source and destination of the information, but also the transmitter and receiver, the message, signal sent and signal received, and noise sources. This is shown graphically in Figure 4. There are three main points along the communication path where the message can be misinterpreted or altered. First, there may be a difference between the message intended from the information source and what is actually communicated in the signal. Second, as the signal is being transmitted to the intended destination, outside forces – collectively referred to as “noise” – can interfere with the message, reducing or otherwise changing the signal into the received signal. Third, the receiver of the signal may further change the message by interpreting all or part of the message incorrectly, so that the final message that reaches the destination may no longer retain all of the components of the original message.

Information Theory

Additional complexity arises when a subject is asked to read alpha-numeric text in addition to merely identifying that it exists. Cole and Jacobs hypothesized in 1978 that because longer text messages would encompass more visual angle than what could be seen with foveal vision, reading times would increase as the amount of text to be read increased (49). The researchers tested reading times of subjects for sixteen standard highway text signs commonly found in Australia, where the research was conducted. They found their hypothesis to be correct, and additionally found that subjects are limited to reading one line of text at a time, even though two or more could theoretically fit within the area of a subject’s foveal vision.

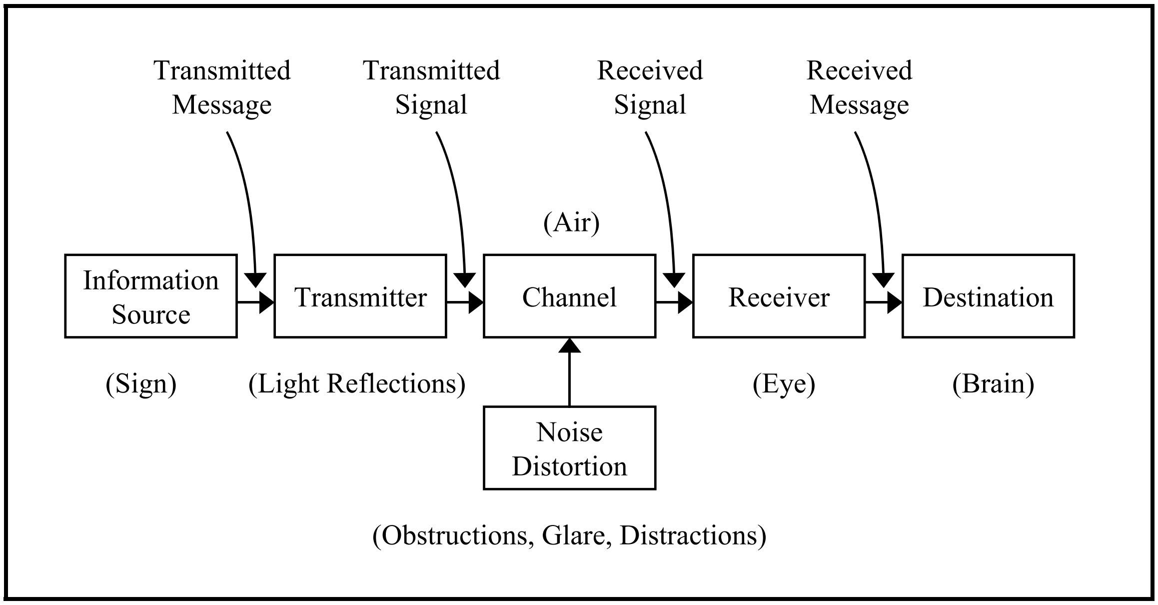


Figure 4. Message Transmission Model (48)

Other researchers have studied the ability of drivers to read text from guide signs while driving. In 1942, Mitchell and Forbes estimated that drivers would be able to read text from traffic signs at a rate of three to four words per second (50). Rockwell, Bhise, and Safford determined in 1970 that subjects could read five to six words per second in actual driving conditions (51). Possibilities of why the rate of word-reading may be different between these two studies may be the size and placement of the signs or the placement of key words in the messages. Another possibility is that the subjects exhibited different reading and scanning habit in real driving conditions compared to controlled laboratory studies. These differing rates of sign reading capabilities underline the difficulty in determining the appropriate amount of information that can be appropriately relayed to drivers at one time.

INFORMATION OVERLOAD COPING STRATEGIES

Several different workload models have been developed to understand how humans deal with situations of high information load and times when mental workload demands are in excess of a person's ability to process that information. In aviation, the training to help pilots deal with high information demands as "situation awareness;" in transportation a similar strategy is referred to as "load shedding." Both of these are useful in understanding how people intuitively deal with and prioritize incoming information.

Situation Awareness

Situation awareness is a concept originally developed to help combat aircraft pilots manage the information load required to successfully fly complex aircraft. In 2006, Strater and Endsley extended this concept more broadly to include all pilots managing the complex environment of modern commercial aircraft (52). Because pilots have many more instruments and displays than they can view at any one time, situation awareness is a method of managing that information in order to provide the pilots with enough timely information to safely fly the aircraft. In short, situation awareness follows the basic strategy for operating effectively and being able to make correct decisions about which information is critical and must be processed in situations when access to information exceeds a pilot's ability to process all of the information. There are several strategies that are used:

- Pilots are trained to maximize their ability to retain the information in order to build a realistic mental model of the situation. This training includes simulator as well as flight time in a real aircraft.
- Pilots are trained to scan the most critical safety information on the cockpit instrument panel more often than less safety-critical information.

- Cockpit control panel instrumentation design can assist in situation awareness in that the most safety-critical information should be intuitive and placed in a prominent position just in front of the pilot. Conversely, less safety-critical information is placed away from the pilot's central view (52).

The concept of situation awareness has since moved beyond the realm of piloting aircraft, and now can be found in many situations where critical decisions need to be quickly made, including nuclear power plant operators (12) air traffic controllers (53), the medical profession (54), other areas of the military such as combat infantry (55), and even driving (56).

Positive Guidance and Load Shedding

Positive Guidance is a concept developed to help traffic engineers understand the mental limitations and strategies drivers use when searching for and processing information (13-15). Developed by Alexander and Lunenfeld in 1975, Positive Guidance includes a hierarchy of driver workload in a framework that encompasses three levels of driver performance and decision making: control, guidance, and navigation. This hierarchy is shown in Figure 5.

The navigation level of driving is described as "the driver's ability to plan and execute a trip." This includes map reading, determining the proper route, and making route changes depending on current situations.

The control level in the Positive Guidance concept includes activities such as steering, accelerating, and braking of the automobile. The guidance level consists of selecting safe speed and lane placement while driving in the traffic stream.

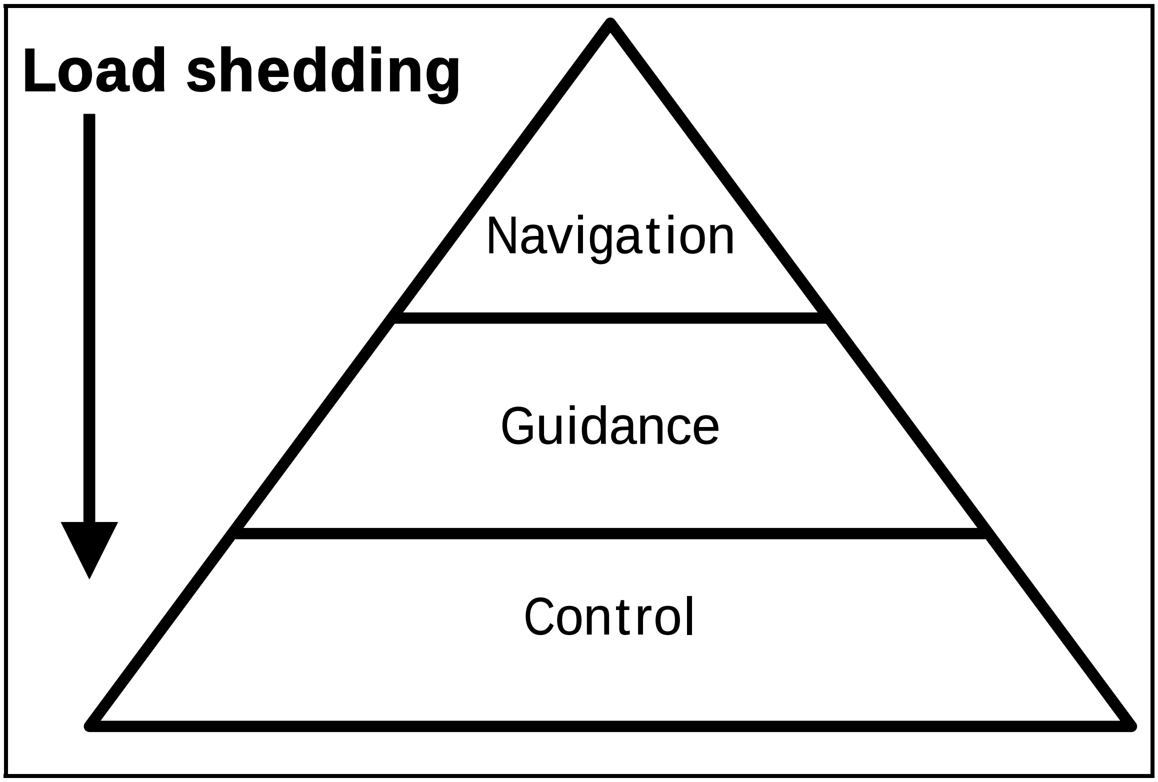


Figure 5. Positive Guidance's Load Shedding Conceptual Model (15)

The vast majority of the driving task requires only the visual portion of the mental workload structure, although the senses of touch, hearing, and in some cases even smell can aid a driver. Under normal driving conditions, however, a driver has merely to scan the roadway ahead to gather enough information to safely operate the vehicle. As more visual data are presented to a subject, the amount of work required to successfully observe and comprehend all the visual stimuli increases. Humans attend to various visual stimuli one at a time in short glances, so it is possible to quickly overload a subject with too many visual stimuli if many sources of information require processing simultaneously.

Most drivers can relate to the feeling of being provided too much information at certain times, such as at unfamiliar freeway interchanges or when temporary signing and permanent signing is placed in close proximity to each other. In the worst cases, large amounts of information are provided in a short time, taxing a driver's ability to read and process all of the information. Most drivers quickly and intuitively perform "load shedding" as a way to concentrate on what is perceived as the most critical bits of information at the expense of other information (13). Load shedding is similar in nature to situation awareness: drivers who find themselves in a situation of information overload tend to focus on the information that they believe will maximize the likelihood of safely traversing a section of roadway. As shown in Figure 5, Alexander theorized that in these situations drivers will first shed navigational information (long-range route information) and then guidance information in order to control their vehicle and guide it through the immediate short-term driving environment.

POTENTIAL SUBJECT CONFOUNDING FACTORS

There is evidence in the literature that some characteristics of subjects could affect the outcome of reading time and comprehension studies. These include age, gender, and education factors.

Age-Related Human Factors Issues

It has been reported that elderly subjects participating in reading and comprehension studies may have degraded performance compared to their younger counterparts. There are possible reasons mentioned in the literature: degraded vision capabilities and degraded mental processing capabilities.

Age-Related Visual Characteristics

In 1985 Evans and Ginsburg studied the ability of subjects to correctly determine the difference between a standard W2-1 intersection warning sign and a W2-4 T-intersection sign at different distances, as shown in Figure 6 (57). Subjects were selected to fill two age groups, a younger group of 19- to 30-year olds and an older group consisting of 55- to 79-year olds. The researchers found that contrast sensitivity – the ability to discern an object relative to the color contrast with its background – was significantly poorer for the older group. As a result, the younger group was able to see and correctly identify the fine differences between the two signs at greater distances than the older groups.

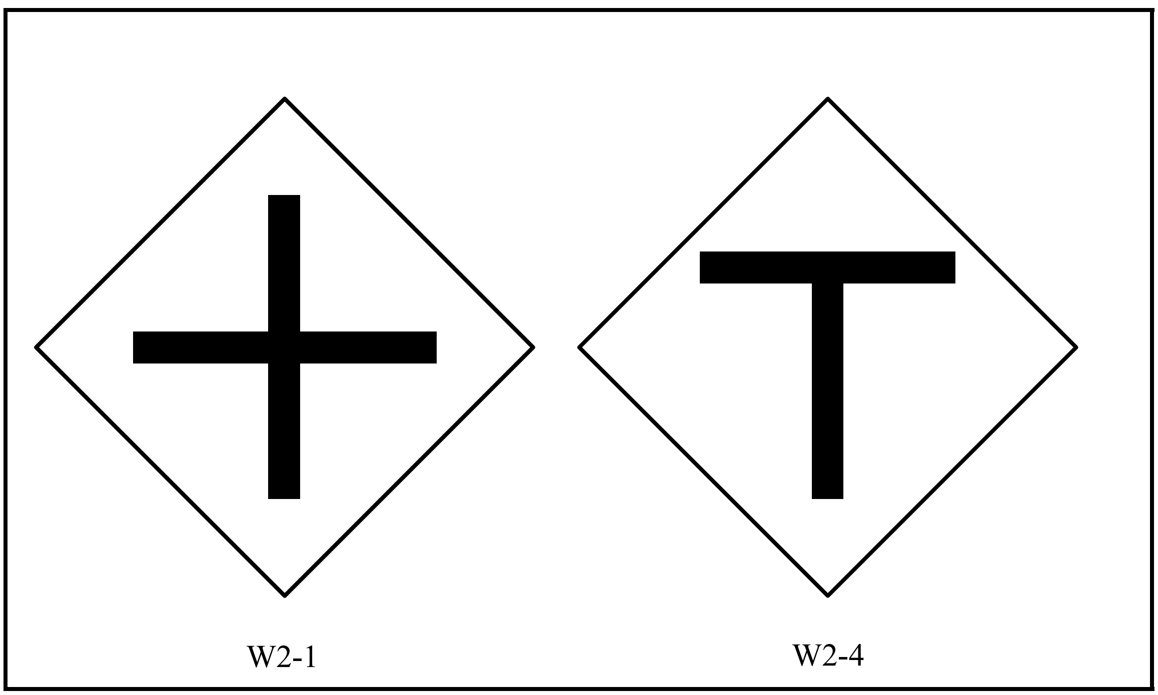


Figure 6. Illustration of a W2-1 and a W2-4 Intersection Sign (57)

In a similar study from 1983, Owsley, Sekuler, and Siemsen examined a wider age group from 18 to 87 in order to determine the extent to which contrast sensitivity changes throughout adulthood (58). Subjects were tested for visual contrast sensitivity with a pre-programmed, computer-controlled television display, which showed a static sinusoidal vertical grating that gradually increased in the number of cycles per visual degree until the subject would report seeing individual bars. The researchers reported that in general, contrast sensitivity remained high and similar for subjects between 18 and 40, but that after about age 40 the contrast sensitivity values steadily degraded as ages increased. Subjects around 70 years of age had contrast sensitivity values about 50 percent of those 40 and younger.

Age-Related Mental Workload Characteristics

There is evidence in the literature that aging has a detrimental effect on a person's workload capacity. Craik found in 1977 that "one of the clearest results in experimental psychology of aging is the finding that older adults are more penalized when they must divide their attention (59)." Other researchers have also identified this relationship, indicating that increased age by itself can have the same result as a secondary task (24,60,61). Put another way, an older subject could be expected to have more difficulty performing a divided attention workload task than a younger subject.

Brouwer, et al., performed a secondary task study in 1991 to compare performance among age groups (62). Subjects were asked to perform a driving task in a driving simulator while counting dots that appeared on the screen and report whether an even or an odd number of dots were present. The researchers found that as the subjects' age increased, it was more likely that the subjects would report incorrectly. They also found that a manual response (e.g., writing down the response) had a greater negative effect than a verbal one.

In 1989 Kochaar studied the variation in response time and accuracy between a young group of subjects (ages 18 to 29) against an older group (ages 52 to 63) (63). Each of the subjects was placed in front of a work area, and was required to take pins from a holder and place them in one of sixteen holes, as directed by the experimenter. The subject repeated this task 1,200 times, with the time taken to identify the appropriate hole – some of which were far to the side of the workstation - and the time to perform the task recorded. Holes that were more at the periphery of the work console were considered a higher workload task, both in terms of identifying the proper pin location and performing the physical task of placing the pin. It was found that the older group identified the correct hole more slowly, but also exhibited a “start-up” lag time before performing the higher workload movements. Kochaar stated that the start-up lag time could be caused from reduced task sharing workload capabilities from older subjects.

The findings of the reviewed literature in this section indicate that in any experiment using secondary tasks as a measure of workload the researcher should anticipate an age effect. However, not all age-related effects are reportedly detrimental to task performance. Some age-related effects seem to benefit people as they age. Specifically, the ability of drivers to predict potential sources of risk in the driving process may increase the ability of older drivers to detect and avoid hazards. Pradhan et al. found this to be true when testing subjects in a driving simulator in 2003 (64). By blanking out portions of the driving simulator screen the researchers obstructed some of the subjects’ visual field. The researchers used this technique to hide several potential hazard locations and recorded eye movements of subjects as they operated the driving simulator. Older drivers were significantly more likely to glance at hazard-prone locations of the visual field even when occluded, while younger drivers did not. This seems to indicate that older drivers are able to use experience to better understand the driving environment to avoid hazards, which may compensate for reduced physical characteristics.

One focus of driving workload research includes the addition of in-vehicle displays and how well drivers can access the information presented on the display while also driving. In 2001, Mourant, et al. examined just this scenario with the use of a fixed-base driving simulator to increase the safety to subjects (65). In their study, the researchers tested twenty subjects (ten older and ten younger) and measured their ability to correctly recall the information presented on an in-vehicle display and remain in their simulated travel lane on a curvy highway scene. The researchers determined that older drivers were less able to attend to both tasks when they had to look into the vehicle interior to read the in-vehicle display. Specifically, as a group the older drivers were 10 to 15 percent less likely to correctly recall the information. Additionally, when a younger subject actually departed their lane the average lane position error ranged from 0.4 to 0.7 meter, while for older drivers this increased by up to 85 percent to 1.1 to 1.3 meters. These researchers suggested that the configuration of the in-vehicle display could pose older drivers with more difficulty than younger drivers. When the information was superimposed directly onto the driving scene the older subjects' performance improved, indicating that head-up display-type displays could be more appropriate for older drivers.

Gender-Related Human Factors Issues

There appears to be little relationship between performance of divided attention tasks and gender. Tsimhoni, et al. did not find a relationship in their 2000 research on heads-up displays (HUDs) (66). The researchers tested sixteen subjects (eight male and eight female) in a driving simulator equipped to provide word-based HUD information on the windshield of the vehicle. While the focus of this research was to determine optimal placement of the HUD information, they researched several subject variables, including gender. Results were tabulated for response time, which these researchers used as a measure of processing time to complete the secondary task. They concluded that no statistically significant differences were noted for response time due to gender.

Dulas also found in 1994 that gender did not have a significant effect on secondary task performance while driving (67). Dulas' research was conducted to determine the proper placement of in-vehicle dash-mounted displays. Driving an automobile on a closed course was the primary task, while simultaneously reading digits from a movable display and entering those digits into a keypad were combined to form the secondary task. Dependent variables measured were lane deviation, response time to say the in-vehicle display’s digits aloud, and the proportion of correct responses. Dulas found that gender did not have a significant relationship with any of these variables. Likewise, gender did not have a significant difference in studies by Dudek et al. (7), Dudek, Schrock, and Ullman (68), and Ullman et al. (69).

Education-Related Human Factors Issues

Little evidence was found in the literature directly correlating education levels with the ability to read and comprehend traffic messages, although a reasonable consideration of the issue seems to indicate that at extreme levels such a relationship should exist. Benson did find that in a series of focus groups and one survey on the content of CMS messages in 1996 that there was a slight negative correlation between education and the perceptions of the CMS messages presented (70). Less educated subjects were somewhat more likely to state that they preferred simple safety messages such as “Drive to Survive,” rather than more specific and therefore more complicated signs. Benson considered that this could mean that more educated subjects did not like being “lectured to.” Another possible explanation not mentioned by Benson could be that more simplistic and general messages are easier to read, and therefore more likely to be approved of by less-educated groups. This seems to fit with another of Benson’s findings: less educated subjects were more likely to support the idea of displaying video screens of downstream traffic conditions or traffic condition maps. Taken together, there seems to be a correlation between education levels and subjects’ desire to read complicated messages about traffic conditions; less educated subjects appeared more likely to have simple generic CMS messages or graphic displays that do not require language at all.

In 2000, Dudek et al. conducted a portable PC-based study to determine how well subjects could understand various CMS phrases and message sets (7). The researchers displayed 42 messages to a total of 260 subjects from five Texas cities. Of interest to the researchers was the amount of time required for subjects to read and understand messages, and whether subjects could correctly recall the message immediately after reading it. Subjects were demographically grouped by education to match the level of educational attainment of Texans, which at the time of the research was approximately 25 percent each of the following ranges: no high school diploma, high school graduate (only), some college (including trade school and junior college graduates), and college graduates. Subjects viewed messages displayed on the PC screen, and were able to view the message for as long as desired – a self-paced study – and when they were ready to answer questions about the message they simply clicked the space bar. The computer automatically recorded the reading time for each sign. The researchers did not uncover any education-based trends for any of the signs displayed.

In an extension of the research of Dudek et al., Ullman et al. in 2005 conducted additional research into CMS messages (69). In this study, the researchers tested a total of 192 subjects in six Texas cities for a variety of new and/or alternative CMS messages that had come into use since the 2000 study, including such areas as flooding, ozone alerts, and missing child alerts. Subjects were again matched to the demographics of Texas, which created the same four groups, each with 25 percent of the subject pool. The study design for this research included reading time and comprehension tests using a PC, as well as several paper-based preference studies. The PC portion of the study was further subdivided into self-paced portions and also times when the messages were only displayed for specific times before disappearing – referred to as fixed-time studies. Again, the researchers did not identify an education-based trend.

There may be two good reasons why education-based trends were either not uncovered or only shown to have a weak correlation in these studies. First, the messages tested were based on messages in actual use and so prior viewing experiences by the subjects may have bolstered their understanding of the messages. Second, well-designed CMS messages –like any traffic control device - are intended to be simple and easy to understand, so even subjects that are minimally literate may still be able to understand the messages.

DRIVING-RELATED HUMAN FACTORS ISSUES

There have been numerous researchers that have attempted to gain understanding of the workload involved in actual driving, and the secondary task method has been used in many of these efforts. In real driving applications the use of an auditory/verbal secondary task has often been selected over other types, presumably because it may be considered a safer manner of imposing a secondary task because the subject's hands and eyes are free to control the vehicle. These studies can provide insight into how subjects perform the driving task, and so provide useful insight for the current research.

Dudek, Huchingson, and Brackett examined the effectiveness of highway advisory radio (HAR) messages in 1983 in actual driving conditions (71). Subjects were asked to drive on the urban Interstate system in San Antonio, Texas, while they were presented with simulated HAR route diversion messages played on a tape recorder. The subjects would then be asked to drive the route based on their understanding of the HAR message, and the researchers recorded the ability of the subjects to correctly follow the messages.

The researchers indicated that generally drivers could understand and successfully recall enough information to drive the diversion route as long as the message had fewer than ten units of information. A unit of information was defined by the researchers as "the number of informational elements that must be recalled by the driver to successfully negotiate the route (71)." Once a route description had ten units of information the researchers found that 60 percent of subjects made driving errors, an indication that the subjects may have been unable to retain all of the required information. The researchers indicated that HAR messages should provide no more than eight units of auditory information provided that the information be presented at least twice in order for drivers to better process the information.

Biever examined the effects of auditory secondary tasks while driving in 2002 (72). Subjects had to listen to and then remember driving instructions while driving on rural Virginia highways in a specially-equipped test vehicle capable of measuring and recording lane placement and following distance to lead vehicles. While driving, each subject was exposed to two different secondary tasks. First, they were asked to select a driving route from a list presented in an auditory fashion. Second they were asked to carry on a conversation meant to replicate a cellular phone conversation. Results showed that subjects had a statistically significant - albeit small in absolute measurements - increase in lane position deviations, as well as an increase in headway variance. The results of this research indicated that driving performance can be slightly negatively impacted by even relatively simple secondary performance tasks that include auditory or spoken language activities. This research did not extend to a reading secondary task.

In 1998, Zeitlin used vanpool drivers in the New York metropolitan area to develop a workload model showing point locations on a daily commute route where mental workload was increased relative to other portions of the commute (73). Drivers of two vanpools were studied for four years, including over 36,000 miles of actual driving. Each vanpool consisted of 6 male drivers who took turns driving into New York City during weekdays, each of whom had at least ten years driving experience, and were completely familiar with the driving route. The purpose of the experiment was to use secondary task analysis to determine which portions of the daily commute were most demanding on the drivers' mental resources.

Two different secondary tasks were studied: delayed-digit recall and random digit generation. Delayed-digit recall consisted of a recorded list of random digits being spoken. After each digit there would be a pause during which the driver must say aloud the digit prior to the one just heard. Alternately, random digit generation consisted of the driver stating aloud a series of numbers for two-minute periods which were recorded and later analyzed. The degree of randomness was assumed to be a reflection of the degree of difficulty in driving: during times of decreased randomness (increased repetitions in the digit stream) workload was hypothesized to be higher than times when true randomness was more easily accomplished. Records were kept of where on the commute the subjects were able to complete the secondary tasks and times when these tasks were not correctly performed by drivers in order to attend fully to driving. Zeitlin then modeled a workload index that related workload and a combination of brake activation rate and the $\log_2$ of speed (73).

Hagiwara, et al. conducted a study in 1999 on how driver subjective mental workload was affected by the use of cell phones while driving in a Japanese expressway (74). While following a lead vehicle at a constant following distance, subjects were also instructed to operate and then talk on a cellular telephone. It was found that the subjects' reaction times during the talking task increased by from 39 to 61 percent than for the other tasks, indicating that the performance of a secondary task may degrade the performance of the primary task in some instances.

DRIVING SIMULATOR-RELATED MENTAL WORKLOAD ISSUES

Driving simulators have been used in one form or another for eighty years. The earliest driving simulators were developed and used in the 1920s to test the skill and competence of public transit operators (75). These earliest simulators made use of mechanical conveyor belts to move objects toward the subject. By the 1930s this process had been refined to include dummy automobiles to test for such factors as brake reaction and included moving scenes (76). By the 1950s simulators included motion picture and at least portions of real car bodies. By the 1960s simulators were in use at insurance companies, automobile manufacturers, and the U.S. armed forces. Interactivity in simulation was added in the 1970s, and computer-generated graphics were available by the 1980s (76). With these innovations, all major components of fixed-base simulators were present.

Experiments using driving simulators have several distinct advantages over real-world experiments, including:

- High degree of control by the researcher over the situational and environmental variables,
- Evaluation of driver performance through nonexistent or rarely-occurring geometric and traffic conditions,
- Evaluation of maneuvers or geometric conditions that could entail risk if performed in the real world, and
- Potential cost-effectiveness for answering certain types of questions (75).

There have been many research efforts that have successfully used driving simulators to examine transportation engineering and/or human factors issues. Crawford et al. studied the effects driving performance and emergency reaction of cellular telephone use while operating a driving simulator in 2001 (77). Subjects were specifically required to use a hand-held cellular telephone while operating the driving simulator, and at one point in the study were required to react to a stopped vehicle directly in their path in order to determine if cellular telephone use would cause an increase in perception-reaction times. Clearly, a study of this type that potentially degrades the reaction time of a subject in an emergency situation could not be performed in an actual driving environment.

Richards, et al. successfully used a fixed-base driving simulator to study the comprehension of graphical congestion display panel - a type of CMS that does not use text, but rather uses graphics and color to depict congested portions of a roadway network (78). The researchers used the driving simulator solely to introduce additional workload similar to what a driver would experience while driving an actual vehicle. Subjects were shown twenty graphical information displays which were displayed for fixed amounts of time and then asked one question pertaining to the information on each display. Researchers found that subjects that were more experienced drivers were more likely to understand and correctly recall the information presented.

Hoffman, et al. used a driving simulator in 2005 to study the effects of text messages displayed on an in-vehicle display (79). The researchers were interested in studying the amount of information that could be displayed, and the rate that new information could be scrolled onto the in-vehicle display. By using a driving simulator, the researchers were able to safely test multiple display rates and configurations, and although several of the versions significantly increased the number and duration of subject glances, there was no fear of causing a crash by over-distraction of a driver. Such a study could not safely be conducted in a real-driving situation. Also, there would be no way to control the effects of traffic across subjects as traffic would be slightly different for every subject, a problem that can be successfully solved in a driving simulator.

In 2005 Dudek, Schrock, and Ullman used a driving simulator to test CMS messages that used dynamic features such as flashing all or parts of the message (68). Also in 2005, Ullman et al. used a driving simulator to display extended messages on sequential CMSs, where part of a message would be displayed on one message, then the rest would be displayed on a second CMS just downstream (80). Generally, these research projects would be difficult to conduct in actual driving situations for several reasons. First, agencies responsible for displaying messages on CMSs would naturally be hesitant to post fictitious information on their messages simply for the purposes of a research study. Second, if a highway agency would allow such a study to go forward, other drivers on the roadway would also see the messages, which may cause unintended consequences. Third, there would be no way to control traffic conditions, so traffic would be slightly different for each subject, resulting in slightly varying levels of task workload for each subject. In a driving simulator environment the traffic could be explicitly controlled, so each subject was exposed to identical driving conditions.

RESULTS OF PREVIOUS CMS MESSAGE-READING STUDIES

As mentioned previously in this literature review, there have been previous studies where the reading times and comprehension rates of subjects were examined as they read simulated CMS messages. The results for each of these studies are summarized, with special attention paid to areas related to this research.

Dudek et al. used portable PCs to evaluate various CMS messages in 2000 (7). The researchers examined how well subjects read and understood alternative message formats that were of interest to TxDOT. Of specific interest with regards to this research, Dudek et al. found:

- The difference between displaying messages that were flashing vs. those that were not flashing;
  - The researchers found that average reading time was 1.5 seconds longer when the message was flashing, and that this was a statistically significant result.
  - Comprehension rates and preferences of the flashing messages were not significantly different from the non-flashing messages.
- The difference between displaying messages that had a single line flashing vs. those that did not flash;
  - The researchers found that average reading time was 1.8 seconds longer when one line of the message was flashing, and that this was a statistically significant result.
  - Comprehension rates and preferences of the messages with one line flashing messages were not significantly different from the non-flashing messages, except for one significant difference which showed that subjects were slightly less able to recall the bottom of three lines when

the top line was flashing. This may have indicated an increased difficulty in reading messages when a single line is flashing;

- The difference between displaying two-phase messages that had a single line changing vs. two-phase messages where the entire message changes;
    - The researchers found that average reading time was 2.8 seconds longer when only a single line of the two-phase message changed, and that this was a statistically significant result.
    - Comprehension rates and preferences of messages with one line changing were not significantly different from those two-phase messages where the entire message changed.

In 2005 Dudek, Schrock, and Ullman used a driving simulator to test CMS messages that used dynamic features such as flashing all or parts of the message (68). The researchers examined how well subjects read and understood various alternative messages formats that were of interest to the FHWA. Of specific interest with regards to this research, the researchers found:

- The difference between displaying messages that were flashing vs. those that were not flashing;
    - The researchers found that average reading times were the same when the message was flashing and when the message did not flash.
    - Subjects were significantly more likely to recall all three lines of the non-flashing message compared with the flashing message (80 percent vs. 67 percent).
- The difference between displaying messages that had a single line flashing vs. those that did not flash;

  - The researchers found that reading time was 0.7 seconds longer when one line of the message was flashing, and that this was a statistically significant result.

  - When allowed to self-select how long they viewed the messages, subjects were significantly more likely to recall the entire message if the message was not flashing, compared to when one line was flashing (56 percent to 47 percent);

  - Subjects were equally likely to prefer non-flashing messages in comparison to messages where one line was flashing;

- The difference between displaying two-phase messages that had a single line changing vs. two-phase messages where the entire message changed;
  - The researchers found that average reading time was 1.8 seconds longer when only a single line of the two-phase message changed, and that this was a statistically significant result.

  - No significant differences were observed in the subjects' abilities in recalling all of the parts of the messages;

  - Subjects were significantly more likely to prefer the two-phase messages with one line flashing compared to the two-phase messages where the entire message changed (59 percent vs. 41 percent).

SUMMARY

Several important considerations were found through the review of the literature. Several of these relate to ways of developing the PCSP in order to provide tasks for subjects to perform that provide mental workload similar to a driving simulator.

- According to Wickens, each subject has a certain amount of available mental capacity, and this is subdivided into different processing regions based on the sense modality being used (12). This is an important concept when considering potential secondary tasks that are similar to other tasks, as in this research, and can be used to screen potential PCSP secondary tasks that access similar mental processing resources as a driving simulator.
- Change blindness can limit a subject's ability to recognize a change in their environment, such as the display of a CMS message. In order to minimize the effects of change blindness, researchers must plan to make visual changes large, clear, and very easy to notice (39-43).
- Alexander and Lunenfeld described the workload of driving (and by extension operating in a driving simulator) as divided into three levels: navigation, guidance, and control (13-15). Navigation is not typically encompassed by typical driving simulator studies unless wayfinding is the research goal, and so is not necessarily a requirement of the PCSP to replicate this workload. However, guidance and control are directly related to operating a driving simulator, and so to the extent possible an attempt should be made to replicate the workload of these tasks in the PCSP.
- Two studies revealed measurable looking-time performance differences when subjects were shown repeated information after a 48-hour delay (46, 47). This indicated that researchers intending to provide repeated viewings of research stimuli need to wait more than 48 hours between viewings in order to minimize any subject learning effects.
- Brouwer et al. indicated that verbal responses by subjects performing a task had a lower error rate than written responses (62). A verbal response may be easier for subjects than manual responses. This consideration had an impact on the design of the PCSP, as well as the study design used for this research.

- The literature provided information on how demographic considerations relate to reading and comprehension of CMS messages. Gender appears to have little statistically significant impact on reading and comprehension studies (66, 67), but there is some indication that age (57-65) and education levels (70) do. Thus, any research that involves having subjects read and recall CMS messages should consider how to best counterbalance these factors.

The information from the literature reported herein was useful in developing the requirements for the development of the PCSP, which is presented in Chapter III. The information was also used in the development of the study design, which is presented in Chapter IV.

CHAPTER III

DEVELOPMENT OF A PERSONAL COMPUTER-BASED STUDY

Two distinct systems were utilized in this research. First was the PCSP developed and tested as part of this research; second was the TTI driving simulator. Both are described in detail in the following sections.

PERSONAL COMPUTER STUDY SYSTEM

A required task for the successful completion of this research was the development of a software program that could be run on a standard portable PC. The software program was created and the associated PC hardware (e.g., the PC and an optical mouse) together were bundled into the PCSP. The PCSP was designed with the following characteristics in mind:

- The ability for the study administrator to pre-prepare several sets of CMS messages into a series of sign message libraries;
- The ability for the study administrator to quickly switch among sign message libraries;
- An easy-to-learn and easy-to-use secondary subject mental workload task;
- The secondary mental workload task needed finely-tunable display rates, including complete deactivation;
- The ability for the study administrator to quickly change the level of workload of the secondary mental loading task; and
- The ability for the study administrator to easily retrieve performance data upon the conclusion of a study session.

Clearly, in order to be a useful system, the PCSP needed to be uncomplicated, easy for both the study administrator and the test subjects to use, and not require bulky additional hardware that would limit its basic portability. Thus, the PCSP software was designed with attention given to the following basic goals laid out by Shneiderman on the effective development of computer software to improve the human-computer interface (81):

- The program must be easy to learn by users,
- The program must allow quick setup and operation by users,
- The program must have simple commands and/or require few actions on the part of users in order to successfully complete the required tasks,
- Subjective satisfaction by users must be high, and
- Users must be able to retain the knowledge of how to use the program for an extended time after use.

Note that the final point in Shneiderman's list was not a consideration for this research, it was not anticipated that the subjects would be exposed to the PCSP in subsequent studies.

Development of a Useful Personal Computer Secondary Task

Within the PCSP software environment, it was desired to create a secondary mental workload task that subjects must perform in addition to the sign message reading tasks. An acceptable secondary task should have many of the following positive characteristics:

- Simple controls that are either drawn from already-learned skills or are easily learned by subjects with minimal training (such as clicking on objects with the PC's mouse;

- Any additional equipment for controls needed to be highly portable;
- Visual aspects that are clear and easy to see; and
- The ability to increase and decrease the difficulty of the physical and mental workload.

The researcher developed a list of four possible candidate secondary tasks. Each of these is briefly described:

1. Monitoring a Control Panel Secondary Task. This secondary task would require a subject to visually scan a control panel of buttons displayed randomly in a rectangular area on the computer screen. As soon as a button is displayed (i.e., it changes color) the subject would be required to use the computer mouse to click on the button to deactivate it (i.e., turn the button back to its original color). The level of difficulty could be varied by changing the button display rate. Subjects would be scored on their ability and speed in successfully turning off the correct buttons.
2. Watch for Brake Light Activation Secondary Task. This secondary task would display an image of the rear of a vehicle, and the PCSP would be equipped with a steering wheel and foot pedal gaming control system. The subject would be asked to use the steering wheel, accelerator pedal, and brake pedal to mimic car-following actions similar to following a vehicle in the driving simulator. Actions would include:
    - Monitoring the vehicle on the screen for brake applications. If the vehicle on the screen has its brake lights activated, the subject would be required to press the brake pedal with his or her foot.
    - Monitoring the vehicle on the computer screen for left and right tracking movements. The vehicle on the computer screen could track left or right

similar to a vehicle moving through a left or right curve. The subject would be required to follow the vehicle by turning the steering wheel to keep the car on the computer screen centered on the screen.

- Maintaining the proper following speed. The subject would be asked to depress the accelerator pedal to simulate trying to maintain a following speed. It was anticipated that a simple indicator light could be displayed on the screen to show the subject if they were driving too slow or too fast.

This level of difficulty of this secondary task could be modified by adding or removing these control requirements. For example, an easy workload setting might only include one of these control tasks, while a hard workload setting would include all three.

3. Driving a Game Secondary Task. This secondary task would require a subject to play a computer video game using a steering wheel and foot pedal gaming control system. This video game would be a currently available commercial driving game that can be modified to change the difficulty level of driving.
4. Tracking a Moving Object Secondary Task. This secondary task would require a subject to visually track a moving object on the computer screen and use the computer's mouse to hold the cursor over the object. The moving object might be a circle, square, or other simple geometric shape. The level of difficulty could be varied by increasing the size of the object, the speed that the object moves, and the rate at which the object changes direction on the screen. Subjects would be scored on their ability to keep the cursor over the moving object.

It was beyond the scope of this research to test all of the above possible secondary workload tasks. Therefore, there was a need to select one secondary task approach. This selection process consisted of comparing each of the potential secondary tasks previously listed to determine how they compared in the following categories:

- Ability to measure the subject's secondary task performance,
- Ability to provide at least three levels of difficulty,
- Required skills comparable to driving skills,
- Minimal computer knowledge required by subjects in order to successfully participate,
- Portability of equipment such as a portable PC and additional control systems, and
- Study repeatability.

Note that it was not required that the task selected for this research contain positive attributes from all of the qualities listed. The list is merely a list of desirable qualities for a task. Naturally, then, the more qualities a given task has from the list, the more favorable the task would be for this research.

Each of these characteristics was rated by the researcher as "very good," "good," "neutral," "poor," and "very poor." for each secondary task. The ratings are listed in Table 1. A "very good" rating was scored with a +2, a "good" rating was scored with a +1, a "neutral" rating would receive a 0 score, a "poor" rating was scored with a -1, and a "very poor" rating would receive a -2. A summation of the scores in each category provided the total score. The total score for each secondary task can be found in the right-hand column of Table 1. As shown in the Table, the Control Panel Monitoring Secondary Task had the highest overall score, and was selected as the secondary task in this research for use within the PCSP for comparison with TTI's driving simulator.

Table 1. Comparison of Possible Personal Computer Study Procedure Secondary Tasks

Secondary Task	Ability to Measure Performance	Control Difficulty Levels	Similar to Driving	Equipment Portability	Repeat-ability	Total Score	Ranking
Control Panel Monitoring	Good (+) (1 point)	Good (+) (1 point)	Poor (-) (-1 point)	Very Good (++) (2 points)	Very Good (++) (2 points)	5	**1**
Brake Light Activation	Good (+) (1 point)	Good (+) (1 point)	Good (+) (1 point)	Poor (-) (-1 point)	Very Good (++) (2 points)	4	**2**
Game Driving	Poor (-) (-1 point)	Poor (-) (-1 point)	Very Good (++) (2 points)	Poor (-) (-1 point)	Poor (-) (-1 point)	-2	**4**
Object Tracking	Neutral (0 points)	Neutral (0 points)	Poor (-) (-1 point)	Very Good (++) (2 points)	Very Good (++) (2 points)	3	**3**

Development of Secondary Task for use on a Personal Computer Study Procedure

In order to determine an appropriate range of button display rates for the button-pressing control panel secondary task, a group of human factors experts was convened to provide input into the process. These experts were asked to evaluate the relative workload of the driving simulator and to relate this with the workload imposed using the button display task incorporated into the PCSP. The expert panel consisted of:

- Dr. Susan Chrysler, TTI,
- Dr. Conrad Dudek, P.E., Civil Engineering Department, Texas A&M University,

- Dr. Rodger Koppa, P.E.; Industrial Engineering Department, Texas A&M University, and
- Dr. Gerald Ullman, P.E.; TTI.

The comparison between the mental workload in the driving simulator and that imposed by the button-pressing task within the PCSP was made by having each expert operate the driving simulator for approximately ten minutes and view several example CMS messages. Then the expert immediately exited the driving simulator and was placed in front of a portable PC with the PCSP button-pressing control panel secondary task and shown CMS messages while performing the secondary task. A push-button display rate of 1.7 buttons/second was selected as an initial setting based on a pilot study that was conducted by the researcher. After viewing one or two CMS messages, each expert was asked to rate the difficulty of the PCSP compared to the driving simulator using the Cooper-Harper Rating Scale (82,83). The rating scale form is shown in Figure 7. The Cooper-Harper Rating Scale provided a mechanism to quantify the subjective opinions of each of the human factors experts in order to directly compare the results between experts.

The button display rate was initially set at a level that the researcher believed to be exceedingly hard: 1.7 button/sec. The 1.7 buttons/sec. display rate required much more workload on the part of the subject to successfully attend to the button-pressing secondary task than what was necessary for the conditions used. Thus, the initial rating by each expert was expected to be that the 1.7 buttons/second rate would exceed the workload of the driving simulator. After each rating by the expert, the button display rate was reduced in stepwise fashion, and after each display rate the expert was asked to rate the updated relative workload. Table 2 shows the results of how each expert’s Cooper-Harper Scale results changed as the button display rate changed, with the initial

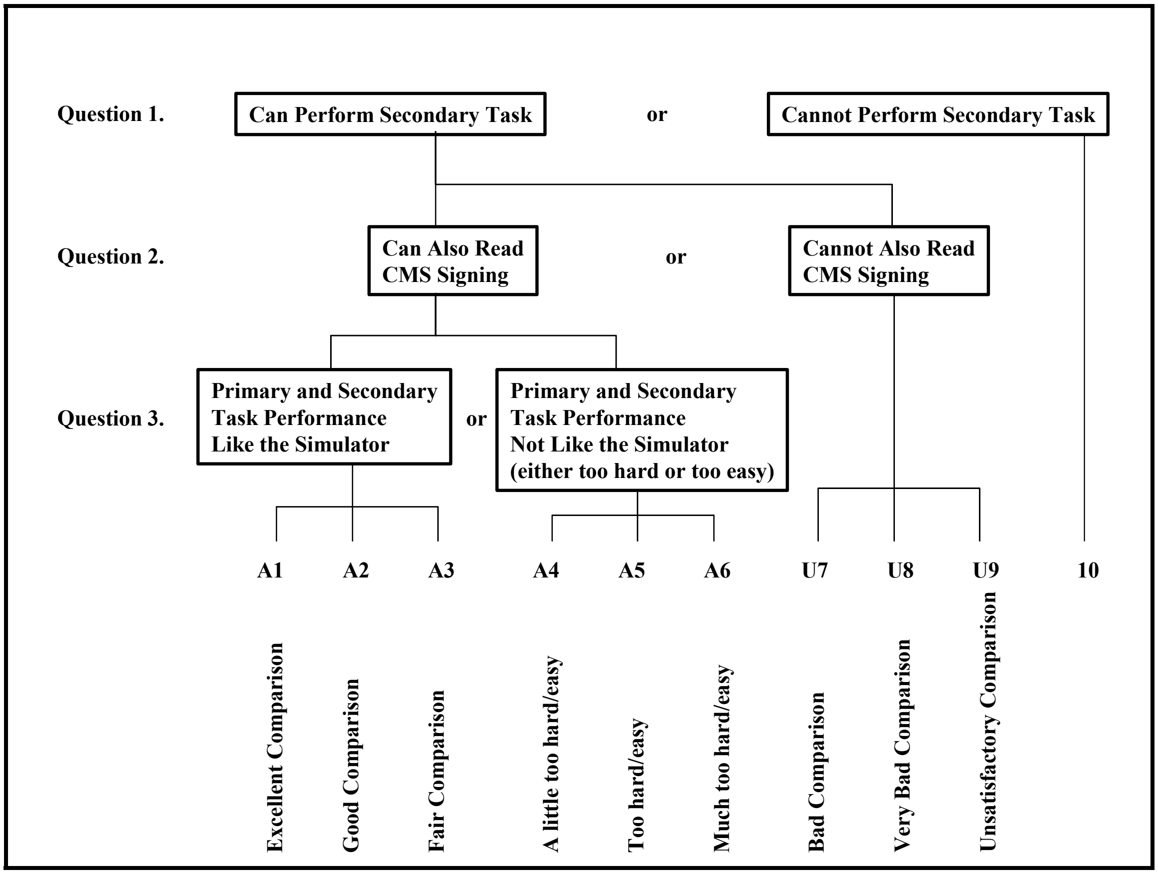


Figure 7. Modified Cooper-Harper Rating Scale used by Human Factors Experts

Table 2. Expert Panel Feedback on Comparison of the Personal Computer Study Procedure with the Driving Simulator

Display Rate (button/second)	Cooper-Harper Rating		
	Dr. Chrysler	Dr. Koppa	Dr. Ullman
0.60	10	10	1
0.65	10	10	1
0.70	10	10	1
0.75	5	3	2
0.80	4	2	3
0.90	2	1	3
1.00	2	2.5	4
1.10	2	7	5
1.25	2	10	6
1.50	3	10	9
1.75	3	10	10

ratings given at the right of the figure, and each subsequent rating shown to the left. Note that Dr. Dudek's participation on the panel was in a pilot effort, and so his data do not appear in Table 2.

The resulting graphs for the experts followed a "U"-shaped curve. On the right-hand part of the "U" (representing the first button display rate presented) the experts as expected indicated that the PCSP workload was too difficult to be comparable with the driving simulator; on the left-hand part of the "U" the experts indicated the PCSP workload was too easy. The bottom portion of the "U" indicated each expert's region of display rates that most closely resembled the workload of the driving simulator. Any rating that was listed as a 3 or less was considered a satisfactory comparison, as the experts would have ranked that level of workload as either “Excellent,” “Good,” or “Fair,” compared with the driving simulator.

The determination of the first display rate selected for use in this research was found by examining the fastest button display rate that all of the experts rated with a 3 or less (“Excellent,” “Good,” or “Fair” comparisons). The 0.909 button/sec. display rate represents the expert panel’s consensus of an upper bound on the acceptable range where the mental workload between the driving simulator and the PCSP were similar. Stated another way, results of the expert panel were an indication that any PCSP display button rate faster than the panel’s consensus would be too hard to provide similar mental workload.

The second display rate was intended to represent the easiest rate where the experts still considered the PCSP imposed mental workload as comparable with the workload imposed by the driving simulator. A slightly different criterion was used to determine this display rate. The display rate was selected as the fastest button display rate that at least one expert still found the PCSP workload and the driving simulator to be comparable (the other two would by then consider the PCSP workload to be too easy). The slightly different criterion was used in order to realize a larger difference between display rates to be tested.

By using this process, two PCSP control panel monitoring display rates were selected for further study. As shown in Figure 8, these button display rates were:

- 0.625 button/second display rate, and
- 0.909 button/second display rate.
- Additionally, as this research project progressed, a third testing level was added, one that had no control panel portion at all, effectively removing the secondary

task portion of the PCSP. This was added in order to explore the task loading effects of the PCSP when used as a single-task survey instrument.

Hardware and Software Components

The portable PC used for this study was a Microsoft® Windows XP®-based system with an Intel® Pentium® M processor and a 15.4-inch liquid crystal display (LCD) monitor. A standard USB optical mouse was also used. The software used to develop the PCSP was based on the Microsoft® Visual C#® programming language.

User Interface Development of the PCSP

A black rectangle measuring 4-inches by 1.25-inches was displayed in the upper right-hand portion of the PC screen; this was meant to represent a CMS. The character height of the message was nominally 3/16-inch in height. Online ergonomic references indicate an ideal PC screen-to-eye distance of from 20 to 40 inches (84,85). Indeed, a small sample of measurements from various subjects indicated that the distance from the PC screen and the subjects' eyes were very close to 30 inches. This provided a similar visual angle as a changeable message sign with nominal 18-inch characters viewed at 240 feet. This was much less than the theoretical maximum viewing distance of 1,030 feet for such as sign, indicating that the message size displayed on the PC screen was much closer to a best-case scenario for message reading.

After 15 seconds of a subject performing the secondary task, a message with yellow characters appeared in the changeable message sign box. An example of both a changeable message sign message and the button-pressing control panel secondary task are shown in Figure 8.

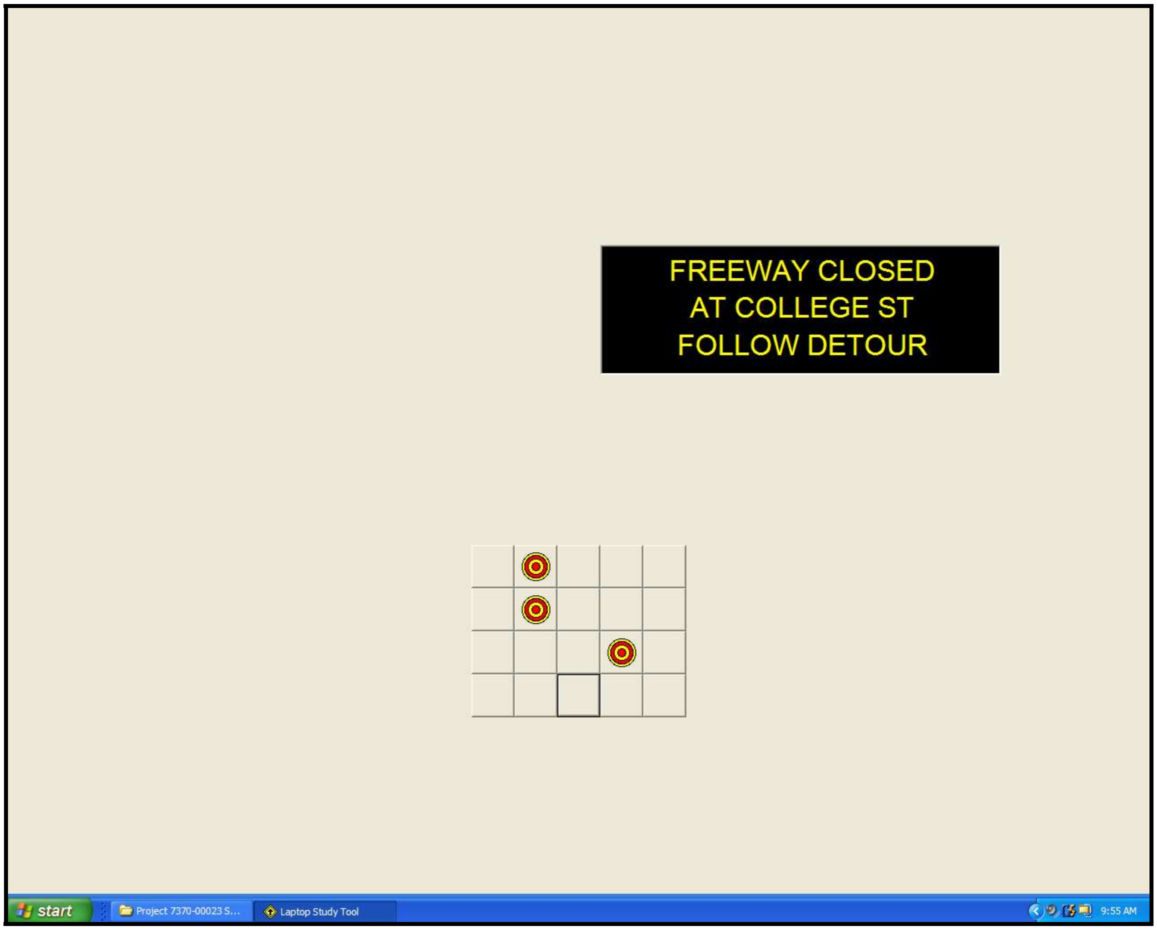


Figure 8. Screen Capture of the Personal Computer Study Procedure Showing On-Screen Changeable Message Sign and Control Panel Monitoring Secondary Task

Software Setting Capabilities

The PCSP software package was created to perform the following functions:

- Display CMS messages that were:
    - One, two, or three lines in length with up to nineteen characters per line;
    - One, two, or three parts in length, allowing multiple-part messages;

- Either displayed for predefined time periods or indeterminately displayed until the subject turns them off; and
- Able to flash on-and-off either individual lines or the entire message;

The input screen where CMS messages were created is shown in Figure 9. The input screen has the following features:

- The input screen could display a control panel of 20 on-screen buttons arranged in a four-by-five grid. Subjects were asked to monitor the control panel, and when a button was activated (denoted by the appearance of a red-and-yellow dot on the button) the subject was required to deactivate it by using the computer's mouse to click on the button. This activity comprised the secondary task capability of the PCSP program, and is referred to in this dissertation as the "button-pressing task."
- The button activation rate can be varied from the settings menu as shown in Figure 10. Likewise, from the settings page the secondary task can be deactivated, leaving only the changeable message sign displayed within the PCSP if that is so desired; and
- The PCSP program was capable of automatically recording the amount of time that each message was displayed and the number of buttons that were deactivated as part of the button-pressing secondary task performance, all of which can be saved to a text file for later analysis.

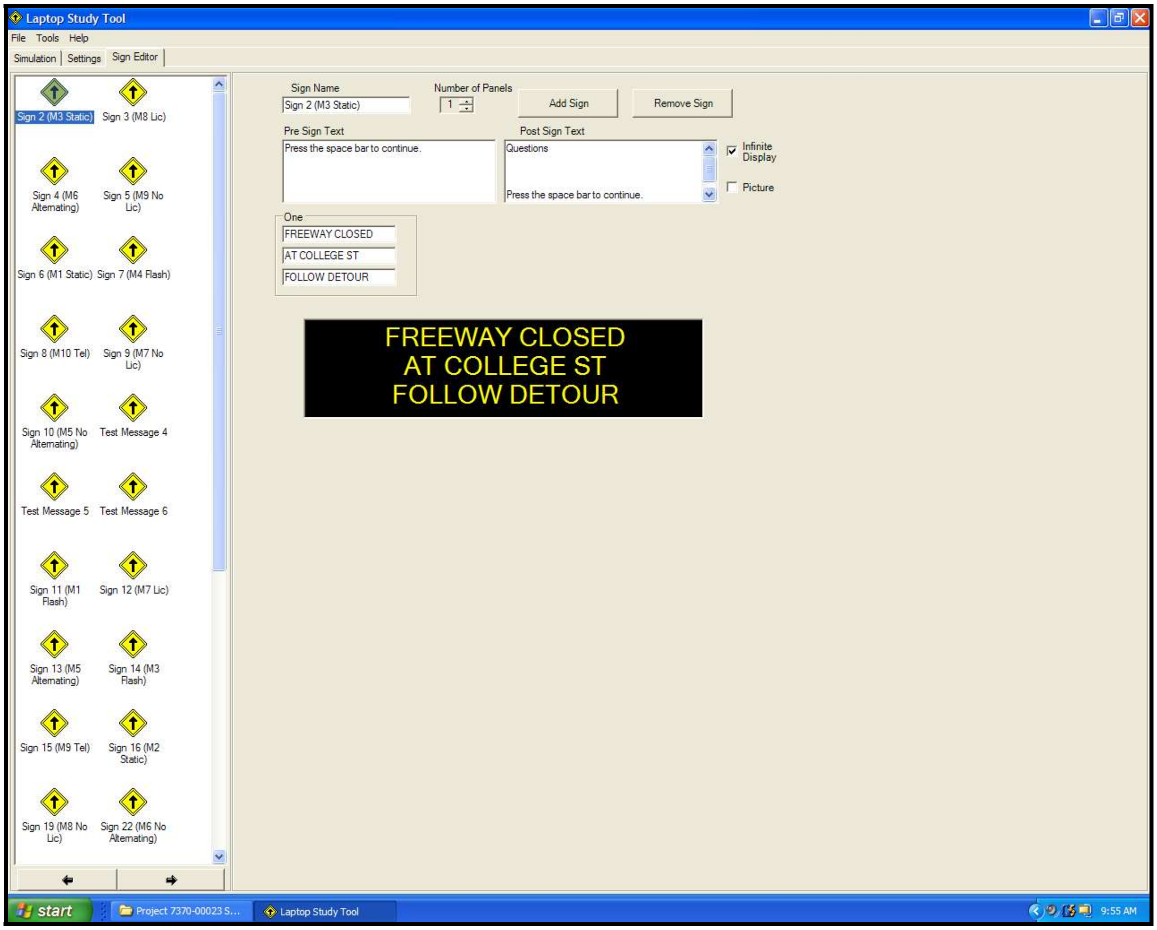


Figure 9. Screen Capture of the Personal Computer Study Procedure Showing Message Library Development Screen

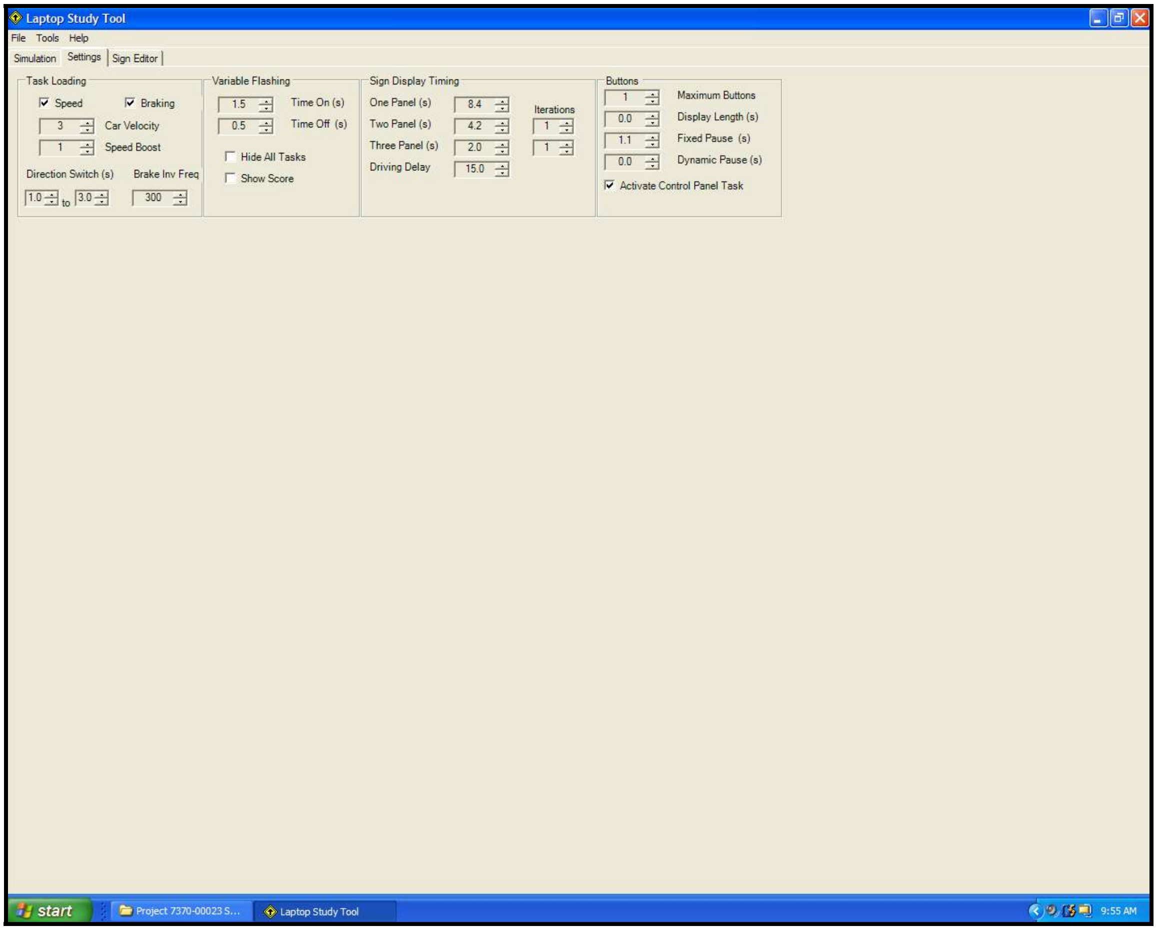


Figure 10. Screen Capture of the Personal Computer Study Procedure Settings Menu

TEXAS TRANSPORTATION INSTITUTE'S DRIVING SIMULATOR

The TTI driving simulator is comprised of four components: vehicle, computers, projectors, and screens. The vehicle, a complete 1995 Saturn SL sedan, 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. The effect of this system is one of a good approximation of actual driving. The Saturn is connected to a computer system that consists of one data collection computer and three image-generation computers. Computer-generated driving scenes are sent to three high-resolution LCD projectors and projected onto three high-reflectance screens.

Simulator Configuration for this Study

The driving simulator has the capability for projecting several different highway scenes and scenarios, so there are a wide variety of possible applications. The highway scenes and scenarios selected for this research were based on those used in previous research on driver understanding of CMSs. These scenes were reported to provide the highest driving workload possible within the capabilities of TTI's driving simulator while minimizing the possibility of nausea. Previous experience by TTI researchers and other research institutions with driving simulators have indicated that horizontal curves should be avoided as much as possible in order to minimize nausea (86-89). The driving scene used for this research was a six-lane freeway consisting entirely of tangent sections with some slight vertical curvature. Additional details regarding the controls used to limit subject discomfort are presented in Appendix B. An example of the simulated highway scene subjects see during the driving simulator portion of this research is shown in Figure 11.

The display of CMS messages within the driving simulator posed a special difficulty to overcome, as the ability to accurately represent the visual characteristics of a CMS was very limited. Furthermore, placing the CMS entirely within the simulation environment would not have allowed the researcher to systematically control and accurately measure the reading time required by subjects to read each CMS message. Therefore, messages were displayed on a CMS that was projected via an add-on LCD projector interfaced with a separate PC. The messages were displayed on a 32-inch wide by 18-inch tall rectangle that replaced a portion of the simulated roadway scene on the right side of the driving scene. The center of the rectangle was positioned so that its center was offset laterally from the roadway image by 16 degrees from a subject's "straight ahead"

Figure 11. Simulated Highway Scene Presented in TTI's Driving Simulator

perspective. The CMS messages were displayed with nominal 1.5-inch character letter height, which provided the same visual angle as a CMS with nominal 18-inch characters at a distance of 100 ft. This viewing angle was selected in order to prevent visual acuity of the subjects from being a factor in the message reading times.

In addition to "driving" the vehicle on the simulated freeway section, each subject had additional driver workload to attend to from a car-following task. Each subject was placed in a simulated driving situation by being required to follow a selected vehicle. The additional workload was added by varying the speed of the vehicle the subjects were required to follow 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 in order to minimize the likelihood that subjects would associate the lead vehicle's speed changes with an upcoming CMS display. The time and degree of the speed changes for the lead vehicle are shown in Figure 12.

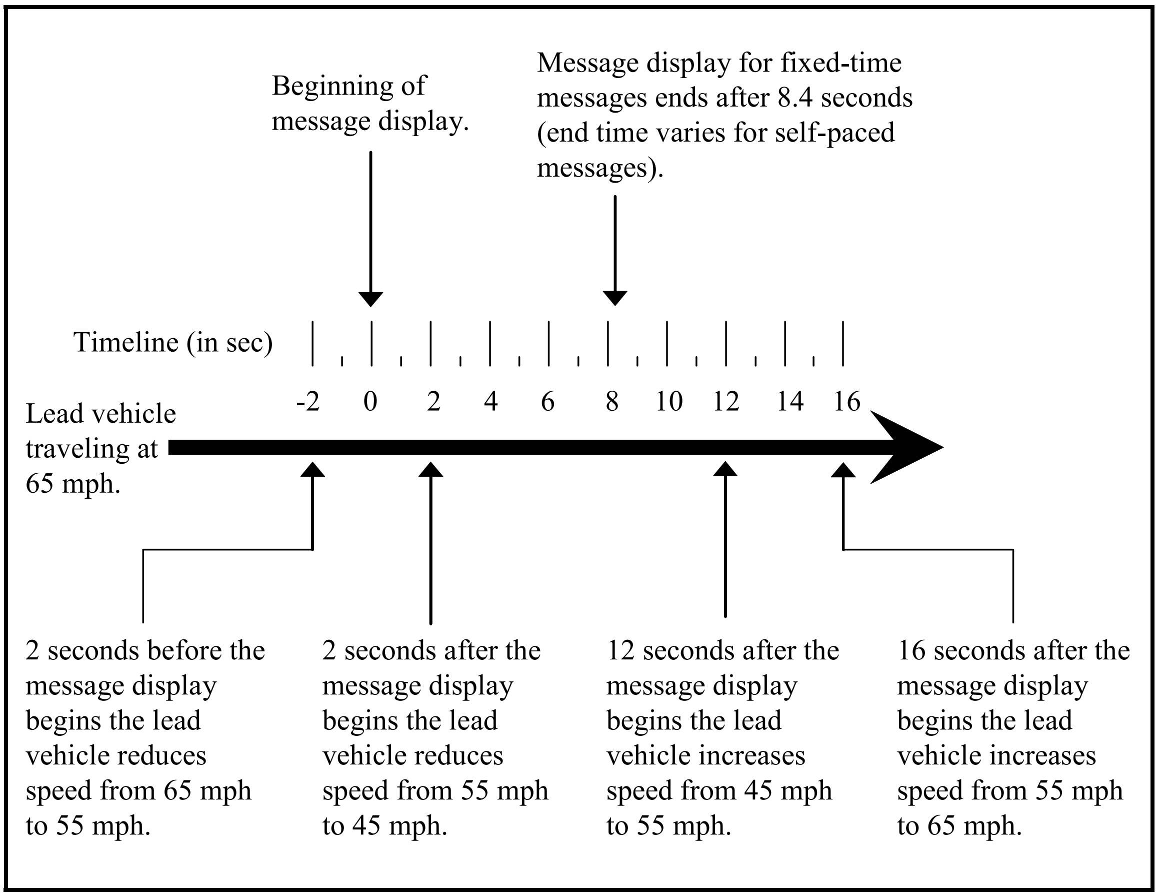


Figure 12. Illustration of the Time and Degree of Speed Changes for the Lead Vehicle in the Driving Simulator

In order to maintain a similar mental workload across all subjects and all instances of message displays, the subjects were instructed to follow closely behind the lead vehicle.

An acceptable car-following distance was left up to the subject with the following two instructions. First, the subject was to keep from hitting the back of the lead vehicle. Second, the subject was required to maintain no more than 180-feet headway behind the vehicle. If the subject fell too far behind the lead vehicle then a red chevron would appear on the center screen in the subject's central field of view. The subject was instructed at the beginning of each study session to reduce the following distance to the lead vehicle until the red chevron disappeared.

The lead vehicle was programmed so that it would maintain a straight path, remain in the right-hand lane, and travel a constant 65 mph except for when the speed changes discussed above occurred. Two seconds prior to the display of a CMS message the lead vehicle performed a series of speed changes, slowing from 65 mph to 45 mph, then increase its speed to 55 mph, and then return to 65 mph, all during the time when the CMS message was displayed. The speed change patterns were also performed at other times when no CMS message was displayed in order to keep subjects from associating the lead vehicle speed change as a cue that a CMS message was about to be shown. The intention of the speed changes was to force the subjects to be more vigilant in the process by attending to the traffic situation in the simulated environment and to read the message at the same time.

To ensure that reading times were measured accurately and consistently, a system to precisely control the presentation time of the CMS message was developed. When a message was displayed, the study administrator pressed a button on the PC which was connected to the LCD projector. This activated the CMS message, which was displayed for the subject to read. When the subject understood the message he/she pressed either of two buttons which were attached to the steering wheel of the driving simulator. Depressing the button removed the message from the scene and the message display times were automatically recorded on the PC. Note that in the fixed-time format the CMS message was automatically deactivated after it was displayed for a fixed amount of time; the steering wheel buttons were disabled by the study administrators during the fixed-time portions of the study.

CHAPTER IV

EXPERIMENTAL DESIGN

In this chapter, a discussion is presented on how the CMS messages that were used for the study were selected and the order that the messages were displayed. A detailed description of the demographics that were followed in gathering a representative sample of subjects for this research is provided. The research hypotheses are stated and the measures of effectiveness (MOEs) used to evaluate the research hypotheses are presented.

SAMPLE SIZE AND SUBJECT DEMOGRAPHIC INFORMATION

All 126 of the subjects for this research were from the Bryan-College Station area. Potential subjects were recruited by telephone, and were accepted as test subjects if they met the following minimum criteria:

- Held a current driver license,
- Drove a minimum of 8,000 miles per year,
- Drove on a freeway at least once per month,
- Had 20/20 vision or vision aides to correct to 20/20 vision,
- Had no carpal tunnel syndrome or other repetitive stress disorders that could be aggravated by participation on the study,
- Had no history of motion sickness, and
- Had no other reason to expect nausea (such as a side-effect of medications, pregnancy, etc.).

The demographic sample of subjects was based on age, education, and gender of drivers in Texas and is shown in Tables 3 through 5 (90,91). The breakdown of the 126 scheduled subjects to provide an even distribution of these demographics is shown in Table 6.

Table 3. Texas Licensed Drivers, All Drivers

Age Category	Number of Licensed Texas Drivers	Proportion of Licensed Texas Population	Number of Subjects Used
18-25	2,076,483	14.3%	16
25-39	4,443,063	30.5%	39
40-54	4,402,120	30.3%	39
55-64	1,843,981	12.7%	16
>65	1,777,881	12.2%	16
Total	**14,543,528**	**100.0%**	**126**

Source: U.S. Department of Transportation – Federal Highway Administration Statistics 2004.

Table 4. Texas Licensed Population by Gender

Gender	Number of Licensed Texas Drivers	Proportion	Number of Subjects Used
Male	7,337,241	50.5%	63
Female	7,206,287	49.5%	63
Total	**14,543,528**	**100.0%**	**126**

Source: U.S. Department of Transportation – Federal Highway Administration Statistics 2004.

Table 5. Texas Educational Background

Highest Level of Educational Attainment	Proportion	Number of Subjects Used
No High School Diploma	24%	31
High School Diploma or GED	25%	32
Some College and/or Associates Degree*	27%	32
College Degree (4 or more years)	24%	31
Total	**100%**	**126**

Source: U.S. Census Bureau, Census 2000.
Note: Based on the Texas Population age 25 and over.
* Some College = 22%; Associates Degree = 5%. These categories were grouped for the purposes of this research to streamline subject recruitment.

Table 6. Demographic Distribution of Subjects

	No High School Diploma		**High School Diploma**		**Some College**		**College Degree**		**Total**
	Male	**Female**	**Male**	**Female**	**Male**	**Female**	**Male**	**Female**	
18-25	2	2	2	2	2	2	2	2	16
25-39	5	5	5	5	5	5	5	4	39
40-54	4	5	5	5	5	5	5	5	39
55-64	2	2	2	2	2	2	2	2	16
>64	2	2	2	2	2	2	2	2	16
Total	**15**	**16**	**16**	**16**	**16**	**16**	**16**	**15**	**126**

MESSAGES SELECTED AND PRESENTATION ORDER

The CMS messages selected for this dissertation research were adopted to match a previous TTI research study for the FHWA where subjects were tested in TTI's driving simulator (68). This allowed an increased sample size for this research, as the subjects tested in the previous TTI research study could then be retested using the PCSP. In this manner more subjects could be tested for this research for the same cost.

In addition to using some of the same subjects as the TTI study, the same messages were also used. The messages used for the TTI study were intended to test pairs of messages to determine if there were reading, comprehension, or preference differences between messages with dynamic components (i.e., flashing all or part of the message, or alternating individual lines) when compared with their non-dynamic alternative messages. Additionally, two other message formats were presented to subjects but not reported in the TTI study: these messages contained numeric components (i.e., license plate and/or telephone numbers) and were compared to messages that did not include numeric components. The two additional numeric messages were AMBER alert messages that are typically displayed on CMSs when a child is abducted. Because the dynamic messages (and their static alternatives) and the numeric messages (and their non-numeric alternatives) had been previously determined to be well-constructed messages (68), it was decided that their use could be extended to this research, thereby minimizing the possibility that poorly-constructed messages might distort the findings.

Twenty different CMS messages were analyzed during this study. The CMS messages used in this study were subdivided into five different CMS display formats. The first three formats had dynamic message features (i.e., flashing or alternating lines) as well as alternative messages that were static (i.e., not flashing):

1. Two one-phase messages that flashed and matching alternative static one-phase messages (Messages M1 and M2),

2. Two one-phase messages where the top line flashed and matching alternative static one-phase messages (Messages M3 and M4),
3. Two two-phase messages with the top two lines static and only the third line having alternating information and matching alternative two-phase messages with two lines per phase (Messages M5 and M6),

The fourth and fifth formats consisted of messages with numeric information (i.e., license plate number or telephone number).

4. Two static one-phase AMBER alert messages that included license plate information on the third line and matching alternative messages with TUNE TO RADIO on the third line (Messages M7 and M8), and
5. Two static one-phase AMBER alert messages that included a ten-digit telephone number on the third line and matching alternative with TUNE TO RADIO on the third line (Messages M9 and M10).

The five CMS display formats are shown in Table 7. Because each message (such as Message M1 Flashing, for example) had a unique alternative message (such as Message M1 Static), there were a total of twenty distinct messages for use as experimental stimulus material.

The order that the messages were presented to subjects is shown in Table 8. The subjects were divided into four groups (A1, A2, B1, and B2) with each group seeing the messages in a different order from the other groups. This counterbalancing in the order of the messages was developed to minimize any order bias in the data. In addition to the twenty study messages, three practice CMS messages were presented at the beginning of the study to familiarize the subjects with the study process, and six test messages were

Table 7. CMS Messages Displayed

Message	Dynamic or Numeric Version		Static or Non-numeric Version	
M1	Flashing (flashing text indicated in bold)	**MAJOR ACCIDENT** **AT LITTLE YORK** **3 LANES CLOSED**	Static	MAJOR ACCIDENT AT LITTLE YORK 3 LANES CLOSED
M2	Flashing (flashing text indicated in bold)	**FREEWAY** **BLOCKED** **AT TIDWELL** **USE OTHER ROUTES**	Static	FREEWAY BLOCKED AT TIDWELL USE OTHER ROUTES
M3	Flashing Line (flashing text indicated in bold)	**FREEWAY CLOSED** AT COLLEGE ST FOLLOW DETOUR	Static	FREEWAY CLOSED AT COLLEGE ST FOLLOW DETOUR
M4	Flashing Line (flashing text indicated in bold)	**TRUCK ACCIDENT** AT AIRPORT RD USE SERVICE ROAD	Static	TRUCK ACCIDENT AT AIRPORT RD USE SERVICE ROAD
M5	Alternating Line (first part of a two-part message)	CONSTRUCTION AT BROADWAY RD ALL LANES CLOSED	No Alternating Line (first part of a two-part message)	CONSTRUCTION AT BROADWAY RD
	(second part of a two-part message)	CONSTRUCTION AT BROADWAY RD USE OTHER ROUTES	(second part of a two-part message)	ALL LANES CLOSED USE OTHER ROUTES

Table 7. (Continued)

Message	Dynamic or Numeric Version		Static or Non-numeric Version	
M6	Alternating Line		No Alternating Line	
	(first part of a two-part message)	MAJOR ACCIDENT AT WAYSIDE RD ALL LANES BLOCKED	(first part of a two-part message)	MAJOR ACCIDENT AT WAYSIDE RD
	(second part of a two-part message)	MAJOR ACCIDENT AT WAYSIDE RD USE OTHER ROUTES	(second part of a two-part message)	ALL LANES BLOCKED USE OTHER ROUTES
M7	License Plate Number	KIDNAPPED CHILD BLUE CHEVROLET LIC 825 493	No License Plate Number	KIDNAPPED CHILD BLUE CHEVROLET TUNE TO RADIO
M8	License Plate Number	MISSING CHILD GREEN OLDSMOBILE LIC 739 452	No License Plate Number	MISSING CHILD GREEN OLDSMOBILE TUNE TO RADIO
M9	Telephone Number	KIDNAPPED CHILD SILVER LINCOLN CALL 800 268 3200	No Telephone Number	KIDNAPPED CHILD SILVER LINCOLN TUNE TO RADIO
M10	Telephone Number	MISSING CHILD YELLOW TOYOTA CALL 888 769 5000	No Telephone Number	MISSING CHILD YELLOW TOYOTA TUNE TO RADIO

Table 8. Order of Message Presentation to Subjects

	Group A		**Group B**	
	Group A1 (31 Subjects)	**Group A2 (32 Subjects)**	**Group B1 (31 Subjects)**	**Group B2 (32 Subjects)**
Practice Session				
	Practice Message 1	Practice Message 1	Practice Message 1	Practice Message 1
	Practice Message 2	Practice Message 2	Practice Message 2	Practice Message 2
	Practice Message 3	Practice Message 3	Practice Message 3	Practice Message 3
Session 1 Reading Time/Comprehension (Self-Paced: message displayed until deactivated by subject)				
	Test Message 1	Test Message 1	Test Message 1	Test Message 1
	Test Message 2	Test Message 2	Test Message 2	Test Message 2
	Test Message 3	Test Message 3	Test Message 3	Test Message 3
1	M2 Flash	M5 Non-Alternating Line	M10 Telephone Number No.	M9 No Telephone Number No.
2	M3 Static Line	M7 No License Plate No.	M4 Flash Line	M3 Static Line
3	M8 License Plate No.	M10 Telephone Number No.	M6 Alternating Line	M5 No Alternating Line
4	M6 Alternating Line	M4 Flash Line	M8 License Plate No.	M7 No License Plate No.
5	M9 No Telephone Number No.	M1 Static	M2 Flash	M1 Static

Table 8. (Continued)

	Group A		**Group B**	
	Group A1 (31 Subjects)	**Group A2 (32 Subjects)**	**Group B1 (31 Subjects)**	**Group B2 (32 Subjects)**
Session 2 Reading Time/Comprehension (Self-Paced: message displayed until deactivated by subject)				
6	M1 Static	M9 No Telephone Number No.	M9 No Telephone Number No.	M10 Telephone Number No.
7	M4 Flash Line	M6 Alternating Line	M3 Static Line	M4 Flash Line
8	M10 Telephone Number No.	M8 License Plate No.	M5 No Alternating Line	M6 Alternating Line
9	M7 No License Plate No.	M3 Static Line	M7 No License Plate No.	M8 License Plate No.
10	M5 Non-Alternating Line	M2 Flash	M1 Static	M2 Flash
Session 3: Comprehension (Fixed Time: message displayed for 8.4 seconds)				
	Test Message 4	Test Message 4	Test Message 4	Test Message 4
	Test Message 5	Test Message 5	Test Message 5	Test Message 5
	Test Message 6	Test Message 6	Test Message 6	Test Message 6
11	M1 Flash	M2 Static	M1 Flash	M6 No Alternating Line
12	M7 License Plate No.	M8 No License Plate No.	M4 Static Line	M8 No License Plate No.
13	M5 Alternating Line	M6 No Alternating Line	M7 License Plate No.	M9 Telephone Number No.
14	M3 Flash Line	M4 Static Line	M5 Alternating Line	M3 Flash Line
15	M9 Telephone Number No.	M10 No Telephone Number No.	M10 No Telephone Number No.	M2 Static

Table 8. (Continued)

	Group A		Group B	
	Group A1 (31 Subjects)	**Group A2 (32 Subjects)**	**Group B1 (31 Subjects)**	**Group B2 (32 Subjects)**
Session 4: Comprehension (Fixed Time: message displayed for 8.4 seconds)				
16	M2 Static	M1 Flash	M2 Static	M10 No Telephone Number No.
17	M8 No License Plate No.	M7 License Plate No.	M3 Flash Line	M5 Alternating Line
18	M6 No Alternating Line	M5 Alternating Line	M9 Telephone Number No.	M7 License Plate No.
19	M4 Static Line	M3 Flash Line	M8 No License Plate No.	M4 Static Line
20	M10 No Telephone Number No.	M9 Telephone Number No.	M6 No Alternating Line	M1 Flash
Session 5: Preference (Fixed Time: Two messages shown from each message pair shown, message on top in each cell displayed first, each message displayed for 8.4 seconds)				
21 22	M2 Static M2 Flash	M1 Flash M1 Static	M9 No Telephone Number No. M9 Telephone Number No.	M10 Telephone Number No. M10 No Telephone Number No.
23 24	M8 No License Plate No. M8 License Plate No.	M7 License Plate No. M7 No License Plate No.	M3 Static Line M3 Flash Line	M4 Flash Line M4 Static Line
25 26	M6 No Alternating Line M6 Alternating Line	M5 Alternating Line M5 No Alternating Line	M5 No Alternating Line M5 Alternating Line	M6 Alternating Line M6 No Alternating Line
27 28	M4 Static Line M4 Flash Line	M3 Flash Line M3 Static Line	M7 No License Plate M7 License Plate No.	M8 License. Plate M8 No License Plate

Table 8. (Continued)

	Group A		**Group B**	
	Group A1 (31 Subjects)	**Group A2 (32 Subjects)**	**Group B1 (31 Subjects)**	**Group B2 (32 Subjects)**
29	M10 No Telephone Number	M9 Telephone Number No.	M1 Static	M2 Flash
30	M10 Telephone Number No.	M9 No Telephone Number	M1 Flash	M2 Static

presented to orient subjects for warm-up purposes - three at the beginning of the first study session and three at the beginning of the third study session. Following the familiarization process, the subjects participated in a practice session and then the actual five sessions where the messages shown in Table 7 were displayed. The five sessions and the messages presented are detailed as follows:

- Ten messages were presented in two sessions where the subject controlled how long the message was displayed (referred to as "self-paced" sessions). Additionally, the first three messages (Test Messages 1 through 3, which are shown in Session 1 in Table 7) were additional practice messages and were not analyzed in this research. Reading time was automatically recorded by the study device - the PC displaying the PCSP and the driving simulator, respectively - and comprehension was determined by questions asked by the study facilitator.
- Ten messages were presented in the next two sessions (Sessions 3 and 4) where each message was displayed for 8.4 seconds (referred to as "fixed-time" sessions). The time of 8.4 seconds was selected because it is equivalent to the available reading time of typical modern light-emitting diode CMSs while drivers are traveling at 65 mph under ideal environmental conditions (92). Additionally, the first three (Test Messages 4 through 6, which are shown in Session 3 in Table 7) were additional practice message and were not analyzed in

this research. Comprehension was determined by questions asked by the study facilitator.

- Five pairs of messages were presented in Session 5, each message for 8.4 seconds (referred to as the "preference" session). Each pair represented the two alternatives of presenting a given message, such as Message M1 displayed with the entire message flashing versus Message M1 displayed in a static mode. After each pair of messages the subjects were asked which display alternative they preferred and why.

DATA COLLECTION PLAN

The data collection portion of the research was divided into two phases, with roughly half of the subjects tested in each phase. The purpose of dividing the subject pool into two data collection phases was to allow for an intermediate analysis of data from the first phase and provide for study design modifications if needed in the second phase. Specifically, if the analysis from the first phase indicated that one or more of the PCSP button display rates did not provide a good comparison of reading time and comprehension with the driving simulator there would be an opportunity to use that information to change the display rates in the second phase, and thus provide improved PCSP-simulator comparisons at the conclusion of this research. As previously shown in Figure 1 (page 5), the first phase of data collection was followed by a preliminary analysis, which was used to determine which of the possible second phase alternative approaches would be used for the remainder of the research data collection.

Data Collection Plan for the First Data Collection Phase

In the original study design, 128 subjects were planned for testing, to provide adequate sample sizes for up to four different PCSP button display rates. Sixty-four subjects were tested in the first data collection phase.

- Thirty-two of the 64 subjects were tested first within the PCSP and then in the driving simulator after a minimum two-week wait. Sixteen of these were tested within the PCSP with a button display rate of 0.625 button/second and sixteen using a button display rate of 0.909 button/second.
- Thirty-two of the 64 subjects were tested first in the driving simulator and then within the PCSP after a minimum two-week wait. Sixteen of these were tested within the PCSP with button display rate of 0.625 button/second and sixteen using a button display rate of 0.909 button/second.

The data collected from the 64 subjects were analyzed to compare the results from the two button display rates. The results of the analysis with recommendations on how to allocate the subjects for the second data collection phase can be found in Appendix C. Based on the analysis of the 64 subjects, it was determined that a third PCSP scenario without any secondary subject task should also be tested. The use of the PCSP without any secondary task simplified the PCSP to a single-task study procedure.

Data Collection Plan for the Second Data Collection Phase

With the addition of a third level of subject workload for the PCSP, the distribution of the remaining subjects was altered in order to provide equal sample sizes and demographics distributions. Since 64 subjects were tested in the first data collection phase, an additional 62 subjects were tested in the second data collection phase in order to allow equal sample sizes among the three workload levels within the PCSP. The subjects within the second data collection phase were allocated as follows:

- Thirty-one of the additional 62 subjects were tested first within the PCSP and then in the driving simulator after a minimum two-week wait. Five of these were tested within the PCSP with button display rate of 0.625 button/second, and five using a button display rate of 0.909 button/second, and 21 subjects were tested with no secondary task and were only asked to read and recall the sign messages as a single-task study.

- Thirty-one of the additional 62 subjects were tested first in the driving simulator and then within the PCSP after a minimum two-week wait. Five of these were tested within the PCSP with button display rate of 0.625 button/second, and five using a button display rate of 0.909 button/second, and 21 subjects were tested with no secondary task and were only asked to read and recall the sign messages as a single-task study.

Once combined, the total distribution of subjects from the two phases allowed for:

- 42 subjects that were tested within the PCSP with no secondary task,
- 42 subjects that were tested within the PCSP with a secondary task with button display rate of 0.625 button/second, and
- 42 subjects that were tested within the PCSP with a secondary task with button display rate of 0.909 button/second.

Counterbalancing Study Methods

The study was divided into two different sections for studying how well subjects could read and comprehend CMS messages: one section where subjects were tested within the PCSP, and another where subjects were tested in TTI's driving simulator. Each subject was tested on both systems with a two-week wait between tests in order to limit any learning effect. In order to prevent an order bias in the order of tests, half of the subjects were tested first within the PCSP and then in the driving simulator after a two-week wait. The other half were tested first in the driving simulator and then within the PCSP after a two-week wait.

Reading Time and Comprehension Data

The self-paced sessions involved measurements of reading time and comprehension. Each CMS message was displayed until the subject read and understood the message at which point the subject turned off the message. For the PCSP the subject would turn off the messages by pressing the space bar; for the driving simulator studies there were switches installed on the driving simulator's steering wheel that the subject used to turn the message off. The time that each message was visible to the subject was automatically recorded and provided data for reading times. Following each message, the study administrator asked three or four questions (one for each line of information presented) relative to the content of the message on each line and recorded the responses on prepared forms. Examples of the questions were:

- What is the traffic problem?
- What type of situation has occurred?
- Where was the problem located?
- What are you supposed to do?
- Did the message tell you what to look for (AMBER alert questions only)?
- Did the message tell you where to get more information (AMBER alert questions only)?

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 every time a given message format was displayed, so a direct comparison between different displays of a given message was possible. The facilitator's survey document for subject group A1 is shown in Appendix A; the survey documents for the remaining three groups are not included in Appendix A, as the only differences are in the order of the specific messages, as shown in Table 7.

Display of the messages in the fixed-time sessions was very similar to the self-paced session with one exception: the CMS messages were displayed for 8.4 seconds and would then automatically turn off. The method of asking questions was identical to that used during the self-paced sessions.

The preference portion of the study involved showing the subject two similar messages with two different formats (such as Message M1 Flashing and Message M1 Static), each displayed for a fixed time of 8.4 seconds. Subjects were then asked which message they preferred and their reasons for selecting the specific message style.

TESTS TO DETERMINE IF DATA FROM SIMILAR CMS MESSAGES CAN BE COMBINED

As shown earlier in Table 6, each CMS message had a similar message with the same format but with slightly different wording. The similar messages were:

- Messages M1 Flashing and Message M2 Flashing,
- Message M1 Static and Message M2 Static,
- Message M3 Flashing Line and Message M4 Flashing Line
- Message M3 Static and Message M4 Static,
- Message M5 Alternating Line and Message M6 Alternating Line,
- Message M5 No Alternating Line and Message M6 No Alternating Line,
- Message M7 License Plate Number and Message M8 License Plate Number,

- Message M7 No License Plate Number and Message M8 No License Plate Number,
- Message M9 Telephone Number and Message M10 Telephone Number, and
- Message M9 No Telephone Number and Message M10 Telephone Number.

Using similar messages for each format provided an increased number of messages to subjects so the subjects would not simply memorize or anticipate the messages. Because each pair of similar messages were intended to have comparable readability characteristics, testing was conducted to determine if the reading time, comprehension, and preference data from the similar messages could be combined prior to testing for the MOEs in this research. The primary advantage to combining the data from the similar messages was to increase the sample sizes of each test, therefore providing an increase in statistical power. The tests to determine if the data from similar messages may be combined are described below.

Hypothesis Testing for Combining Self-Paced Reading Time Data

In order to make a direct analysis of the difference in reading times by a single subject, it was necessary to determine if there were any statistically significant reading time differences between the similar messages. If the average reading times of similar messages were not statistically different, then the reading times for the similar messages could be grouped, allowing a direct comparison of the difference in reading times for two similar messages. For example, if no statistically significant differences for the reading time within the PCSP for Message M1 Flashing and Message M2 Flashing, then these data could be consolidated into a combined dataset Messages M1 & M2. If this can be repeated for the data in the driving simulator, then the testing to determine the similarities between the PCSP and driving simulator would use these combined datasets. The following hypotheses were tested to compare the mean reading times of the similar messages:

H_{0j}: $\mu_{\bullet j,k} = \mu_{\bullet j+2,k}$ (There is no difference between the mean reading time for a message *j* and the similar message *j+2*), and

H_{1j}: $\mu_{\bullet j,k} \neq \mu_{\bullet j+2,k}$ (There is a difference between the mean reading time for a message *j* and the similar message *j+2*).

Where:

j = {Message M1 Static = 1, Message M1 Flashing = 2, Message M3 Static = 5, Message M3 Flashing Line = 6, Message M5 No Alternating Line = 9, Message M5 Alternating Line = 10, Message M7 No License Plate = 13, Message M7 License Plate = 14, Message M9 No Telephone Number = 17, Message M9 Telephone Number = 18}; and

j+2 = {Message M2 Static = 3, Message M2 Flashing = 4, Message M4 Static = 7, Message M4 Flashing Line = 8, Message M6 No Alternating Line = 11, Message M6 Alternating Line = 12, Message M8 No License Plate = 15, Message M8 License Plate = 16, Message M10 No Telephone Number = 19, Message M10 Telephone Number = 20}.

Hypothesis Testing for Combining Comprehension Data

It was also considered desirable to test whether similar message could be combined for the comprehension data. Each test was performed separately for the comprehension data collected during the self-paced sessions and the fixed-time sessions.

The following calculations were made:

$$D_{j,k,l} = (\text{Proportion of Comprehension}_{j,k,l}) - (\text{Proportion of Comprehension}_{j+2,k,l}) \quad (1)$$

The following hypotheses were tested to determine if both the self-paced comprehension data could be combined for similar messages as well as the fixed-time comprehension data could be combined:

H_{0j}: $D_{j,k,l} = 0$, (There is no difference in the comprehension of a given message j and the similar message j+2), and

H_{1j}: $D_{j,k,l} \neq 0$ (There is a difference in the comprehension of a given message j and the similar message j+2).

Where:

k = The study procedure used {PCSP = 1; Driving Simulator = 2}, and

l = The message sets displayed to the subjects {self-paced sessions = 1; fixed time = 2}

Similar Message Analysis from the Preference Session

The preference rates calculated from the responses of all subjects were compared and tested to determine if the similar messages could be compared. The differences in preference rates were calculated as:

$$D_{j,k,l} = (\text{Preference}_{,k,l}) - (\text{Preference}_{j+2,k,l}) \qquad (2)$$

The following hypotheses were tested:

H_{0j}: $D_{j,k,l} = 0$, (There is no difference in the preference of a given message j and the similar message $j+2$), and

H_{1j}: $D_{j,k,l} \neq 0$ (There is a difference in the preference of a given message j and the similar message $j+2$).

The analysis regarding the combination of similar message will be shown in Chapter V.

MEASURES OF EFFECTIVENESS AND HYPOTHESIS STATEMENTS

Five MOEs were selected for this research:

- MOE #1: average reading times between alternative messages presented to subjects, such as the comparison between Message M1 Flashing and Message M1 Static. MOE #1 was used to test whether research conclusions reached for average reading times from the PCSP were the same as the conclusions using the driving simulator. This MOE was used to determine if a researcher could arrive at the same conclusions if the PCSP were used as the research tool instead of the driving simulator during the self-paced portion of the research.
- MOE #2: difference in reading times between messages presented in the driving simulator and those presented within the PCSP. Specifically, MOE #2 was used to test the numeric difference in individual subjects' reading time performance between the driving simulator and the PCSP for the CMS messages displayed during the self-paced sessions of the study.
- MOE #3: percentage of subjects that were able to comprehend messages displayed in the driving simulator and the percentage that comprehended messages displayed within the PCSP. Specifically, MOE #3 was used to test the numeric differences in comprehension rates between the driving simulator and the PCSP. This MOE was used twice:
  - once for the comprehension data collected during the self-paced sessions of the study, and
  - once for the comprehension data collected during the fixed-time sessions of the study.

- MOE #4: numeric differences in the stated preference rates between the driving simulator for CMS messages displayed during the preference sessions of the study.
- MOE #5: numeric differences in Cooper-Harper Rating Scale ratings provided by each individual after using both the driving simulator and the PCSP.

Research Hypotheses

Statistical hypotheses were developed in order to test MOEs #1 through #5. Each statistical hypothesis test is presented below.

Hypothesis Statements for MOE #1

MOE #1 was included to investigate the usefulness of the PCSP in arriving at the same research conclusions as the driving simulator with respect to average reading times. For example, MOE #1 was useful in determining how well results from the PCSP at a given secondary task subject loading compared to the driving simulator, such as if one format of CMS message display (flashing the entire message, for example) took longer to read than a non-flashing alternative message. If the results are the same, MOE #1 will indicate that the PCSP at a given secondary task subject loading will provide a good alternative to the driving simulator. The intent in using this MOE was to test the results as a researcher would do if they were using the PCSP to conduct research on the differences in how long it takes subjects to read different alternative messages (such as flashing the entire message and the static alternative), and to compare the results with that provided from the driving simulator.

The CMS messages used for this research were grouped into pairs of similar message formats, as previously shown in Table 6, such as Messages M1 & M2 Flashing, Messages M1 & M2 static, Messages M3 & M4 Flashing Line, and so on. During the self-paced portion of the study, each subject viewed a variation of one of the CMS message formats (e.g., Message M1 Flashing) and the other variation of the other similar CMS message (e.g., Message M2 Static). Other subjects saw the opposite variations of these messages, depending on which group a given subject was in. This analysis was a necessary step conducted prior to the testing of the hypotheses for MOE #1.

The following hypotheses were developed for testing:

> H_{0j}: The difference in average reading time between the dynamic messages (e.g., flashing message) or the numeric AMBER alert messages and the alternative message (e.g., non-flashing message, non-numeric AMBER alert, etc.) are the same for both the driving simulator and the PCSP; and

> H_{1j}: The difference in average reading time between the dynamic messages (e.g., flashing message) or the numeric AMBER alert messages and the alternative message (e.g., non-flashing message, non-numeric AMBER alert, etc.) are not the same for both the driving simulator and the PCSP.

Where:

j = Combined Messages {Messages M1 & M2 Static = 1; Messages M1 & M2 Flashing = 2; Messages M3 & M4 Static = 5; Messages M3 & M4 Flashing Line = 6; Messages M5 & M6 No Alternating Line = 9; Messages M5 & M6 Alternating Line = 10; Messages M7 & M8 No License Plate Number = 13; Messages M7 & M8 Alternating Line = 14; Messages M9 & M10 No Telephone Number = 17; Messages M9 & M10 Telephone Number = 18}.

Hypothesis Statements for MOE #2

As in the hypothesis tests for MOE #1, similar messages for MOE #2 were combined into a single dataset. The reading time for each alternative CMS message was recorded when the subjects viewed the sign within the PCSP, and again when they viewed the same message in the driving simulator. The only difference then between the two reading time measurements was the procedure used to impose mental workload on the subject (PCSP or driving simulator).

If overall the actual reading times had a small numeric difference, then the difference in reading times (DRT) between the PCSP and the driving simulator would be close to zero, and the mean of all of the subjects' DRTs would also be close to zero

The following calculations were made for this MOE:

$$DRT_{i,j} = (\text{PCSP Reading Time}_{i,j}) - (\text{Driving Simulator Reading Time}_{i,j}) \qquad (3)$$

Where:

i = Subject Number {1 to 126}, and assuming the similar CMS messages were not statistically significantly different and therefore able to be consolidated into combined datasets.

The following hypotheses were developed for testing:

H_{0j}: $DRT_{\bullet,j} = 0$ (mean difference in reading times for a given set of combined message displays j are equal), and

H_{1j}: $DRT_{\bullet,j} \neq 0$ (mean difference in reading times for a given set of combined message displays j are not equal).

Hypothesis Statements for MOE #3

Each combined CMS message *j* was analyzed using the Bernoulli Model to compare proportions of subjects that were able to correctly recall all of the information presented in the message (3 lines of information for Messages M1, M2, M3, M4, M7, M8, M9, and M10 (j = 1-8, 13-20); 4 lines of information for Messages M5 and M6 (j = 9-12) (93). The Bernoulli Model is as follows:

$$z = \frac{f_1 - f_2}{\sqrt{\frac{p_c(1-p_c)}{n_1} + \frac{p_c(1-p_c)}{n_2}}} \qquad (4)$$

Where:

f_1 = the proportion of subjects that correctly recalled all of a message in the PCSP,

f_2 = the proportion of subjects that correctly recalled all of a message on the driving simulator,

n_1 = the number of subjects tested on a given PCSP button-pressing display rate, and

n_2 = the number of subjects tested in the driving simulator.

$$p_c = \frac{X_1 + X_2}{n_1 + n_2}, \qquad (5)$$

Where:

X_1 = the number of correct responses in the PCSP dataset, and

X_2 = the number of correct responses in the driving simulator dataset.

The following calculations were made:

$$D_{j,k,l} = (\text{PCSP Comprehension}_{j,k,l}) - (\text{Driving Simulator Comprehension}_{j,k,l}) \tag{6}$$

The following hypotheses were developed for testing:

H_{0j}: Mean Value of $D_{j,k,l} = 0$ (message comprehension for a given message display *j* are equal), and

H_{1j}: Mean Value of $D_{j,k,l} \neq 0$ (message comprehension for a given message *j* are not equal).

Hypothesis Statements for MOE #4

The Bernoulli Model was also used to test the stated preference of subjects regarding which CMS message they preferred out of ten message pairs. The following calculations were made:

$$D_{j,k} = (\text{PCSP Preference}_{j,k}) - (\text{Driving Simulator Preference}_{j,k}) \tag{7}$$

The following hypotheses were tested:

H_{0j}: Mean Value of $D_{j,k} = 0$ (message preference for a given message display *j* are equal), and

H_{1j}: Mean Value of $D_{j,k} \neq 0$ (message preference for a given message *j* are not equal).

Hypothesis Statements for MOE #5

When the subject was finished with the PCSP portion of the study they were asked to provide a Cooper-Harper rating on the relative difference between the PCSP and their experiences driving real vehicles in typical driving circumstances. The scale used was similar to that shown previously in Figure 7 , but the rating scale was extended to include three possible scores indicating that the driving simulator was “too easy to be comparable with real driving” (0, -1, and -2 indicating too easy).

The Cooper-Harper rating process was repeated at the end of the driving simulator portion of the study, so the two ratings could be compared. There was an interest to see if subjects were more likely to rate the PCSP portion of the study as harder or easier based on the button-pressing display rates when compared to their ratings in the driving simulator. The differences between the PCSP rating and the driving simulator rating were determined for each subject. The differences in the individual responses, $D_{i,j}$, were calculated as follows and were tested for the difference in median values between two populations (94):

The following calculations were made:

$D_{i,j}$ = Cooper-Harper Rating for the PCSP minus Cooper-Harper Rating for the driving simulator. (8)

The following hypotheses were tested:

H_{0j}: Median Value of $D_{\bullet,j} = 0$, (The median difference between the driving simulator and the PCSP are equal), and

H_{1j}: Median Value of $D_{\bullet,j} \neq 0$ (The median difference between the driving simulator and the PCSP are not equal).

FACTS REGARDING DATA COLLECTION

Data were gathered for the first data collection phase from June 2004 through September 2004. Data were gathered for the second data collection phase from April 2006 through June 2006. A total of 126 subjects were successfully tested in both the driving simulator and the PCSP. In addition, 26 subjects were partially tested and had to be replaced because they were unable to complete the entire study for the following reasons:

- Eight subjects got sick in the driving simulator and so could not complete the study, and
- Eighteen other subjects completed one study method (fourteen in the driving simulator and four within the PCSP), but then chose not to return and complete the second study method.

The 26 subjects that were only able to complete part of the study were replaced with subjects that were able to complete the entire study. The data from the 26 subjects that were unable to complete the entire study were not used in the results shown in the following chapters.

The study design presented in this chapter was prepared in order to test the hypothesis statements and to minimize any bias in the data due to order effects or demographic effects. A summary of the actual data collection process and the analysis of the data are presented in Chapter V.

CHAPTER V

RESEARCH RESULTS

The study design was presented in the previous chapter, which showed how subjects were tested both within the PCSP and in the driving simulator. The PCSP was presented to subjects in three different subject loading levels: as a single task study tool with no control panel button-pressing task, and with the control panel button-pressing task at two display rates, 0.625 button/second, and 0.909 button/second. In this chapter, the data collection analysis and the results of the analysis are presented and discussed.

ANALYSIS OF SIMILAR CMS MESSAGES

All of the data for the subjects that completed the study were tested to determine if the similar messages (such as Message M1 Flashing and Message M2 Flashing) were statistically significantly different in reading time, comprehension, and preference. It was revealed during the analysis that very few instances of statistical significance were observed when comparing similar messages. These few instances were examined to determine if any trends could be identified which would indicate that it would be inappropriate to consolidate the data into combined datasets (such as Messages M1&M2 Flashing). No trends were observed, and so all of the data were consolidated into combined datasets.

Analysis for Combining Self-Paced Reading Time Data for Similar CMS messages

The results of the statistical tests for the comparisons of the messages for the driving simulator and the PCSP are shown in Tables 9 and 10, respectively. In only three cases

Table 9. Comparison of Mean Reading Times of Similar CMS Message Formats during Personal Computer Study Procedure Sessions

Message and Display Format	n	Mean	St. Dev.	p-value	Significant Difference? (α =0.05)
M1 Flashing	63	6.68	3.77	0.187	No
M2 Flashing	63	7.66	4.49		
M1 Static	63	7.20	3.12	**0.023**	**Yes**
M2 Static	63	6.01	2.65		
M3 Flashing Line	63	6.79	3.25	0.161	No
M4 Flashing Line	63	7.55	2.78		
M3 Static	63	7.65	4.73	0.341	No
M4 Static	63	6.94	3.51		
M5 Alternating Line	62*	14.01	7.14	0.321	No
M6 Alternating Line	63	15.18	5.93		
M5 No Alternating Line	63	12.26	4.60	0.809	No
M6 No Alternating Line	62†	12.48	5.54		
M7 License Plate Number	63	9.46	4.23	0.675	No
M8 License Plate Number	63	9.80	4.83		
M7 No License Plate Number	63	7.16	4.03	0.538	No
M8 No License Plate Number	63	6.70	4.32		
M9 Telephone Number	63	9.80	4.19	0.696	No
M10 Telephone Number	63	10.14	5.46		
M9 No Telephone Number	63	7.25	3.95	**0.006**	**Yes**
M10 No Telephone Number	63	5.45	3.17		

* One subject did not follow instructions for Message "M6 No Alternating" during the PCSP session reduced the sample size for this message to 62.

† One subject did not follow instructions for Message "M5 Alternating" during the PCSP session and so reduced sample size for this message to 62.

Table 10. Comparison of Mean Reading Times of Similar CMS Message Formats during Driving Simulator Self-Paced Sessions

Message and Display Format	n	Mean	St. Dev.	p-value	Significant Difference? (α =0.05)
M1 Flashing	63	6.80	4.16	0.551	No
M2 Flashing	63	7.21	3.51		
M1 Static	63	6.54	2.86	0.562	No
M2 Static	63	6.87	3.48		
M3 Flashing Line	63	7.01	3.00	0.129	No
M4 Flashing Line	63	7.96	3.91		
M3 Static	63	7.12	3.24	0.763	No
M4 Static	63	7.30	3.45		
M5 Alternating Line	62*	14.85	6.49	0.783	No
M6 Alternating Line	63	14.51	7.25		
M5 No Alternating Line	63	14.16	6.12	0.597	No
M6 No Alternating Line	62†	13.62	5.22		
M7 License Plate Number	63	10.09	5.93	0.641	No
M8 License Plate Number	63	9.65	4.55		
M7 No License Plate Number	63	7.23	3.33	0.205	No
M8 No License Plate Number	63	6.46	3.45		
M9 Telephone Number	63	10.21	6.03	0.160	No
M10 Telephone Number	63	8.97	3.49		
M9 No Telephone Number	63	7.02	2.87	**0.011**	**Yes**
M10 No Telephone Number	62‡	5.77	2.56		

* One subject did not follow instructions for Message "M5 Alternating" during driving simulator session and so reduced sample size for this message to 62.
† Data error for one subject for Message "M6 No Alternating" during the driving simulator session reduced the sample size for this message to 62.
‡ One subject did not follow instructions for Message "M10 No Telephone Number" during the driving simulator session and so reduced sample size for this message to 62.

was the null hypothesis was rejected, indicating that there was evidence that the mean reading times of the similar messages were different in those cases. No trends were observed based on these statistical differences. In the other seventeen cases the null hypothesis was not rejected, meaning that there was no evidence that the mean reading times of the similar messages were different. As a result, for the remainder of this research all of the reading time data were combined, so that all remaining analyses were made comparing Messages M1 & M2 Flashing versus Messages M1 & M2 Static, Messages M3 & M4 Flashing Line versus Messages M3 & M4 Static, and so on.

Analysis for Combining Comprehension Data for Similar CMS messages

From the self-paced sessions performed within the PCSP, the comprehension for each similar message was compared to determine if they could be appropriately consolidated into a combined dataset. All ten pairs of similar messages were found to be not significantly different with respect to subject comprehension. Because no statistical differences were found between any of the similar CMS messages, the researcher considered it acceptable to combine these data; the message datasets were combined for subsequent analysis. The results of these tests are shown in Table 11.

For the self-paced sessions performed in the driving simulator, ten message pairs were compared, with nine of the ten showing no significant differences, as shown in Table 12. The comparison of Message M1 Flashing and Message M2 Flashing revealed that the two messages had a statistically significantly different comprehension level, with Message M1 Flashing being correctly comprehended by 89 percent of subjects, while 70 percent of subjects correctly recalled Message M2 Flashing. However, as shown in Table 13, the comprehension of Message M1 Flashing and Message M2 Flashing during the *fixed-time sessions* were not significantly different from each other. This finding indicated that no trend or pattern was evident for these messages. Because no trend was observed for Message M1 Flashing and Message M2 Flashing, and the fact that no other

Table 11. Comparison of Message Comprehension by CMS Message Format during Personal Computer Study Procedure Self-Paced Sessions

Message and Display Format	n	Number Correct	Percent Correct	p-value	Significant Difference? (α =0.05)
M1 Flashing	63	50	79	0.301	No
M2 Flashing	63	45	71		
M1 Static	63	49	78	0.828	No
M2 Static	63	50	79		
M3 Flashing Line	63	39	62	0.586	No
M4 Flashing Line	63	36	57		
M3 Static	63	34	54	0.367	No
M4 Static	63	39	62		
M5 Alternating Line	62†	38	61	0.515	No
M6 Alternating Line	63	35	56		
M5 No Alternating Line	63	29	46	0.325	No
M6 No Alternating Line	62*	34	55		
M7 License Plate Number	63	21	33	0.357	No
M8 License Plate Number	63	26	41		
M7 No License Plate Number	63	58	92	0.380	No
M8 No License Plate Number	63	55	87		
M9 Telephone Number	63	23	37	0.573	No
M10 Telephone Number	63	20	32		
M9 No Telephone Number	63	52	83	0.116	No
M10 No Telephone Number	62‡	57	92		

* One subject did not follow instructions for Message "M5 Alternating" during the PCSP session reduced the sample size for this message to 62.
† One subject did not follow instructions for Message "M6 No Alternating" during the PCSP session and so reduced sample size for this message to 62.
‡ One subject did not follow instructions for Message "M10 No Telephone Number" during the driving simulator session and so reduced sample size for this message to 62.

Table 12. Comparison of Message Comprehension by CMS Message Format during Driving Simulator Self-Paced Sessions

Message and Display Format	n	Number Correct	Percent Correct	p-value	Significant Difference? (α =0.05)
M1 Flashing M2 Flashing	63 63	56 44	89 70	**0.008**	**Yes**
M1 Static M2 Static	63 63	54 52	86 83	0.626	No
M3 Flashing Line M4 Flashing Line	63 63	40 31	63 49	0.106	No
M3 Static M4 Static	63 63	39 42	62 67	0.577	No
M5 Alternating Line M6 Alternating Line	62* 63	39 39	63 62	0.908	No
M5 No Alternating Line M6 No Alternating Line	63 62†	42 40	67 65	0.800	No
M7 License Plate Number M8 License Plate Number	63 63	27 23	43 37	0.466	No
M7 No License Plate Number M8 No License Plate Number	63 63	60 62	95 98	0.310	No
M9 Telephone Number M10 Telephone Number	63 63	25 24	40 38	0.855	No
M9 No Telephone Number M10 No Telephone Number	63 62‡	58 60	92 97	0.252	No

* One subject did not follow instructions for Message "M5 Alternating" during driving simulator session and so reduced sample size for this message to 62.

† Data error for one subject for Message "M6 No Alternating" during the driving simulator session reduced the sample size for this message to 62.

‡ Data error for one subject for Message "M10 No Telephone Number" during the driving simulator session reduced the sample size for this message to 62.

Table 13. Comparison of Message Comprehension by CMS Message Format during the Personal Computer Study Procedure Fixed-Time Sessions

Message and Display Format	n	Number Correct	Percent Correct	p-value	Significant Difference? (α =0.05)
M1 Flashing	63	54	86	0.794	No
M2 Flashing	63	55	87		
M1 Static	63	55	87	0.380	No
M2 Static	63	58	92		
M3 Flashing Line	63	39	62	0.083	No
M4 Flashing Line	63	48	76		
M3 Static	63	42	67	0.563	No
M4 Static	63	45	71		
M5 Alternating Line	63	39	62	0.469	No
M6 Alternating Line	63	35	56		
M5 No Alternating Line	58*	40	69	0.062	No
M6 No Alternating Line	63	33	52		
M7 License Plate Number	63	18	29	0.342	No
M8 License Plate Number	63	23	37		
M7 No License Plate Number	58†	58	100	0.335	No
M8 No License Plate Number	63	62	98		
M9 Telephone Number	63	23	37	0.450	No
M10 Telephone Number	63	19	30		
M9 No Telephone Number	63	54	86	**0.027**	**Yes**
M10 No Telephone Number	63	61	97		

* Data errors for five subjects for Message "M5 No Alternating" during the PCSP fixed-time session reduced the sample size for this message to 58.
† Data errors for five subjects for Message "M7 No License Plate" during the PCSP fixed-time session reduced the sample size for this message to 58.

statistical significance was observed for the self-paced reading time comprehension, it was considered appropriate to combine the Message M1 Flashing and Message M2 Flashing into a combined dataset.

The same hypothesis statements used to analyze the comprehension data during the self-paced study sessions were used to determine if the fixed-time comprehension data could be combined in the same manner. The results of these tests are shown in Table 14. During the fixed-time sessions presented within the PCSP, ten CMS message pairs were compared, for both the driving simulator sessions and the PCSP sessions, as shown in Tables 13 and 14. The comparison of Messages M9 and M10 No Telephone Number revealed that the two messages had a statistically significant difference in comprehension levels for the PCSP sessions, with Message M9 No Telephone Number being correctly comprehended by 86 percent of subjects, while 97 percent of subjects correctly recalled Message M10 No Telephone Number. Again, because no statistical significance was only found for the fixed-time results, but not for the self-paced results, it was not clear that any trend was established. Therefore, it was considered appropriate to consolidate the Message M9 No Telephone Number and Message M10 No Telephone Number into a combined dataset.

Analysis for Combining Preference Data for Similar CMS messages

The results of the analysis for combining preference data for similar CMS messages are shown in Tables 15 and 16. Most messages presented within the PCSP were found to be not significantly different from their similar messages based on the preference data. However, two sets of messages were found to be statistically significantly different: Messages M7 and M8, and Messages M9 and M10. Each of these results was examined more closely.

When asked which message they preferred between Message M7 No License Plate

Table 14. Comparison of Message Comprehension by CMS Message Format during Driving Simulator Fixed-Time Sessions

Message and Display Format	N	Number Correct	Percent Correct	p-value	Significant Difference? (α =0.05)
M1 Flashing M2 Flashing	63 63	57 56	90 89	0.770	No
M1 Static M2 Static	63 63	56 54	89 86	0.593	No
M3 Flashing Line M4 Flashing Line	63 63	47 49	75 78	0.676	No
M3 Static M4 Static	63 63	51 47	81 75	0.391	No
M5 Alternating Line M6 Alternating Line	63 63	47 42	75 67	0.328	No
M5 No Alternating Line M6 No Alternating Line	63 63	37 35	64 56	0.719	No
M7 License Plate Number M8 License Plate Number	63 63	21 18	33 29	0.563	No
M7 No License Plate Number M8 No License Plate Number	63 63	56 59	97 94	0.344	No
M9 Telephone Number M10 Telephone Number	63 63	25 20	40 32	0.353	No
M9 No Telephone Number M10 No Telephone Number	63 63	57 60	90 95	0.299	No

Table 15. Comparison of Message Preference by CMS Message Format during Personal Computer Study Procedure Preference Sessions

Message and Display Format	n	Number Preferred	Percent Preferred	p-value	Significant Difference? (α =0.05)
M1 Static (Preferred over M1 Flashing)	63	37	59	0.473	No
M2 Static (Preferred over M2 Flashing)	63	33	52		
M3 Static (Preferred over M3 Flashing Line)	63	26	41	0.473	No
M4 Static (Preferred over M4 Flashing Line	63	30	48		
M5 No Alternating Line (Preferred over M5 Alternating Line)	63	29	46	0.858	No
M6 No Alternating Line (Preferred over M6 Alternating Line)	63	28	44		
M7 No License Plate Number (Preferred over M7 License Plate Number)	63	50	79	**0.031**	**Yes**
M8 No License Plate Number (Preferred over M8 License Plate Number)	63	39	62		
M9 No Telephone Number (Preferred over M9 Telephone Number)	63	55	87	**0.017**	**Yes**
M10 No Telephone Number (Preferred over M10 Telephone Number)	63	44	70		

Table 16. Comparison of Message Preference by Message Format during Driving Simulator Preference Sessions

Message and Display Format	n	Number Preferred	Percent Preferred	p-value	Significant Difference? (α =0.05)
M1 Static (Preferred over M1 Flashing)	63	40	63	0.278	No
M2 Static (Preferred over M2 Flashing)	63	34	54		
M3 Static (Preferred over M3 Flashing Line)	63	33	52	0.859	No
M4 Static (Preferred over M4 Flashing Line	63	32	51		
M5 No Alternating Line (Preferred over M5 Alternating Line)	62	30	48	0.366	No
M6 No Alternating Line (Preferred over M6 Alternating Line)	62	25	40		
M7 No License Plate Number (Preferred over M7 License Plate Number)	63	49	78	0.207	No
M8 No License Plate Number (Preferred over M8 License Plate Number)	62	42	68		
M9 No Telephone Number (Preferred over M9 Telephone Number)	63	55	87	0.329	No
M10 No Telephone Number (Preferred over M10 Telephone Number)	63	51	81		

Number and Message M7 License Plate Number, 79 percent of subjects preferred the nonnumeric alternative. When asked which message they preferred between Message M8 No License Plate Number and Message M8 License Pate Number, 62 percent of subjects preferred the nonnumeric alternative. It is possible that the differences in the vehicle descriptions used (BLUE CHEVROLET for Message M7 and GREEN OLDSMOBILE for Message M8) combined with the variations in license plate numbers used (LIC 825 493 for Message M7 and LIC 739 452 for Message M8) may have varied the subjects' preferences, even though their reading times and comprehension of these messages were unaffected. These preferences are in the same relative range: 62 to 79 percent, indicating that a majority of subjects preferred the nonnumeric messages, but not anything approaching 100 percent of the subjects. Therefore, it still appeared reasonable to combine the results of Messages M7 and M8 into a combined dataset for further analysis.

When asked which message they preferred between Message 9 No Telephone Number and Message 9 Telephone Number, 87 percent of subjects preferred the nonnumeric alternative. When asked which message they preferred between Message 10 No Telephone Number and Message 10 Telephone Number, 70 percent of subjects preferred the nonnumeric alternative. Again, it is possible that the differences in the vehicle descriptions used (SILVER LINCOLN for Message M9 and YELLOW TOYOTA for Message M10) combined with the variations in telephone numbers used (800 268 3200 for Message M9 and 888 769 5000 for Message M10) may have varied the subjects' preferences. In any event, these data still appeared to be similar to the driving simulator in an overall sense, and so these data were consolidated into a combined dataset.

All five of the tests of hypothesis for the preference messages in the driving simulator could not be rejected. Therefore, there was no evidence indicating that the preference data could not be combined.

ANALYSIS AND RESULTS OF COMBINED CMS MESSAGE DATA

Using the combined data for each set of similar CMS messages, analyses were performed to compare the PCSP results with the driving simulator results. Five MOEs were used to determine how well the PCSP was able to provide similar results to the driving simulator at each of the three tested button display settings. Comparisons were made for each of the ten sets of combined CMS message data for average reading times, differences in reading times, comprehension of both the self-paced and fixed-time reading sessions, the five sets of combined CMS message data for the preference sessions, and for the overall Cooper-Harper workload ratings provided by the subjects. Because all of the similar message data were successfully combined, the remainder of the analyses presented use only the combined datasets.

MOE #1: Comparison of Reading Times of Alternative Message Formats during Self-Paced Reading Sessions

The objective of this analysis was to aid in determining which of the three PCSP button display rates resulted in the same conclusions relative to average reading times compared with those reached with the driving simulator. Direct comparisons were made between the average reading time results obtained in the driving simulator and the three different button display rates used in the PCSP. Of interest for this research was whether the PCSP provided statistically significant differences for the same message formats as the driving simulator. Additionally, if a given message format (such as Messages M1&M2 Flashing) takes significantly longer to read in the driving simulator than its alternative message (such as Messages M1&M2 Static), then it should ideally take longer to read when presented within the PCSP as well.

Table 17 shows the mean and standard deviations of the reading times. Table 18 shows the difference in average reading time between each message format and its alternative

Table 17. Comparison of Reading Time Results from the Driving Simulator with the Reading Time Results from the Personal Computer Study Procedure at Different Button Display Rates.

Message	Message Display Format	Driving Simulator Reading Time n = 126*		Personal Computer Study Procedure: No Secondary Task Reading Time n = 42		Personal Computer Study Procedure: 0.625 button/second display rate Reading Time n = 42		Personal Computer Study Procedure: 0.909 button/second display rate Reading Time n = 42	
		Mean (sec)	St. Dev. (sec)	Mean (sec)	St. Dev. (sec)	Mean (sec)	St. Dev. (sec)	Mean (sec)	St. Dev. (sec)
M1&2	Flashing	7.06	3.86	7.47	3.82	7.65	5.37	6.54	3.04
	Static	6.77	3.25	6.99	3.01	6.85	3.09	5.99	2.66
M3&4	Flashing Line	7.50	3.50	7.20	3.20	7.53	3.58	7.03	2.69
	Static	7.25	3.35	7.68	3.65	7.42	5.56	6.81	2.83
M5&6	Alternating Line	14.70	6.84	14.86	5.41	15.88	8.52	13.31	5.21
	No Alternating Line	13.90	5.66	13.18	5.75	13.06	5.36	11.07	3.80
M7&8	License Plate Number	9.94	5.29	9.37	3.74	10.14	6.46	9.59	4.49
	No License Plate Number	6.88	3.40	7.77	4.12	5.42	4.54	6.58	3.71
M9&10	Telephone Number	9.67	5.00	10.34	4.39	10.49	6.54	9.17	3.73
	No Telephone Number	6.42	2.78	6.99	4.12	6.12	3.91	5.56	2.80

* One subject did not follow instructions for Message "M5 Alternating" during driving simulator session and so the sample size for Messages M5&M6 Alternating was reduced to 125. A data error for one subject for Message "M6 No Alternating" during the driving simulator session reduced the sample size for Messages M5&M6 No Alternating to 125. One subject did not follow instructions for Message "M10 No Telephone Number" during the driving simulator session and so the sample size for Messages M9&M10 No Telephone Number was reduced to 125.

Table 18. Comparison of Difference in Average Reading Times of Dynamic or AMBER Alert Messages and Their Alternative Messages: Driving Simulator and Personal Computer Study Procedures.

Message	Study Procedure	N	Mean Difference (s)	p-value	Message That Took Longer Time to Read (α = 0.05)
M1 & M2 Flashing vs. M1 & M2 Static	Driving Simulator	126	0.29	0.519	No Difference
	PCSP: No Secondary Task	42	0.48	0.520	No Difference
	PCSP: 0.625 button/second	42	0.80	0.403	No Difference
	PCSP: 0.909 button/second	42	0.55	0.378	No Difference
M3 & M4 Flashing Line vs. M3 & M4 Static	Driving Simulator	126	0.25	0.558	No Difference
	PCSP: No Secondary Task	42	-0.48	0.522	No Difference
	PCSP: 0.625 button/second	42	0.11	0.912	No Difference
	PCSP: 0.909 button/second	42	0.22	0.716	No Difference
M5 & M6 Alternating Line vs. M5 & M6 No Alternating Line	Driving Simulator	124	0.79	0.321	No Difference
	PCSP: No Secondary Task	42	1.68	0.171	No Difference
	PCSP: 0.625 button/second	41	2.82	0.077	No Difference
	PCSP: 0.909 button/second	42	**2.24***	0.027	Alternating Line

Table 18. (Continued)

Message	Study Procedure	N	Mean Difference (s)	p-value	Message That Took Longer Time to Read (α = 0.05)
M7 & M8 License Plate Number vs. M7 & M8 No License Plate Number	Driving Simulator	126	**3.06***	< 0.001	License plate number
	PCSP: No Secondary Task	42	1.63	0.066	No Difference
	PCSP: 0.625 button/second	41	**4.72***	0.001	License plate number
	PCSP: 0.909 button/second	42	**3.01***	0.001	License plate number
M9 & M10 Telephone Number vs. M9 & M10 No Telephone Number	Driving Simulator	125	**3.25***	< 0.001	Telephone Number
	PCSP: No Secondary Task	42	**3.35***	0.001	Telephone Number
	PCSP: 0.625 button/second	42	**4.37***	0.001	Telephone Number
	PCSP: 0.909 button/second	42	**3.61***	< 0.001	Telephone Number

Note: the Mean Difference column was calculated from data provided in Table 16.
* A significant difference exists between the two alternative message formats at the 0.05 level of significance.

message for both the driving simulator and the PCSP. Also given is whether the difference was statistically significant. As shown in Table 18, the PCSP resulted in the same research conclusions as the driving simulator for all of the messages at all three subject loading levels (no loading, 0.625 button/second, and 0.909 button/second) with two exceptions. For the Messages M5 & M6, the conclusion reached with the PCSP 0.909 button/second level did not match that reached with the driving simulator. For the Messages M7 & M8, the conclusion reached with the PCSP no secondary task level did not match that reached with the driving simulator.

MOE #2: Difference in Reading Times during Self-Paced Reading Sessions

The differences in mean reading time (DRT) were calculated for each of the combined CMS message data sets, and these differences were then tested to determine if the mean DRTs between the PCSP and the driving simulator were different. The DRT values were calculated for each individual subject as the reading time for a specific message presented within the PCSP minus the reading time for the same message presented in the driving simulator. The data for each combined CMS message dataset from the PCSP were further separated into three sub-groups: one for each of the three PCSP button-pressing display rates tested: no secondary task, 0.625 button/second, and 0.909 button/second. Thus, MOE #2 considered whether the actual numeric values of average reading time differences for the PCSP were the same as for the driving simulator.

The mean DRT values, standard deviations, 95 percent confidence intervals, and a decision as to whether the null hypotheses were rejected are shown in Table 19. These differences are also shown graphically in Figure 13. From this analysis, the following findings were determined:

- First, the PCSP setting with no secondary task provided average DRTs that were not statistically different from the average DRTs of the driving simulator; this was true regardless of the CMS messages that were displayed.

Table 19. Mean Difference in Reading Times of CMS Messages (Individual Subject Personal Computer Study Procedure Reading Time minus Individual Subject Driving Simulator Reading Time).

Message	PCSP Setting	n	Mean DRT	St. Dev.	p-value	Reject H_0 ($\alpha = 0.05$)?
M1 & M2 Flashing	No Secondary Task	42	0.18	4.67	0.801	No
	0.625 button/second	42	1.48	4.22	**0.023**	**Yes**
	0.909 button/second	42	-1.00	4.43	0.143	No
M1 & M2 Static	No Secondary Task	42	0.07	4.32	0.922	No
	0.625 button/second	42	0.45	3.28	0.371	No
	0.909 button/second	42	-0.83	3.60	0.134	No
M3 & M4 Flashing Line	No Secondary Task	42	-0.30	3.51	0.579	No
	0.625 button/second	42	0.69	3.17	0.158	No
	0.909 button/second	42	-0.94	3.80	0.108	No
M3 & M4 Static	No Secondary Task	42	0.47	4.15	0.464	No
	0.625 button/second	42	0.16	5.16	0.839	No
	0.909 button/second	42	-0.28	2.69	0.496	No
M5 & M6 Alternating Line	No Secondary Task	42	1.45	5.78	0.103	No
	0.625 button/second	41*	1.05	7.43	0.365	No
	0.909 button/second	42	-2.20	6.31	**0.024**	**Yes**
M5 & M6 No Alternating Line	No Secondary Task	42	-0.97	5.57	0.258	No
	0.625 button/second	41[†]	-0.87	5.47	0.311	No
	0.909 button/second	42	-2.24	5.28	**0.006**	**Yes**

Table 19. (Continued)

Message	PCSP Setting	n	Mean DRT	St. Dev.	p-value	Reject H_0 ($\alpha = 0.05$)?
M7 & M8 License Plate Number	No Secondary Task	42	0.12	5.92	0.900	No
	0.625 button/second	42	0.03	5.21	0.967	No
	0.909 button/second	42	-0.63	5.56	0.463	No
M7 & M8 No License Plate Number	No Secondary Task	42	0.76	4.58	0.281	No
	0.625 button/second	42	0.44	4.85	0.555	No
	0.909 button/second	42	-0.87	5.21	0.279	No
M9 & M10 Telephone Number	No Secondary Task	42	1.16	5.94	0.205	No
	0.625 button/second	42	0.52	7.10	0.635	No
	0.909 button/second	42	-0.45	4.62	0.532	No
M9 & M10 No Telephone Number	No Secondary Task	42	0.51	5.03	0.515	No
	0.625 button/second	41‡	0.52	3.41	0.332	No
	0.909 button/second	42	-0.97	3.28	0.054	No

* One subject did not follow instructions for Message “M5 Alternating” during driving simulator session and so reduced sample size for this message to 62.

† Data error for one subject for Message “M6 No Alternating” during the driving simulator session reduced the sample size for this message to 62.

‡ One subject did not follow instructions for Message “M10 No Telephone Number” during the driving simulator session and so reduced sample size for this message to 62.

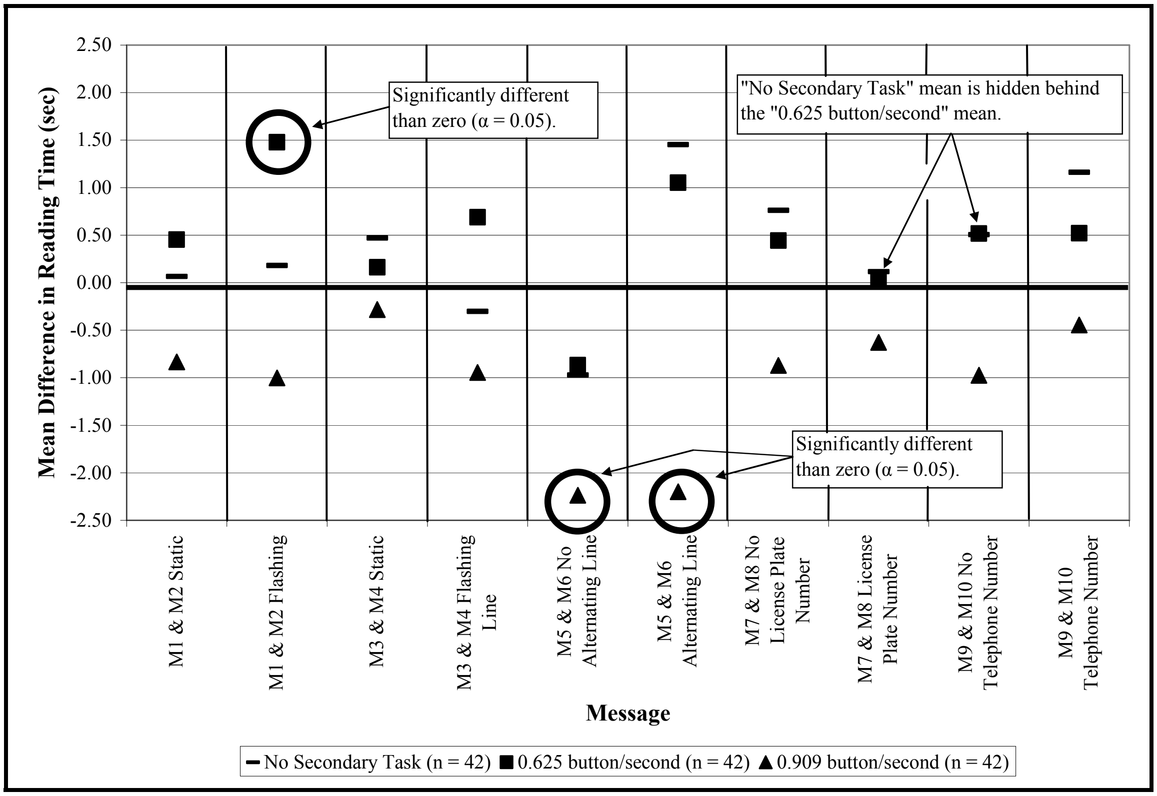


Figure 13. Comparison of Mean Difference in Reading Time by CMS Message Format (Individual Subject Personal Computer Reading Time minus Individual Subject Simulator Reading Time)

- Second, when the PCSP included the button-pushing task with a button display rate of 0.625 button/second, the difference in average DRTs for the combined message datasets were found to be not significant for nine of the 10 message formats. One significant difference was found with the Messages M1 & M2 Flashing format: The average DRT was 1.48 seconds, indicating that it took on average 1.48 seconds longer for subjects to read and turn off these messages when displayed within the PCSP than when displayed in the driving simulator. There is a possibility that the workload imposed by flashing messages and the manner in which subjects reacted to this resulted in different responses in the PCSP than in the driving simulator, but as there was no statistically significant difference with no workload and when the 0.909 button/second display rate (discussed later), no trend was established.

- Third, both of the DRT analyses that included two-phase messages (Messages M5 & M6 Alternating Line and Messages M5 & M6 No Alternating Line) were found to have statistically significant differences between mean subject reading time in the driving simulator and the PCSP at the 0.909 button/second button display rate. Specifically, the PCSP resulted in shorter average reading times compared to the driving simulator (2.20 seconds shorter for Messages M5 & M6 Alternating Line and 2.24 seconds shorter for Messages M5 & M6 No Alternating Line). It was anticipated that the average reading times within the PCSP would be longer than the driving simulator as the button display rates (subject workload) increased, which should result in positive DRT values; this was not the case. It is possible that the manner in which the subjects viewed the button display panel may have affected the reading time values for the two-phase messages within the PCSP. Subjects may have had trouble viewing the button display panel with their peripheral vision while focusing on the CMS messages, which could differ from the manner in which they used their focused and peripheral vision in the driving simulator. If this is true then when the messages alternated between the first and second phases subjects in the driving simulator were more easily able to read both phases of the message than when it was displayed within the PCSP. Also, the increased display rate of the PCSP buttons would presumably have increased the workload imposed on subjects within the PCSP.
- Fourth, the two-phase messages had four units of information, which would have increased the subject workload compared with the one-phase messages that were tested. All of this may have combined to overwhelm some subjects, and so they may have chosen to cut short their viewing of the messages within the PCSP, and thus the average reading times may not be a good comparison with those found with subjects in the driving simulator.

In summary, in addition to the fact that the same conclusions were reached for each of the three PCSP button display rates in comparison to the driving simulator (MOE #1), the actual numeric values of average reading times were essentially the same (MOE #2) for the majority of the CMS messages.

MOE #3 Message Comprehension

As discussed previously, the analysis of message comprehension was conducted twice: once for the comprehension results that were collected during the self-paced reading sessions and again for the fixed-time reading sessions. The analyses of both of these are presented separately.

Message Comprehension during Self-Paced Reading Sessions

An analysis was conducted to determine the comparability of the comprehension percentages using the combined CMS message data for the self-paced reading time session. The Bernoulli Model was again used for this analysis. As shown in Table 20, it was found that no significant differences were found for eight of the ten combined CMS message sets. A significant difference at the 0.05 level of significance existed for only two combined CMS message datasets. First, Messages M1& M2 Static was found to have a significant difference between the driving simulator and the 0.909 button/second display rate within the PCSP.

Second, statistically significant differences were found for the Messages M5 & M6 No Alternating Line format between the driving simulator and the No Secondary Task display within the PCSP (66 percent and 48 percent, respectively), and also between the driving simulator and the 0.909 button/second display rate within the PCSP (66 percent versus 50 percent, respectively). It is likely that a difference of this magnitude could result in different research conclusions. This may indicate that the PCSP is not able to provide results comparable to the driving simulator - at least for two-phase messages - regardless of whether or not a button-pressing task is used within the PCSP.

Table 20. Comparison of Message Comprehension for CMS Messages Displayed during Self-Paced Sessions

Message	Percentage of Subjects that Correctly Recalled All Units of the Message				
	Number of Message Lines to Recall	**Driving Simulator n = 126***	**No Secondary Task display rate n = 42**	**0.625 button/second display rate n = 42**	**0.909 button/second display rate n = 42**
M1 & M2 Flashing	3	75	74	79	74
M1 & M2 Static	3	**84** [A]	83	81	**71** [A]
M3 & M4 Flashing Line	3	56	62	52	64
M3 & M4 Static	3	63	52	62	60
M5 & M6 Alternating Line	4	62	64	55	55
M5 & M6 No Alternating Line	4	**66** [B,C]	**48** [B]	52	**50** [C]
M7 & M8 License Plate Number	3	40	33	50	29
M7 & M8 No License Plate Number	3	**97** [D,E,F]	90 [D]	**88** [E]	90 [F]
M9 & M10 Telephone Number	3	39	33	33	36
M9 & M10 No Telephone Number	3	94 [G,H]	86 [G]	88	86 [H]

* n = 125 for Messages M5 & M6 No Alternating Line, M5 & M6 Alternating Line, and M9 & M10 Telephone Number.
A A significant difference exists in Messages M1 & M2 Static between the driving simulator and the PCSP 0.909 button/second display rate at the 0.05 level of significance. P-value = 0.070.
B A significant difference exists in Messages M5 & M6 No Alternating Line between the driving simulator and the PCSP with No Secondary Task display rate at the 0.05 level of significance. P-value = 0.045.
C A significant difference exists in Messages M5 & M6 No Alternating Line between the driving simulator and the PCSP 0.909 button/second display rate at the 0.05 level of significance. P-value = 0.082.
D p-value = 0.094.
E A significant difference exists in Messages M7 & M8 No License Plate Number between the driving simulator and the PCSP 0.625 button/second display rate at the 0.05 level of significance. P-value = 0.030.
F p-value = 0.094.
G p-value = 0.107.
H p-value = 0.107.

Message Comprehension during Fixed-Time Reading Sessions

The Bernoulli Model was also used to test the differences of the three PCSP groups with the driving simulator for the fixed-time comprehension data. As shown in Table 21, it was found that no significant differences were found for seven of the ten combined CMS message sets at the 0.05 level of significance.

Statistically significant differences were found between the comprehension rates for the driving simulator and the 0.625 button/second display rate for Messages M3 & M4 Static and for Messages M5 & M6 Alternating Line. The driving simulator yielded a comprehension rate of 71 percent, while the PCSP with a 0.625 button/second display rate yielded only a 50 percent comprehension rate; this difference is pronounced enough that a research conclusion could be different depending on whether the driving simulator was used or the PCSP. This is an indication that the results of the PCSP may not be appropriately mimicking the results of the driving simulator, at least for two-phase messages.

A closer look at the data for Messages M7 & M8 No License Plate indicate little practical difference between the driving simulator results with any of the three PCSP button activation rates. The lowest comprehension rate calculated for the four different datasets was 91 percent, with the highest being 100 percent; research results in this range of comprehension would likely be considered acceptable. While statistically significant, these high levels of comprehension indicate that little practical significance exists, and that similar results would likely be drawn from these data.

Table 21. Comparison of Message Comprehension for CMS Messages Displayed during Fixed-Time Sessions

Messages	Percentage of Subjects that Correctly Recalled All Units of the Message				
	Number of Message Lines to Recall	**Driving Simulator n = 126***	**No Secondary Task display rate n = 42**	**0.625 button/second display rate n = 42†**	**0.909 button/second display rate n = 42‡**
M1 & M2 Flashing	3	90	86	86	88
M1 & M2 Static	3	87	93	83	93
M3 & M4 Flashing Line	3	76	74	64	69
M3 & M4 Static	3	**78** A	79	**60** A	69
M5 & M6 Alternating Line	4	**71** B	69	**50** B	57
M5 & M6 No Alternating Line	4	60	60	53	68
M7 & M8 License Plate Number	3	31	36	26	36
M7 & M8 No License Plate Number	3	**91** C,D,E	**100** C	97 D	**100** E
M9 & M10 Telephone Number	3	36	36	31	33
M9 & M10 No Telephone Number	3	93	95	88	90

* n = 121 for M5 & M6 No Alternating Line and M7 & M8 No License Plate Number.
† n = 38 for M5 & M6 No Alternating Line and M7 & M8 No License Plate Number.
‡ n = 41 for M5 & M6 No Alternating Line and M7 & M8 No License Plate Number.
A A significant difference exists in Message M3 & M4 Static between the driving simulator and the PCSP 0.625 button/second display rate at the 0.05 level of significance. P-value = 0.021.
B A significant difference exists in Message M5 & M6 Alternating Line between the driving simulator and the PCSP with 0.625 button/second display rate at the 0.05 level of significance. P-value = 0.017.
C A significant difference exists in Message M7 & M8 No License Plate Number between the driving simulator and the PCSP No Secondary Task display rate at the 0.05 level of significance. P-value = 0.043.
D P-value = 0.189.
E A significant difference exists in Message M7 & M8 No License Plate Number between the driving simulator and the PCSP 0.909 button/second display rate at the 0.05 level of significance. P-value = 0,046.

MOE #4: Preference during Preference Session

The Bernoulli Model was also used to test the proportions of the stated preferences of which message subjects preferred. No differences were found between any of the PCSP results and the driving simulator results at the 0.05 level of significance. These results are shown in Table 22. This indicates that subject preference may be insensitive to the mental workload levels tested, which would mean that the PCSP can appropriately be used in place of a driving simulator when collecting preference data.

MOE #5: Cooper-Harper Rating Scale Rating Analysis

Additionally, an analysis was performed on the differences in the Cooper-Harper Rating that was conducted at the conclusion of the PCSP sessions and the driving simulator sessions. This was performed as a method of determining whether or not the subjects considered the subjective levels of mental workload of the driving simulator comparable with each of the PCSP display rates. This was an additional check on the comparability of any one PCSP secondary task display rate: a significant difference would serve as an indication that subjects subjectively felt that the two systems provided different levels of mental workload.

Three histograms of the differences in the Cooper-Harper rating scale – one for each PCSP secondary task display rate are shown in Figure 14. As can be seen, each of the histograms appears roughly bell-shaped, and all appear to center near 0, an indication that the median differences may be small, and more importantly that overall the subjects reported little differences in the ease or difficulty of using both the driving simulator and the PCSP. Ninety-five percent confidence intervals of the median values were prepared,

Table 22. Comparison of Message Preference for Messages Displayed during Preference Sessions

Message	Percentage of Subjects that Correctly Recalled All Units of the Message				
	Number of Message Lines to Recall	Driving Simulator n = 126*	No Secondary Task display rate n = 42	0.625 button/second display rate n = 42†	0.909 button/second display rate n = 42
M1 & M2 Flashing	3	41	55	38	40
M1 & M2 Static	3	59	45	62	60
M3 & M4 Flashing Line	3	48 Δ	64 Δ	50	52
M3 & M4 Static	3	52	36	50	48
M5 & M6 Alternating Line	4	56	67	52	45
M5 & M6 No Alternating Line	4	44	33	48	55
M7 & M8 License Plate Number	3	27	33	38	17
M7 & M8 No License Plate Number	3	73	67	62	83
M9 & M10 Telephone Number	3	16	24	26	14
M9 & M10 No Telephone Number	3	84	76	74	86

* n = 124 for Messages M5 & M6.
† n = 125 for Messages M7 & M8.
Δ p-value = 0.061.

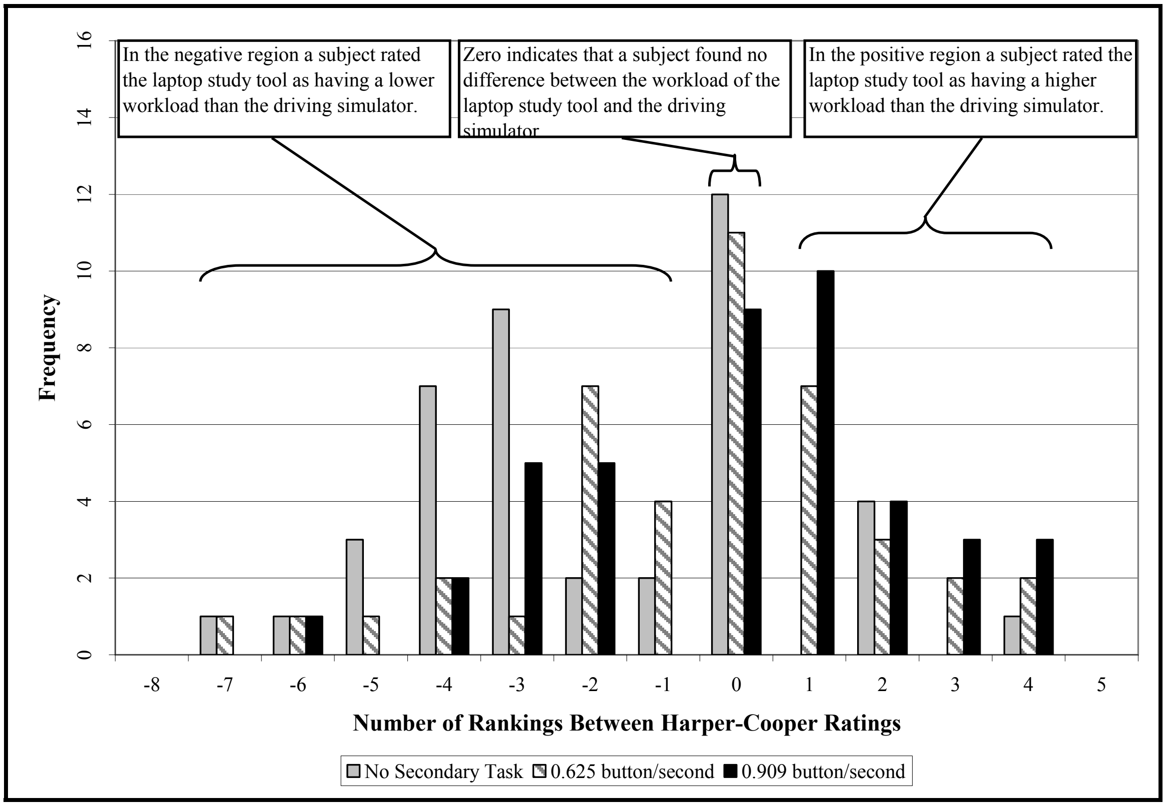


Figure 14. Difference in Cooper-Harper Rating Scale Ratings (Personal Computer Study Procedure Rating minus Driving Simulator Rating)

and are shown in Table 23; all three confidence intervals were found to include 0. This means that all three PCSP groups (no secondary task, 0.625 button/second and 0.909 button/second) showed no significant difference in the median responses regarding the difference in difficulty of using the driving simulator and the PCSP. This is an important finding, as this indicates that subjects believe that the mental workload required to use the PCSP was not different from that required to use the driving simulator, an important finding if recommendations for use of the PCSP in lieu of the driving simulator can be made.

Table 23. Difference in Cooper-Harper Rating Scale Ratings (Personal Computer Study Procedure Rating minus Driving Simulator Rating)

	Difference in Cooper-Harper Rating Scales		
	No Secondary Task n = 42	**0.625 button/second Secondary Task n = 42**	**0.909 button/second Secondary Task n = 42**
Median Difference, D	-2.5	0	0
95% Confidence interval of Median Difference	[-3.5,0]	[-2,1]	[-1.5,1.5]
Median Difference Significantly Different than Zero ($\alpha = 0.05$)?	No*	No	No

* p-value = 0.2

SUMMARY OF SIMULATOR INDUCED DISCOMFORT

Before each subject got into the driving simulator they were asked to complete a questionnaire that tracked 29 physiological conditions; at the conclusion of the driving simulator session the subjects were again given the same questionnaire to track if their self-reported physiological conditions had changed. The questionnaire is shown in Appendix D.

Seventy-three of the one-hundred-forty-eight subjects that were tested in the driving simulator (126 that completed the study plus 22 that were only tested in the driving simulator) reported experiencing one or more physiological symptoms, including:

- Drowsiness (24 reported instances),
- Headache (21 reported instances),
- Nausea (21 reported instances),

- Eye strain (18 reported instances),
- General discomfort (18 reported instances),
- Fatigue (17 reported instances),
- Stomach awareness (16 reported instances),
- Boredom (13 reported instances),
- Dizziness with eyes open (13 reported instances),
- Difficulty concentrating (12 reported instances),
- "Fullness of the head," (nasal/sinus congestion) (9 reported instances),
- Burping (8 reported instances),
- Dizziness with eyes closed (8 reported instances),
- Salivation increased (8 reported instances),
- Sweating (8 reported instances),
- Difficulty focusing (7 reported instances),
- Blurred vision (6 reported instances),
- Faintness (5 reported instances),
- Vertigo (5 reported instances),
- Confusion (3 reported instances),
- Increased appetite (3 reported instances),
- Loss of appetite (3 reported instances),
- Salivation decreased (3 reported instances),
- Vomiting (3 reported instances),
- Awareness of breathing (2 reported instances), and

- Visual flashbacks (2 reported instances).

Seventeen of the subjects reported only one symptom, while 56 reported between two and 16 symptoms. Some of the reported symptoms may be explained simply by the relatively long length of the driving simulator study (1-1/2 to 2 hours), such as boredom, difficulty concentrating, difficulty focusing, increased appetite, and salivation decreased (could indicate a dry mouth due to thirst). If these reported symptoms are removed, the number of subjects reporting at least one symptom is only reduced by six. Therefore, 67 of the remaining subjects - 41 percent of all subjects tested in the driving simulator - reported at least one physiological symptom that appears to have been caused by the driving simulator system.

By contrast, all subjects that were tested within the PCSP were able to successfully complete the PCSP study without negative symptoms. This is an indication that the PCSP may have an advantage as a study tool compared to the driving simulator for some categories of research.

SUMMARY OF RESULTS

Three different levels of PCSP secondary task button-pressing display rates were examined in this research - no secondary button-pressing task, 0.625 button/second, and 0.909 button/second - for five CMS message formats (flashing, flashing line, alternating line, license plate number, and telephone number) and their alternative messages (e.g., static, static, non-alternating line, no license plate, and no telephone number). Each of the PCSP secondary task display rates was considered individually in order to determine how well they compared with the driving simulator.

Personal Computer Study Procedure with No Button Display

The PCSP with no secondary subject task was found to perform like the driving simulator in the following manner:

- The same conclusions were reached regarding the differences in average reading time between alternative messages (such as between Messages M1&M2 Flashing and Messages M1&M2 Static) for four of five message formats;
- No statistical differences were found in the actual numeric DRT between message formats (such as between Messages M1&M2 Flashing in the driving simulator and Messages M1&M2 Flashing within the PCSP) for all five message formats;
- No statistical differences were found in preference data between alternative messages (such as between Messages M1&M2 Flashing and Messages M1&M2 Static); and
- No differences were found in Cooper-Harper ratings of subjective mental workload between the driving simulator and the PCSP.

Slight differences were found between the driving simulator and the PCSP with no button display in the following manner:

- Different conclusions were reached from the driving simulator results regarding the differences in average reading time between alternative messages M7&M8 License Plate Number and M7&M8 No License Plate. While a statistically significant difference was found at the 0.05 level of significance when using the driving simulator, none was found with the PCSP with no secondary task. The p-value for the PCSP analysis was 0.192, which may be a weak indication that a difference does exist, just not enough to meet the 0.05 level of significance;

- A statistical difference in comprehension for the self-paced sessions was found in only one of ten tests of hypotheses – one for each combined CMS message dataset; and
- A statistical difference in comprehension for the fixed-time sessions was found in only one of ten tests of hypothesis.

These results indicate that the PCSP - when used without a button display – can provide the same results as the driving simulator with regards to reading time, and preference and has only slight differences with regards to comprehension.

Personal Computer Study Procedure with 0.625 button/second Display Rate

The PCSP with a 0.625 button/second display rate was found to perform like the driving simulator in the following manner:

- The same conclusions were reached regarding the differences in average reading time between alternative messages for all five message formats;
- No statistical differences were found in comprehension data for the self-paced sessions;
- No statistical differences were found in preference data between alternative messages; and
- No statistical differences were found in the Cooper-Harper ratings of subjective mental workload between the driving simulator and the PCSP.

Slight differences were found between the driving simulator and the PCSP with 0.625 button/second display rate in the following manner:

- A statistical difference was found in the average reading time between alternative messages for only one of five tests of hypothesis;
- A statistical difference was found in the analysis of DRT (driving simulator reading time minus PCSP reading time) for only one of ten tests of hypotheses – one for each combined CMS message dataset;
- A statistical difference in comprehension for the fixed-time sessions was found in two of ten tests of hypotheses – one for each combined CMS message dataset).

These results indicate that the PCSP – when used with a button-pressing secondary task with button display rate of 0.625 button/second – can provide the same results as the driving simulator with regards to collecting reading time data, and has very few differences with regards to comprehension data. However, there is evidence that subject reading time results for Messages M5&M6 within the PCSP were not the same as in the driving simulator.

Personal Computer Study Procedure with 0.909 button/second Display Rate

The PCSP with a 0.909 button/second display rate was found to perform like the driving simulator in the following manner:

- The same conclusions were reached regarding the differences in average reading time between alternative messages for four of five alternative messages;
- No statistical differences were found in preference data between alternative messages; and
- No statistical differences were found in the Cooper-Harper ratings of subjective mental workload between the driving simulator and the PCSP.

Slight differences were found between the driving simulator and the PCSP with 0.909 button/second display rate in the following manner:

- A statistical difference was found in the average reading time between alternative messages for only one of five tests of hypothesis;
- Statistical differences were found in the DRT between similar messages for two of ten tests of hypotheses – one for each combined CMS message dataset;
- Statistical differences were found in the comprehension for the self-paced sessions in two of ten tests of hypotheses – one for each combined CMS message dataset; and
- Statistical differences were found in the comprehension for the fixed-time sessions in only one of ten tests of hypotheses – one for each combined CMS message dataset.

These results indicate that the PCSP – when used with a button-pressing secondary task with button display rate of 0.909 button/second – can provide the same results as the driving simulator with regards to collecting reading time data, and has very few differences with regards to comprehension data. As with the 0.625 button/second button display rate, there is evidence that subject reading time results for Messages M5&M6 within the PCSP were not the same as in the driving simulator.

CHAPTER VI

CONCLUSIONS AND RECOMMENDATIONS

In this chapter, a discussion of the meaning of the preceding analysis is presented, as well as consideration of how well the results of the PCSP with each of the three button pushing rates compared with the results from the driving simulator. A discussion of how well the PCSP button pushing rates would affect the overall research conclusions made based on the use of the PCSP is also given. Finally, concluding thoughts on the usefulness of the PCSP as a study tool, as well as avenues for further refinements are given.

CONCLUSIONS

In order to make a determination of how each of the PCSP secondary task rates compared with the results of the driving simulator, several steps were undertaken. First, a ranking of all of the statistical analyses found in the preceding chapter was performed. Second, consideration was given to those instances when statistical differences also appeared large enough that the differences could change a researcher’s conclusions.

Results of Statistical Testing

The summary of the hypothesis test results presented in the preceding chapter was tabularized as shown in Table 24. For each MOE, each of the PCSP secondary task rates was ranked from one to three; a one indicated the best comparison for that MOE in terms of the lowest number of statistically significant differences for each statistical test performed, a three indicating the most statistical differences observed. In the event of

Table 24. Ranking of Personal Computer Study Procedure Button Display Rates Based on Primary Analysis Methods

Analysis Method **Numbers in Parentheses indicate Relative Comparison with Driving Simulator:** **(1) = Most Comparable, (3) = Least Comparable**	**Number of Times Null Hypotheses were Rejected between the PCSP and the Driving Simulator (α = 0.05)**			**Indications of Which Display Rate Provides Similar Results as the Driving Simulator**
	No Secondary Task	**0.625 button/second Secondary Task**	**0.909 button/second Secondary Task**	
Differences in Average Reading Time between Dynamic/AMBER and Alternative Messages (MOE #1)	1 out of 5 (2.5)	0 out of 5 (1)	1 out of 5 (2.5)	0.625 button/second display rate.
Numerical Differences in Reading Time between PCSP and Driving Simulator (MOE #2)	0 out of 10 (1)	1 out of 10 (2)	2 out of 10 (3)	No Secondary Task display rate.
Numerical Differences in Comprehension during Self-Paced Display Sessions (MOE #3)	1 out of 10 (2)	0 out of 10 (1)	2 out of 10 (3)	0.625 button/second display rate.
Numerical Differences in Comprehension during Fixed-Time Display Sessions (MOE #3)	1 out of 10 (1.5)	2 out of 10 (3)	1 out of 10 (1.5)	No Secondary Task and 0.909 button/second display rates (tie).
Numerical Differences in Preferences (MOE #4)	0 out of 5 (2)	0 out of 5 (2)	0 out of 5 (2)	No difference indicated.
Numerical Differences in Cooper-Harper Rating Scale Data (MOE #5)	0 out of 1 (2)	0 out of 1 (2)	0 out of 1 (2)	No difference indicated.
Summation of Ranked Scores	(11)	(11)	(14)	
Overall Ranking Relative to Driving Simulator	**More Comparable**	**More Comparable**	**Less Comparable**	

ties the two (or three as applicable) rankings were averaged. The sum of the rankings for the five MOEs was then prepared for each PCSP secondary task rate. The display rate that had the lowest ranked score was determined to be the most comparable to the driving simulator. From Table 24, it was found that the No Secondary Task and the 0.625 button/second versions of the PCSP tied for the fewest overall statistically significant differences from the results of the driving simulator. Also of interest is that the 0.909 button/second version of the PCSP only had three more statistically significant differences than the two other versions. This is an interesting finding, indicating that all three of the versions of the PCSP seem acceptable for use in studying CMS messages in order to find comparable results to TTI's driving simulator.

However, considering only the number of statistically significant differences is to only look at part of the picture. There were four instances of statistical testing where the differences were such that they could change a researcher's conclusions depending on which study tool (driving simulator or PCSP) was used. The specific instances of this were:

- When comparing the differences in mean reading times between the driving simulator and the different PCSP button display rates, the 0.909 button/second setting within the PCSP had significantly different reading times for the Messages M5&M6 Alternating Line and the Messages M5&M6 No Alternating Line. This did not compare with the results of the driving simulator, where the reading times of the alternating line messages were found to not be significantly different.
- When comparing the differences in mean reading times between the driving simulator and the different PCSP button display rates, the no secondary task setting within the PCSP did not show significantly different reading times for the Messages M7&M8 License Plate Number and the Messages M7&M8 No License Plate Number. This did not compare with the results of the driving

simulator, where the license plate number messages were found to take significantly longer to read.

- The differences between the driving simulator results and the PCSP results - regardless of the button-pressing display rates - for the comprehension rates during self-paced message reading sessions for Messages M5 & M6 No Alternating Line appeared large enough that a researcher's conclusions might be affected depending on the research tool used (driving simulator or PCSP).
- The differences between the driving simulator results and the PCSP results for the 0.625 button/second display rate comprehension rates during self-paced message reading sessions for Messages M5 & M6 Alternating Line appeared large enough that a researcher's conclusions might be affected depending on the research tool used (driving simulator or PCSP).

The fact that three of these four statistically significant differences occurred with two-phase messages was perhaps an indicator that the PCSP may not well suited to testing subjects by showing two-phase messages, regardless of the PCSP button display rate that is chosen. Subjects may not be able to attend to the button-pressing task with their peripheral vision as they might be better able to do with the driving task in the driving simulator. If this is true, it seems logical that this shortcoming would be most pronounced for signs that require additional looking time, such as two-phase messages, and could be masked for messages that only involve a single phase. Based on this it is recommended that the current PCSP design should not be used if two-phase messages are used and if the goal is to compare successfully with message comprehension results from the driving simulator.

Performance within the PCSP with no secondary task and with the 0.625 button/second rate provided the fewest statistically significant differences compared to the driving simulator. However, the 0.909 button/second task loading rate produced only three more statistically significant differences from the driving simulator than the other two PCSP versions, and so it is recommended that any of the three PCSP versions tested are appropriate to produce results similar to TTI's driving simulator when CMS messages are being evaluated. However, if two-phase messages are planned for use in future studies, it is recommended that only the PCSP with no button display be used, in order to minimize the issues that were observed in this research.

CONSIDERATIONS OF THE PERSONAL COMPUTER STUDY PROCEDURE AS A RESEARCH TOOL

The PCSP was found to have several advantages over the driving simulator for CMS research. In the manner used, the TTI driving simulator was more likely to have subjects suffer negative physiological effects from simulator sickness and the driving simulator was more costly. As discussed in the Chapter V, 41 percent of the subjects reported experiencing at least one negative physiological side-effect from operating the driving simulator. Perhaps more importantly, eight subjects experienced simulator sickness so intensely that they had to stop their participation in the study. The PCSP had no reported side effects.

Detailed records were not kept of the software development costs for preparing the simulated driving environment in the driving simulator or preparing the PCSP program. However, both took several weeks of staff time, so the costs were easily thousands of dollars each. The marginal cost of testing the subjects were easier to determine, and it was found that the driving simulator had a higher marginal cost to use per subject:

- $120 charged by TTI for access to the driving simulator,
- $40 paid to subjects, and
- $160 (estimated) labor costs to test subjects, requiring two facilitators for two hours.

This provides a total marginal cost in the driving simulator per subject of $320. By comparison, the PCSP provided similar data for lower marginal cost, particularly by avoiding the cost of using the driving simulator:

- $40 paid to subjects, and
- $40 (estimated) labor costs to test subjects, requiring one facilitator for one hour.

Therefore, the marginal cost per subject to test using the PCSP is estimated to be $80, or 25 percent of the cost of using the driving simulator.

In combination with the other advantages of the PCSP including the ability to provide similar data, a cost comparison indicates that the PCSP has great potential as a procedure in future research on CMS message research, as well as research on other categories of traffic control devices.

FUTURE RESEARCH EFFORTS

There are several avenues for future work to extend the efforts of this research in order to improve the utility of the PCSP.

- Future researchers may benefit from an improved button-pressing secondary task, specifically one that could more easily be attended to with a subject's peripheral vision. This would make the button-pressing task more similar to the manner in which drivers attend to the driving task while their main focus is on roadside signs. This would improve the physical similarities between the driving task in the driving simulator and the button-pressing task in the PCSP from a user's standpoint. One example of this could be to make the button-pressing task and the mouse cursor much larger, so it is easier to see objects and movement with a subject's peripheral vision.

- In this research, only the PCSP's button-pressing secondary task up to a rate of 0.909 button/second was examined. Some researchers may desire to determine an even faster button display rate, possibly to mimic more demanding driving situations. Additional research would be needed to determine if the PCSP results would still be similar to the driving simulator at any rate higher than that tested as part of this research.
- Only one secondary task procedure - the button-pressing task - was studied in this research. It was determined to have several advantages, including ease of instructing and acclimating new subjects on to perform the task and that it required no additional equipment. Other secondary tasks could also provide similarities to the driving simulator. Specifically, there is the potential that a driving-based secondary task that in some form used driving control interfaces such as a gaming steering wheel, accelerator pedal, and brake pedal could access more of a subject's learned driving skills. Even though this would require additional peripheral computer equipment, it could provide an improved comparison of results.
- One of the considered advantages of the PCSP concept is that its inherent portability can be useful in studying the regional variation of the reading times and comprehension of messages by subjects in different regions or cities. This was not studied as a part of this research, and future work is needed in order to determine if the PCSP can indeed differentiate regional variability.
- The ultimate goal in this research area is to make a direct comparison between the PCSP and reading CMS messages while driving in a driving simulator. Additional research is needed in this area to extend the validity of the PCSP to include similarity with real-world driving on an actual roadway. This could be accomplished in phases, such as closed-course driving and driving on real

roadways while displaying images on some type of heads-up display or other in-vehicle device. While it is unlikely that that this can be accomplished in a single research step, it remains a worthy goal.

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APPENDIX A

DATA COLLECTION FORMS

Data Collection Forms, Subject Group A1, Driving Simulator

Introductory Remarks by Test Administrator and Subject Activities

"You are going to be driving the car northbound on Interstate 45 freeway from downtown Houston to downtown Dallas.

"You will initially be on the right shoulder. Watch the vehicles on the lanes as they pass you. As soon as you see a yellow SUV, drive onto the freeway and follow the yellow SUV. You will have to drive fast initially to catch up to the yellow SUV.

"You are to follow the yellow SUV at a distance that you feel safe. Your job is to keep the same distance between you and the yellow SUV throughout the trip. Keep in mind that the yellow SUV may change speed, either traveling slower or faster on the trip. If you fall too far behind the SUV a red chevron will appear on the screen. If you see this you are to move closer to the SUV until the chevron disappears.

"Now let's take a test drive. *(Have the subject make at least two test trips, starting on the shoulder, moving onto the freeway when the yellow SUV passes, catch up to the yellow SUV, keeping a consistent distance as the yellow SUV reduces and/or increases speed. When the subject feels comfortable with the driving task, we can start the next introductory phase.)*

"As you travel on the freeway you will occasionally see messages displayed on changeable message signs. In our case, the changeable message sign message will be projected on the rectangular box on the screen." *(Show two examples of CMS messages being projected on the screen. Have subject go through the driving scenario described above—following the yellow SUV-- while messages are projected on the screen.)*

Session 1 Introduction

"OK, we are now ready to begin a driving session. Remember you are taking a trip between downtown Houston and downtown Dallas on northbound Interstate 45. As you travel this route, you will see messages on several changeable message signs.

"The instant you have read the message, press the button on the steering wheel to turn the message off. Then you will be asked questions about the information in the message. So try to remember the information in the message. Continue to drive when I ask the questions. Please do not respond until I have read each first question completely. REMEMBER, press the button on the steering wheel to turn the message off the instant that you have read the message. Do you have any questions at this time?

"OK, we are ready to begin the trip. When you see the highway you need to put the car in drive. As soon as you see the yellow SUV, get on the freeway and follow the car. Keep a close but safe distance behind the yellow SUV." (Subject gets on the freeway and begins to follow the yellow SUV.)

Test Message 1, no flashing. At the appropriate time, **Test Message 1** is projected. No flashing.

CONSTRUCTION
2 LANES CLOSED
AT KIRBY AVE

Questions by Study Administrator:

1. What is affecting traffic? ____
2. What is the traffic problem? ______________________________________
3. Where is the traffic problem located? _______________________________

Test Message 2, only top line flashes. At the appropriate time, **Test Message 2** is projected. Only "I-20 CLOSED" in flashing mode.

I-20 CLOSED
MON-FRI
EXIT 12 TO EXIT 14

Questions by Study Administrator:

1. When will the event take place? ___________________________________
2. Where will the event take place? __________________________________
3. What is the traffic problem? ______________________________________

Test Message 3, entire message flashes. At the appropriate time, **Test Message 3** is projected. The entire message flashes.

2 LANES CLOSED
AT KIRBY ST
MAJOR DELAY

Questions by Study Administrator:

1. What is the problem? ____
2. What is the effect on traffic? ____________________________________
3. Where is the problem located? ___________________________________

Reminder by Study Administrator

"I would like to remind you again, for the next changeable message sign messages you see, press the button on the steering wheel the instant that you have read the message. I will then ask questions about the information in the message. Again, please do not respond until I have read each first question completely. So try to remember the information in the message."

Sign 1 (M2 Flash), Entire message flashes. At the appropriate time, **Message M2 Flash** is projected. Entire message flashes.

FREEWAY BLOCKED
AT TIDWELL
USE OTHER ROUTES

Questions by Study Administrator:

1. Where is the traffic problem located? ________________________________
2. What is the traffic problem? ____
3. What are you to do? ____

Sign 2 (M3 Static Line), no flashing. At the appropriate time, **Message M3 Static Line** is projected. No flashing.

FREEWAY CLOSED
AT COLLEGE ST
FOLLOW DETOUR

Questions by Study Administrator:

1. What are you to do? ____
2. Where is the traffic problem located? ________________________________
3. What is the traffic problem? ____

Sign 3 (M8 License Plate No.), amber alert with license plate number – no flashing. At the appropriate time, **Message M8 License Plate No.** is projected. No flashing.

MISSING CHILD
GREEN OLDSMOBILE
LIC 739 452

Questions by Study Administrator:

1. What type of situation has occurred? ______________________________
   (If reply is not clearly stated such as Amber Alert, ask 1b.)
   1b. Can you explain that situation? ______________________
2. Did the message tell you where to get information? Yes ________ No _
   If yes, where (need to get Radio Station and station number or Telephone Number) ____
3. Did the message tell you what to look for? Yes ______ No ______
   If yes, what (need to get subject to state type of vehicle and license number)?
   ____
   Vec: ___________ Lic #: __________

Instructions by Study Administrator

"The message on the next changeable message sign will be shown in TWO parts and will continue to repeat. The instant you have read the entire message, press the button on the steering wheel to turn the message off. As before, you will be asked questions about the information in the message. So try to remember the information in the message. This is just like the two-part message that you saw in the practice session. Do you understand?"

Sign 4 (M6 Alternating Line), two-phase message, message continues to repeat – no flashing. At the appropriate time, **Message M6 Alternating Line** is projected. Two phase, No flashing, Message repeats.

1st Phase	2nd Phase
MAJOR ACCIDENT **AT WAYSIDE RD** **ALL LANES BLOCKED**	**MAJOR ACCIDENT** **AT WAYSIDE RD** **USE OTHER ROUTES**

1st Phase *2nd Phase*

Questions by Study Administrator:

1. What are you told to do? ____
2. What is the traffic problem? ____________________________________
3. How many lanes are blocked? ___________________________________
4. Where is the traffic problem located? ____________________________

Instructions by Study Administrator

"The next few messages on the next changeable message sign will be shown in ONE part."

Sign 5 (M9 No License Plate No.), amber alert without telephone number – no flashing. At the appropriate time, **Message M9 No License Plate No.** is projected. No flashing.

KIDNAPPED CHILD

SILVER LINCOLN

TUNE TO RADIO

Questions by Study Administrator:

1. Did the message tell you where to get information?
   Yes: ___________ No: ____________
   If yes, where *(need to get "tune to radio" or telephone number)*
   ____
2. Did the message tell you what to look for? Yes ______ No ____________
   If yes, what (need to get subject to state type of vehicle)? Vec: _____
3. What type of situation has occurred? ______________________________
   (If reply is not clearly stated such as Amber Alert, ask 3b.)
   3b. Can you explain that situation? ______________________

Instructions by Study Administrator

"Now drive onto the shoulder and stop the car and we will take a break." (The highway scene then disappears). **END OF SESSION 1.**

Session 2 Introduction

Instructions by Study Administrator

OK, we are now ready to begin another driving session. Remember you are taking a trip between downtown Houston and downtown Dallas on northbound Interstate 45. As you travel this route, you will see messages on several changeable message signs.

As in the previous trip, the instant you have read the message, press the button on the steering wheel to turn the message off. Then you will be asked questions about the information in the message. So try to remember the information in the message. Continue to drive when I ask the questions. REMEMBER, press the button on the steering wheel to turn the message off the instant that you have read the message. Do you have any questions at this time?

OK, we are ready to begin the trip. As soon as you see the yellow SUV, get on the freeway and follow the car. Keep a close but safe distance behind the yellow SUV. *(Subject gets on the freeway and begins to follow the yellow SUV.)*

Sign 6 (M1 Static), no flashing. At the appropriate time, **Message M1 Static** is projected. No flashing.

MAJOR ACCIDENT

AT LITTLE YORK

3 LANES CLOSED

<u>Questions by Study Administrator:</u>

1. What is the traffic problem? ____
2. What is told about the lanes? ____
3. Where is the traffic problem located? ________________________________

Sign 7 (M4 Flash Line), only top line flashes. At the appropriate time, **Message M4 Flash Line** is projected. Only top line flashes.

TRUCK ACCIDENT

AT AIRPORT RD

USE SERVICE ROAD

<u>Questions by Study Administrator:</u>

1. Where is the traffic problem located? ________________________________
2. What is the traffic problem? ____
3. What are you to do? ____

Sign 8 (M10 Telephone Number No.), amber alert with telephone number – no flashing. At the appropriate time, **Message M10 Telephone Number No.** is projected. No flashing.

MISSING CHILD
YELLOW TOYOTA
CALL 888 769 5000

Questions by Study Administrator:

1. What type of situation has occurred? ______________________________
   (If reply is not clearly stated such as Amber Alert, ask 1b.)
   1b. Can you explain that situation? ______________________
2. Did the message tell you what to look for? Yes ______ No ____________
   If yes, what (need to get subject to state type of vehicle)? Vec:____
3. Did the message tell you where to get information? Yes: _____ No ___
   If yes, where (need to get telephone number)? __________________

Sign 9 (M7 No License Plate No.), amber alert message without license number - no flashing. At the appropriate time, **Message M7 No License Plate No.** is projected. No flashing.

KIDNAPPED CHILD
BLUE CHEVROLET
TUNE TO RADIO

Questions by Study Administrator:

1. Did the message tell you what to look for? Yes ______ No ____________
   If yes, what (need to get subject to state type of vehicle)? Vec: ___
2. Did the message tell you where to get information? Yes: _____ No: ___
   If yes, where (need to get "Tune to radio.") _____________________

3. What type of situation has occurred? ________________________________
   (If reply is not clearly stated such as Amber Alert, ask 3b.)
   3b. Can you explain that situation? ________________________

Instructions by Study Administrator

"The message on the next changeable message sign will be shown in TWO parts and then will repeat. The instant you have read the entire message, press the button on the steering wheel to turn the message off. As before, you will be asked questions about the information in the message. So try to remember the information in the message."

Sign 10 (M5 No Alternating Line), two-phase message, message continues to repeat – no flashing. At the appropriate time, **Message M5 No Alternating Line** is projected. Two phase, No flashing, Message repeats.

1st Phase	2nd Phase
CONSTRUCTION **AT BROADWAY RD**	**ALL LANES CLOSED** **USE OTHER ROUTES**

1st Phase *2nd Phase*

Questions by Study Administrator:

1. How many lanes are closed? ____
2. What are you told to do? ____
3. What is the traffic problem? ____
4. Where is the traffic problem located? ________________________________

Instructions by Study Administrator

"Now drive onto the shoulder and stop the car. We will take a break." **END OF SESSION 2.**

Session 3 Introduction

"OK, we are now ready to begin a driving session. Remember you are taking a trip between downtown Houston and downtown Dallas on northbound Interstate 45. As you travel this route, you will again see messages on several changeable message signs.

"In this part of the study, the changeable message sign messages will stay on for a few seconds and then will automatically turn off. After the message turns off, I will ask questions about the information in the message. So try to remember the information in the message. Continue to drive as I ask the questions. Do you have any questions at this time?"

Test Message 4, entire message flashes. At the appropriate time, **Test Message 4** is projected. The entire message flashes. Message is displayed for 8.4 seconds.

2 LANES CLOSED
AT KIRBY ST
MAJOR DELAY

Questions by Study Administrator:

1. What is the effect on traffic? ____
2. What is the problem? ____
3. Where is the problem? ____

Test Message 5, at the appropriate time, **Test Message 5** is projected. Message is displayed for 8.4 seconds.

CONSTRUCTION
2 LANES CLOSED
AT KIRBY AVE

Questions by Study Administrator:

1. What is the traffic problem? ______________________________
2. What is affecting traffic? ______________________________
3. Where is the traffic problem located? ______________________________

Test Message 6, only top line flashes. At the appropriate time, **Test Message 6** is projected. Only "I-20 CLOSED" in flashing mode. Message is displayed for 8.4 seconds.

I-20 CLOSED
MON-FRI
EXIT 12 TO EXIT 14

Questions by Study Administrator:

1. Where will the event take place? ______________________________
2. When will the event take place? ______________________________
3. What is the problem? ______________________________

Sign 11 (M1 Flash), entire message flashes. At the appropriate time, **Message M1 Flash** is projected. Entire message flashes. Message is displayed for 8.4 seconds.

MAJOR ACCIDENT
AT LITTLE YORK
3 LANES CLOSED

Questions by Study Administrator:

1. What is the traffic problem? ______________________________
2. What was told about the lanes? ____________________________
3. Where is the traffic problem located? ________________________

Sign 12 (M7 License Plate No.), amber alert with license plate number – no flashing. At the appropriate time, **Message M7 License Plate No.** is projected. No flashing. Message is displayed for 8.4 seconds.

KIDNAPPED CHILD
BLUE CHEVROLET
LIC 825 493

Questions by Study Administrator:

1. Did the message tell you what to look for? Yes No Vec: __________
   Lic #: _________
   If yes, what (need to get subject to state type of vehicle and license number)?
   ____
2. Did the message tell you where to get information?
   Yes: __________No: __________
   If yes, where? ________________________________
3. What type of situation has occurred? __________________________
   (If reply is not clearly stated such as Amber Alert, ask 3b.)

3b. Can you explain that situation? ________________________

Sign 13 (M5 Alternating Line), two-phase message, no repeat – no flashing. At the appropriate time, **Message M5 Alternating Line** is projected. Two phase, No flashing. Each phase is displayed for 4.2 seconds, for a message total of 8.4 seconds.

1st Phase	2nd Phase
CONSTRUCTION **AT BROADWAY RD** **ALL LANES CLOSED**	**CONSTRUCTION** **AT BROADWAY RD** **USE OTHER ROUTES**

1st Phase *2nd Phase*

<u>Questions by Study Administrator:</u>

1. How many lanes are closed? ____
2. What are you told to do? ____
3. What is the traffic problem? ____
4. Where is the traffic problem located? ________________________________

Sign 14 (M3 Flash Line), only top line flashes. At the appropriate time, **Message M3 Flash Line** is projected. Only top line flashes. Message is displayed for 8.4 seconds.

FREEWAY CLOSED
AT COLLEGE ST
FOLLOW DETOUR

<u>Questions by Study Administrator:</u>

1. What are you to do? ____
2. Where is the traffic problem located? ________________________________
3. What is the traffic problem? ____

Sign 15 (M9 Telephone Number No.), amber alert with telephone number – no flashing. At the appropriate time, **Message M9 Telephone Number No.** is projected. No flashing. Message is displayed for 8.4 seconds.

KIDNAPPED CHILD
SILVER LINCOLN
CALL 800 268 3200

Questions by Study Administrator:

1. Did the message tell you where to get information?
   Yes: ____________ No: _____________
   If yes, where?____
2. Did the message tell you what to look for?
   Yes ____________No _____________Vec: ___________
   If yes, what? ____
3. What type of situation has occurred?
   (If reply is not clearly stated such as Amber Alert, ask 3b.)
   3b. Can you explain that situation? _______________________

"This is the end of this part of the study. Stop the vehicle on the shoulder and we will take a break." **END OF SESSION 3.**

Session 4 Introduction

"OK, we are now ready to begin another driving session. Remember you are taking a trip between downtown Houston and downtown Dallas on northbound Interstate 45. As you travel this route, you will again see messages on several changeable message signs.

"In this part of the study, the changeable message sign messages will again stay on for a few seconds and then will automatically turn off just like the previous session. After the message turns off, I will ask questions about the information in the message. So try to remember the information in the message. Continue to drive as I ask the questions. Do you have any questions at this time?"

Sign 16 (Group A1) (M2 Static), no flashing. At the appropriate time, **Message M2 Static** is projected. No flashing. Message is displayed for 8.4 seconds.

FREEWAY BLOCKED
AT TIDWELL
USE OTHER ROUTES

Questions by Study Administrator:

1. Where is the traffic problem located? ______________________________
2. What is the traffic problem? ____________________________________
3. What are you to do? ____

Sign 17 (M8 No License Plate No.), amber alert without license plate number – no flashing. At the appropriate time, **Message M8 No License Plate No.** is projected. No flashing. Message is displayed for 8.4 seconds.

MISSING CHILD
GREEN OLDSMOBILE
TUNE TO RADIO

Questions by Study Administrator:

1. What type of situation has occurred? ______________________________
   (If reply is not clearly stated such as Amber Alert, ask 1b.)

1b. Can you explain that situation? ______________________

2. Did the message tell you where to get information?

   Yes: ___________ No:

   If yes, where?____

3. Did the message tell you what to look for?

   Yes: ___________ No: ___________ Vec: __________

   If yes, what? ____

Sign 18 (M6 No Alternating Line), two-phase message – no flashing. At the appropriate time, **Message M6 No Alternating Line** is projected. Two phase, No flashing. Each phase is displayed for 4.2 seconds, and then the message turns off.

1st Phase	2nd Phase
MAJOR ACCIDENT **AT WAYSIDE RD**	**ALL LANES BLOCKED** **USE OTHER ROUTES**

1st Phase *2nd Phase*

<u>Questions by Study Administrator:</u>

1. What are you told to do? ______________________________________
2. What is the traffic problem? ___________________________________
3. How many lanes are blocked? _________________________________
4. Where is the traffic problem located? ____________________________

Sign 19 (M4 Static), No flashing. At the appropriate time, **Message M4 No Flash Line** is projected. No flashing. Message is displayed for 8.4 seconds.

TRUCK ACCIDENT
AT AIRPORT RD
USE SERVICE ROAD

Questions by Study Administrator:

1. Where is the traffic problem located? ______________________________
2. What is the traffic problem? ______________________________
3. What are you to do? ______________________________

Sign 20 (Group A1) (M10 No Telephone Number No.), amber alert without telephone number – no flashing. At the appropriate time, **Message M10 No Telephone Number No.** is projected. No flashing. Message is displayed for 8.4 seconds.

MISSING CHILD
YELLOW TOYOTA
TUNE TO RADIO

Questions by Study Administrator:

1. What type of situation has occurred? ______________________________
   (If reply is not clearly stated such as Amber Alert, ask 1b.)
   1b. Can you explain that situation? ______________________
2. Did the message tell you what to look for?
   Yes: ___________ No: ___________ Vec: __________
   If yes, what? ______________________________
3. Did the message tell you where to get information?
   Yes: ___________ No: ___________
   If yes, where? ______________________________

"This is the end of this part of the study. Stop the vehicle and we will take a break."
END OF SESSION 4.

Session 5 Introduction

"OK, we are now ready to begin another driving session. Remember you are taking a trip between downtown Houston and downtown Dallas on northbound Interstate 45. As you travel this route, you will see messages on several changeable message signs.

"In this study you will see two ways of showing the same information for a number of signs. You will be asked your opinions about which of the two ways of displaying the message that you prefer.

"OK, we are ready to begin the trip. As soon as you see the yellow SUV, get on the freeway and follow the car. Keep a close but safe distance behind the yellow SUV.
(Subject gets on the freeway and begins to follow the yellow SUV.)

"As I mentioned, you will see two ways of displaying the same message. After you view both message styles, you will be asked to let us know which style you like the best. The messages will stay on for a few seconds and then will turn off."

Sign 21 (M2 Static), No flashing. At the appropriate time, **Message M2 Static** is projected. No flashing. Message is displayed for 8.4 seconds.

FREEWAY BLOCKED

AT TIDWELL

USE OTHER ROUTES

Instructions by Study Administrator

"The second message style has the same message as the first, but it will flash on and off."

Sign 22 (M2 Flash), entire message flashes. At the appropriate time, **Message M2 Flash** is projected, entire message flashes. Message is displayed for 8.4 seconds.

FREEWAY BLOCKED
AT TIDWELL
USE OTHER ROUTES

Questions by Study Administrator:

1. Which message style do you prefer?
   _________________ The first message style (shown previously)
   _________________ The second message style (shown last)
2. Why do you prefer the message style that you selected?
   ____

Instructions by Study Administrator

"You will again see two similar ways of displaying a message. After you view both message styles, you will be asked to let us know which style you like the best. The messages will remain on the screen for a few seconds. Then they will turn off."

Sign 23 (M8 No License Plate No.), amber alert without license plate number – no flashing. At the appropriate time, **Message M8 No License Plate No.** is projected. No flashing. Message is displayed for 8.4 seconds.

MISSING CHILD
GREEN OLDSMOBILE
TUNE TO RADIO

Instructions by Study Administrator

"The second message style is similar to the first with slightly different information."

Sign 24 (Group A1) (M8 License Plate No.), amber alert with license plate number – no flashing. At the appropriate time, **Message M8 License Plate No.** is projected. No flashing. Message is displayed for 8.4 seconds.

MISSING CHILD
GREEN OLDMOBILE
LIC 739 452

Questions by Study Administrator

1. Which message style do you prefer?
   _________________ The first message style (shown previously)
   _________________ The second message style (shown last)
2. Why do you prefer the message style that you selected?
   ____

Instructions by Study Administrator

"You will again see two ways of displaying the same message. After you view both styles, you will be asked to let us know which style you like best. The messages will be in displayed for a few seconds and then they will turn off."

Sign 25 (M6 No Alternating Line), two-phase message – no flashing. At the appropriate time, **Message M6 No Alternating Line** is projected. Two phase, No flashing. Each phase is displayed for 4.2 seconds, and then the message turns off.

MAJOR ACCIDENT **AT WAYSIDE RD**	**ALL LANES BLOCKED** **USE OTHER ROUTES**
1st Phase	*2nd Phase*

Instructions by Study Administrator

"The second message style has the same information as the first, but is presented in a slightly different manner."

Sign 26 (Group A1) (M6 Alternating Line), two-phase message – no flashing. At the appropriate time, **Message M6 Alternating Line** is projected. Two phase, No flashing. Each phase is displayed for 4.2 seconds, and then the message turns off.

MAJOR ACCIDENT AT WAYSIDE RD ALL LANES BLOCKED	MAJOR ACCIDENT AT WAYSIDE RD USE OTHER ROUTES
1st Phase	*2nd Phase*

Questions by Study Administrator

1. Which message style do you prefer?
   ________________ The first message style (shown previously)
   ________________ The second message style (shown last)
2. Why do you prefer the message style that you selected?
   ____

Instructions by Study Administrator

"Again, you will see two ways to displaying the same message. After you view both message styles, you will be asked to let us know which style you like best. The messages will remain on the screen for a few seconds. Then the messages will turn off."

Sign 27 (M4 No Flash Line), No flashing. At the appropriate time, **Message M4 No Flash Line** is projected. No flashing. Message is displayed for 8.4 seconds.

TRUCK ACCIDENT AT AIRPORT ROAD USE SERVICE ROAD

Instructions by Study Administrator

"The second message style will have the same message as the first but part of the message will flash."

Sign 28 (M4 Flash Line), Only top line flashes. At the appropriate time, **Message M4 Flash Line** is projected. Only top line flashes. Message is displayed for 8.4 seconds.

TRUCK ACCIDENT
AT AIRPORT ROAD
USE SERVICE ROAD

Questions by Study Administrator

1. Which message style do you prefer?
   _________________ The first message style (shown previously)
   _________________ The second message style (shown last)
2. Why do you prefer the message style that you selected?
   ____

"Again, you will see two similar ways of displaying a message. After you view both message styles, you will be asked to let us know which style you like the best. The messages will remain on the screen for a few seconds. Then they will turn off."

Sign 29 (M10 No Telephone Number No.), amber alert without telephone number – no flashing. At the appropriate time, **Message M10 No Telephone Number No.** is projected. No flashing. Message is displayed for 8.4 seconds.

MISSING CHILD
YELLOW TOYOTA
TUNE TO RADIO

Instructions by Study Administrator

"The second message style is similar to the first with slightly different information."

Sign 30 (M10 Telephone Number No.), amber alert with telephone number – no flashing. At the appropriate time, **Message M10 Telephone Number No.** is projected. No flashing. Message is displayed for 8.4 seconds.

MISSING CHILD
YELLOW TOYOTA
CALL 888 769 5000

Questions by Study Administrator

1. Which message style do you prefer?
   _________________ The first message style (shown previously)
   _________________ The second message style (shown last)
2. Why do you prefer the message style that you selected?
   ____

Instructions by Study Administrator

"This is the end of the study. Drive onto the shoulder and stop the vehicle. We want to thank you for your participation and help. The information that you provided will be extremely beneficial to the State of Texas and to the federal government as they develop better signing information for the motoring public." **END OF STUDY.**

Data Collection Forms, Subject Groups A2, B1, and B2, Driving Simulator

The forms used for subject groups A2, B1, and B2 were very similar to that used for subject group A1. The only difference was the order of the messages, which is detailed in Appendix A.

Data Collection Forms, Subject Group A1, PC Survey Procedure

Introductory Remarks by Test Administrator and Subject Activities

"We are ready to begin the practice session. When you press the space bar you will begin the session. You are to use the mouse to click on the red dots that appear in the box on the screen. Your job is to click on as many of the red dots as possible, and to click on each red dot before another one appears. Try to keep from having two red dots on the screen at the same time. We will be keeping an electronic count of the number of dots that you click on during the study."

"As you travel on the freeway you will occasionally see changeable message sign messages displayed on the computer monitor." *(Show three examples of CMS messages being projected on the screen. Have subject go through the scenario described above—clicking on the red dots—while messages are projected on the screen.)*

"There will be five sessions in this study."

Session 1 Introduction

"OK, we are now ready to begin a session. When you press the space bar the red dots will begin to appear and you should click on them with the mouse as fast as possible."

"The instant you have read the message, press the space bar on the PC to turn the message off. Then you will be asked questions about the information in the message. So try to remember the information in the message. Please do not respond until I have read each question completely. REMEMBER, press the space bar on the PC to turn the message off the instant that you have read the message. Do you have any questions at this time?"

"OK, we are ready to begin the session. When you press the space bar the red dots will begin to appear."

Test Message 1, no flashing. At the appropriate time, **Test Message 1** is projected. No flashing.

CONSTRUCTION
2 LANES CLOSED
AT KIRBY AVE

Questions by Study Administrator:

1. What is affecting traffic? ____
2. What is the traffic problem? ____
3. Where is the traffic problem located? ________________________________

Test Message 2, only top line flashes. At the appropriate time, **Test Message 2** is projected. Only "I-20 CLOSED" in flashing mode.

I-20 CLOSED
MON-FRI
EXIT 12 TO EXIT 14

Questions by Study Administrator:

1. When will the event take place? ___________________________________
2. Where will the event take place? __________________________________
3. What is the traffic problem? ____

Test Message 3, entire message flashes. At the appropriate time, **Test Message 3** is projected. The entire message flashes.

2 LANES CLOSED
AT KIRBY ST
MAJOR DELAY

Questions by Study Administrator:

1. What is the problem? ____
2. What is the effect on traffic? __________________________________
3. Where is the problem located? _________________________________

Reminder by Study Administrator

"I would like to remind you again, for the next changeable message sign messages you see, press the space bar on the PC the instant that you have read the message. I will then ask questions about the information in the message. Again, please do not respond until I have read each question completely. So try to remember the information in the message."

Sign 1 (M2 Flash), Entire message flashes. At the appropriate time, **Message M2 Flash** is projected. Entire message flashes.

FREEWAY BLOCKED
AT TIDWELL
USE OTHER ROUTES

Questions by Study Administrator:

1. Where is the traffic problem located? ______________________________
2. What is the traffic problem? ______________________________
3. What are you to do? ______________________________

Sign 2 (M3 Static Line), no flashing. At the appropriate time, **Message M3 Static Line** is projected. No flashing.

FREEWAY CLOSED

AT COLLEGE ST

FOLLOW DETOUR

Questions by Study Administrator:

1. What are you to do? ______________________________
2. Where is the traffic problem located? ______________________________
3. What is the traffic problem? ______________________________

Sign 3 (M8 License Plate No.), amber alert with license plate number – no flashing. At the appropriate time, **Message M8 License Plate No.** is projected. No flashing.

MISSING CHILD

GREEN OLDSMOBILE

LIC 739 452

<u>Questions by Study Administrator:</u>

1. What type of situation has occurred? ________________________________
   (If reply is not clearly stated such as Amber Alert, ask 1b)
   1b. Can you explain that situation? ________________________________
2. Did the message tell you where to get information? Yes ________ No ___
   If yes, where (need to get Radio Station and station number or Telephone Number) ____
3. Did the message tell you what to look for? Yes ______ No __
   If yes, what (need to get subject to state type of vehicle and license number)?
   Vec: ____________ Lic #: ___________

<u>Instructions by Study Administrator</u>

"The message on the next changeable message sign will be shown in TWO parts and will continue to repeat. The instant you have read the entire message, press the space bar to turn the message off. As before, you will be asked questions about the information in the message. So try to remember the information in the message. This is just like the two-part message that you saw in the practice session. Do you understand?"

Sign 4 (M6 Alternating Line), two-phase message, message continues to repeat – no flashing. At the appropriate time, **Message M6 Alternating Line** is projected. Two phase, No flashing, Message repeats.

MAJOR ACCIDENT **AT WAYSIDE RD** **ALL LANES BLOCKED**	**MAJOR ACCIDENT** **AT WAYSIDE RD** **USE OTHER ROUTES**
1st Phase	*2nd Phase*

Questions by Study Administrator

1. What are you told to do? ______________________________
2. What is the traffic problem? ______________________________
3. How many lanes are blocked? ______________________________
4. Where is the traffic problem located? ______________________

Instructions by Study Administrator

"The next few messages on the next changeable message sign will be shown in ONE part."

Sign 5 (M9 No License Plate No.), amber alert without telephone number – no flashing. At the appropriate time, **Message M9 No License Plate No.** is projected. No flashing.

KIDNAPPED CHILD

SILVER LINCOLN

TUNE TO RADIO

Questions by Study Administrator

1. Did the message tell you where to get information?
   Yes: __________ No: __________
   If yes, where *(need to get "tune to radio" or telephone number)*
   ____
2. Did the message tell you what to look for? Yes __________ No ____
   If yes, what (need to get subject to state type of vehicle)? Vec: ____
3. What type of situation has occurred? ______________________
   (If reply is not clearly stated such as Amber Alert, ask 3b.)
   3b. Can you explain that situation? ________________

Instructions by Study Administrator

"This is the end of Session 1. We will now take a short break." **END OF SESSION 1.**

Session 2 Introduction

Instructions by Study Administrator

"OK, we are now ready to begin another session. When you press the space bar the red dots will begin to appear and you should click on them with the mouse as fast as possible."

"After a few seconds a changeable message sign will appear and display a message. The instant you have read the message, press the space bar on the PC to turn the message off. Then you will be asked questions about the information in the message. So try to remember the information in the message. Please do not respond until I have read each question completely. REMEMBER, press the space bar on the PC to turn the message off the instant that you have read the message. Do you have any questions at this time?"

"OK, we are ready to begin the session. When you press the space bar the red dots will begin to appear."

Sign 6 (M1 Static), no flashing. At the appropriate time, **Message M1 Static** is projected. No flashing.

MAJOR ACCIDENT

AT LITTLE YORK

3 LANES CLOSED

Questions by Study Administrator

1. What is the traffic problem? ___________________________________
2. What is told about the lanes? ___________________________________
3. Where is the traffic problem located? ____________________________

Sign 7 (M4 Flash Line), only top line flashes. At the appropriate time, **Message M4 Flash Line** is projected. Only top line flashes.

TRUCK ACCIDENT
AT AIRPORT RD
USE SERVICE ROAD

Questions by Study Administrator

1. Where is the traffic problem located? ____________________________
2. What is the traffic problem? ___________________________________
3. What are you to do? ____

Sign 8 (M10 Telephone Number No.), amber alert with telephone number – no flashing. At the appropriate time, **Message M10 Telephone Number No.** is projected. No flashing.

MISSING CHILD
YELLOW TOYOTA
CALL 888 769 5000

Questions by Study Administrator

1. What type of situation has occurred? ____________________________
   (If reply is not clearly stated such as Amber Alert, ask 1b.)

1b. Can you explain that situation? ________________________

2. Did the message tell you what to look for? Yes ______ No ____________
   If yes, what (need to get subject to state type of vehicle)? Vec:____
3. Did the message tell you where to get information? Yes: _____ No ___
   If yes, where (need to get telephone number)? ___________________

Sign 9 (M7 No License Plate No.), amber alert message without license number - no flashing. At the appropriate time, **Message M7 No License Plate No.** is projected. No flashing.

KIDNAPPED CHILD
BLUE CHEVROLET
TUNE TO RADIO

<u>Questions by Study Administrator</u>

1. Did the message tell you what to look for? Yes ______ No ___________
   If yes, what (need to get subject to state type of vehicle)? Vec: ___
2. Did the message tell you where to get information? Yes: _____ No: __
   If yes, where (need to get “Tune to radio.”) ____________________
3. What type of situation has occurred? ________________________________
   (If reply is not clearly stated such as Amber Alert, ask 3b)
   3b. Can you explain that situation? ________________________

<u>Instructions by Study Administrator</u>

“The message on the next changeable message sign will be shown in TWO parts and will continue to repeat. The instant you have read the entire message, press the space bar to turn the message off. As before, you will be asked questions about the information in the message. So try to remember the information in the message. This is just like the two-part message that you saw in the practice session. Do you understand?”

Sign 10 (M5 No Alternating Line), two-phase message, message continues to repeat – no flashing. At the appropriate time, **Message M5 No Alternating Line** is projected. Two phase, No flashing, Message repeats.

CONSTRUCTION **AT BROADWAY RD**	**ALL LANES CLOSED** **USE OTHER ROUTES**
1st Phase	*2nd Phase*

Questions by Study Administrator

1. How many lanes are closed? ______________________________
2. What are you told to do? ______________________________
3. What is the traffic problem? ______________________________
4. Where is the traffic problem located? ______________________________

Instructions by Study Administrator

"This is the end of the second session. We will now take a short break." **END OF SESSION 2.**

Session 3 Introduction

"OK, we are now ready to begin another session. As you click on the red dots you will see messages on several changeable message signs."

"In this part of the study, the changeable message sign messages will stay on for a few seconds and then will automatically turn off. After the message turns off, I will ask questions about the information in the message. So try to remember the information in the message. Do you have any questions at this time?"

"OK, we are ready to begin the session. When you press the space bar the red dots will begin to appear. Immediately start clicking on them to turn them off."

Test Message 4, entire message flashes. At the appropriate time, **Test Message 4** is projected. The entire message flashes. Message is displayed for 8.4 seconds.

2 LANES CLOSED
AT KIRBY ST
MAJOR DELAY

Questions by Study Administrator

1. What is the effect on traffic? ______________________________________
2. What is the problem? ____
3. Where is the problem? ____

Test Message 5, at the appropriate time, **Test Message 5** is projected. Message is displayed for 8.4 seconds.

CONSTRUCTION
2 LANES CLOSED
AT KIRBY AVE

Questions by Study Administrator:

1. What is the traffic problem? _______________________________________
2. What is affecting traffic? ____
3. Where is the traffic problem located? ________________________________

Test Message 6, only top line flashes. At the appropriate time, **Test Message 6** is projected. Only "I-20 CLOSED" in flashing mode. Message is displayed for 8.4 seconds.

I-20 CLOSED
MON-FRI
EXIT 12 TO EXIT 14

<u>Questions by Study Administrator:</u>

1. Where will the event take place? ___________________________________
2. When will the event take place? ____________________________________
3. What is the problem? ____

Sign 11 (M1 Flash), entire message flashes. At the appropriate time, **Message M1 Flash** is projected. Entire message flashes. Message is displayed for 8.4 seconds.

MAJOR ACCIDENT
AT LITTLE YORK
3 LANES CLOSED

<u>Questions by Study Administrator:</u>

1. What is the traffic problem? _______________________________________
2. What was told about the lanes? _____________________________________
3. Where is the traffic problem located? ________________________________

Sign 12 (M7 License Plate No.), amber alert with license plate number – no flashing. At the appropriate time, **Message M7 License Plate No.** is projected. No flashing. Message is displayed for 8.4 seconds.

KIDNAPPED CHILD
BLUE CHEVROLET
LIC 825 493

Questions by Study Administrator:

1. Did the message tell you what to look for? Yes No Vec: ____________
   Lic #: ___________
   If yes, what (need to get subject to state type of vehicle and license number)? ____
2. Did the message tell you where to get information?
   Yes: ___________No: ____________
   If yes, where? ____
3. What type of situation has occurred? ______________________________
   (If reply is not clearly stated such as Amber Alert, ask 3b)
   3b. Can you explain that situation? ______________________

Sign 13 (M5 Alternating Line), two-phase message, no repeat – no flashing. At the appropriate time, **Message M5 Alternating Line** is projected. Two phase, No flashing. Each phase is displayed for 4.2 seconds, for a message total of 8.4 seconds.

1st Phase	2nd Phase
CONSTRUCTION	**CONSTRUCTION**
AT BROADWAY RD	**AT BROADWAY RD**
ALL LANES CLOSED	**USE OTHER ROUTES**

1st Phase *2nd Phase*

Questions by Study Administrator:

1. How many lanes are closed? ______________________________________
2. What are you told to do? ____
3. What is the traffic problem? ______________________________________
4. Where is the traffic problem located? ______________________________

Sign 14 (M3 Flash Line), only top line flashes. At the appropriate time, **Message M3 Flash Line** is projected. Only top line flashes. Message is displayed for 8.4 seconds.

FREEWAY CLOSED
AT COLLEGE ST
FOLLOW DETOUR

Questions by Study Administrator

1. What are you to do? ____
2. Where is the traffic problem located? ______________________________
3. What is the traffic problem? ______________________________________

Sign 15 (M9 Telephone Number No.), amber alert with telephone number – no flashing. At the appropriate time, **Message M9 Telephone Number No.** is projected. No flashing. Message is displayed for 8.4 seconds.

KIDNAPPED CHILD
SILVER LINCOLN
CALL 800 268 3200

Questions by Study Administrator

1. Did the message tell you where to get information?

Yes: ____________ No: ____________
If yes, where? ____

2. Did the message tell you what to look for?
Yes ____________No _____________Vec: ____________
If yes, what? ____

3. What type of situation has occurred? _________________________________
(If reply is not clearly stated such as Amber Alert, ask 3b)
3b. Can you explain that situation? _______________________

Instructions by Study Administrator

"This is the end of the third session. We will now take a short break." **END OF SESSION 3.**

Session 4 Introduction

"OK, we are now ready to begin another session. As you click on the red dots you will see messages on several changeable message signs."

"In this part of the study, the changeable message sign messages will stay on for a few seconds and then will automatically turn off. After the message turns off, I will ask questions about the information in the message. So try to remember the information in the message. Do you have any questions at this time?"

"OK, we are ready to begin the session. When you press the space bar the red dots will begin to appear. Immediately start clicking on them to turn them off."

Sign 16 (Group A1) (M2 Static), no flashing. At the appropriate time, **Message M2 Static** is projected. No flashing. Message is displayed for 8.4 seconds.

FREEWAY BLOCKED
AT TIDWELL
USE OTHER ROUTES

Questions by Study Administrator

1. Where is the traffic problem located? ______________________________
2. What is the traffic problem? ______________________________________
3. What are you to do? ____

Sign 17 (M8 No License Plate No.), amber alert without license plate number – no flashing. At the appropriate time, **Message M8 No License Plate No.** is projected. No flashing. Message is displayed for 8.4 seconds.

MISSING CHILD
GREEN OLDSMOBILE
TUNE TO RADIO

Questions by Study Administrator

1. What type of situation has occurred? ______________________________
   (If reply is not clearly stated such as Amber Alert, ask 1b.)
   1b. Can you explain that situation? ______________________
2. Did the message tell you where to get information?
   Yes: ___________ No:
   If yes, where?____
3. Did the message tell you what to look for?
   Yes: ___________ No: ___________ Vec: __________
   If yes, what? ____

Sign 18 (M6 No Alternating Line), two-phase message – no flashing. At the appropriate time, **Message M6 No Alternating Line** is projected. Two phase, No flashing. Each phase is displayed for 4.2 seconds, and then the message turns off.

1st Phase	2nd Phase
MAJOR ACCIDENT **AT WAYSIDE RD**	**ALL LANES BLOCKED** **USE OTHER ROUTES**

1st Phase *2nd Phase*

Questions by Study Administrator:

1. What are you told to do? ________________________________
2. What is the traffic problem? ______________________________
3. How many lanes are blocked? _____________________________
4. Where is the traffic problem located? ________________________

Sign 19 (M4 Static), No flashing. At the appropriate time, **Message M4 No Flash Line** is projected. No flashing. Message is displayed for 8.4 seconds.

TRUCK ACCIDENT
AT AIRPORT RD
USE SERVICE ROAD

Questions by Study Administrator:

1. Where is the traffic problem located? ________________________
2. What is the traffic problem? ______________________________
3. What are you to do? ____________________________________

Sign 20 (Group A1) (M10 No Telephone Number No.), amber alert without telephone number – no flashing. At the appropriate time, **Message M10 No Telephone Number No.** is projected. No flashing. Message is displayed for 8.4 seconds.

MISSING CHILD
YELLOW TOYOTA
TUNE TO RADIO

<u>Questions by Study Administrator:</u>

1. What type of situation has occurred? ________________________________
   (If reply is not clearly stated such as Amber Alert, ask 1b)
   1b. Can you explain that situation? ________________________
2. Did the message tell you what to look for?
   Yes: ____________ No: ____________ Vec: ___________
   If yes, what? ____
3. Did the message tell you where to get information?
   Yes: ____________ No: ____________
   If yes, where? ____

<u>Statement by Study Administrator</u>

"This is the end of the fourth session. We will now take a short break." **END OF SESSION 4.**

Session 5 Introduction

"OK, we are now ready to begin another session. As you click on the red dots you will see messages on several changeable message signs."

"In this session you will see two ways of showing the same information for a number of signs. You will be asked your opinions about which of the two ways of displaying the message that you prefer."

“OK, we are ready to begin the trip. Press the space bar to begin. Remember to turn off the red dots as soon as they appear.”

Sign 21 (M2 Static), No flashing. At the appropriate time, **Message M2 Static** is projected. No flashing. Message is displayed for 8.4 seconds.

FREEWAY BLOCKED
AT TIDWELL
USE OTHER ROUTES

Instructions by Study Administrator

“The second message style has the same message as the first, but it will flash on and off.”

Sign 22 (M2 Flash), entire message flashes. At the appropriate time, **Message M2 Flash** is projected, entire message flashes. Message is displayed for 8.4 seconds.

FREEWAY BLOCKED
AT TIDWELL
USE OTHER ROUTES

Questions by Study Administrator:

1. Which message style do you prefer?
   _________________ The first message style (shown previously)
   _________________ The second message style (shown last)
2. Why do you prefer the message style that you selected?
   ____

<u>Instructions by Study Administrator</u>

"You will again see two similar ways of displaying a message. After you view both message styles, you will be asked to let us know which style you like the best. The messages will remain on the screen for a few seconds. Then they will turn off."

Sign 23 (M8 No License Plate No.), amber alert without license plate number – no flashing. At the appropriate time, **Message M8 No License Plate No.** is projected. No flashing. Message is displayed for 8.4 seconds.

MISSING CHILD
GREEN OLDSMOBILE
TUNE TO RADIO

<u>Instructions by Study Administrator</u>

"The second message style is similar to the first with slightly different information."

Sign 24 (Group A1) (M8 License Plate No.), amber alert with license plate number – no flashing. At the appropriate time, **Message M8 License Plate No.** is projected. No flashing. Message is displayed for 8.4 seconds.

MISSING CHILD
GREEN OLDMOBILE
LIC 739 452

Questions by Study Administrator:

1. Which message style do you prefer?
   ______________ The first message style (shown previously)
   ______________ The second message style (shown last)
2. Why do you prefer the message style that you selected?
   ____

Instructions by Study Administrator

"You will again see two ways of displaying the same message. After you view both styles, you will be asked to let us know which style you like best. The messages will be in displayed for a few seconds and then they will turn off."

Sign 25 (M6 No Alternating Line), two-phase message – no flashing. At the appropriate time, **Message M6 No Alternating Line** is projected. Two phase, No flashing. Each phase is displayed for 4.2 seconds, and then the message turns off.

MAJOR ACCIDENT **AT WAYSIDE RD**	**ALL LANES BLOCKED** **USE OTHER ROUTES**
1st Phase	*2nd Phase*

Instructions by Study Administrator

"The second message style has the same information as the first, but is presented in a slightly different manner."

Sign 26 (Group A1) (M6 Alternating Line), two-phase message – no flashing. At the appropriate time, **Message M6 Alternating Line** is projected. Two phase, No flashing. Each phase is displayed for 4.2 seconds, and then the message turns off.

MAJOR ACCIDENT **AT WAYSIDE RD** **ALL LANES BLOCKED**	**MAJOR ACCIDENT** **AT WAYSIDE RD** **USE OTHER ROUTES**
1st Phase	*2nd Phase*

<u>Questions by Study Administrator:</u>

1. Which message style do you prefer?
   ________________ The first message style (shown previously)
   ________________ The second message style (shown last)

2. Why do you prefer the message style that you selected?
   ____

<u>Instructions by Study Administrator</u>

“Again, you will see two ways to displaying the same message. After you view both message styles, you will be asked to let us know which style you like best. The messages will remain on the screen for a few seconds. Then the messages will turn off.”

Sign 27 (M4 No Flash Line), No flashing. At the appropriate time, **Message M4 No Flash Line** is projected. No flashing. Message is displayed for 8.4 seconds.

TRUCK ACCIDENT

AT AIRPORT ROAD

USE SERVICE ROAD

Instructions by Study Administrator

"The second message style has the same information as the first, but is presented in a slightly different manner."

Sign 28 ***(M4 Flash Line)***, only top line flashes. The second message style will have the same message as the first but part of the message will flash. At the appropriate time, **Message M4 Flash Line** is projected. Only top line flashes. Message is displayed for 8.4 seconds.

TRUCK ACCIDENT

AT AIRPORT ROAD

USE SERVICE ROAD

Questions by Study Administrator

1. Which message style do you prefer?
   ________________ The first message style (shown previously)
   ________________ The second message style (shown last)
2. Why do you prefer the message style that you selected?
   ____

<u>Instructions by Study Administrator</u>

"Again, you will see two similar ways of displaying a message. After you view both message styles, you will be asked to let us know which style you like the best. The messages will remain on the screen for a few seconds. Then they will turn off."

Sign 29 (M10 No Telephone Number No.), amber alert without telephone number – no flashing. At the appropriate time, **Message M10 No Telephone Number No.** is projected. No flashing. Message is displayed for 8.4 seconds.

MISSING CHILD
YELLOW TOYOTA
TUNE TO RADIO

<u>Instructions by Study Administrator</u>

"The second message style is similar to the first with slightly different information."

Sign 30 (M10 Telephone Number No.), amber alert with telephone number – no flashing. At the appropriate time, **Message M10 Telephone Number No.** is projected. No flashing. Message is displayed for 8.4 seconds.

MISSING CHILD
YELLOW TOYOTA
CALL 888 769 5000

Questions by Study Administrator

1. Which message style do you prefer?
   ________________ The first message style (shown previously)
   ________________ The second message style (shown last)
2. Why do you prefer the message style that you selected?
   ____

Statement by Study Administrator

"This is the end of the study. We want to thank you for your participation and help. The information that you provided will be extremely beneficial to the State of Texas and to the federal government as they develop better signing information for the motoring public." **END OF STUDY.**

Data Collection Forms, Subject Groups A2, B1, and B2, PCSP

The forms used for subject groups A2, B1, and B2 were very similar to that used for subject group A1. The only difference was the order of the messages, which is detailed in Table 7. Additionally, for the subjects that had no secondary task the instructions pertaining to the pressing of the on-screen buttons were deleted.

APPENDIX B

CONTROLS FOR SUBJECT NAUSEA IN THE DRIVING SIMULATOR

Based on anecdotal experiences from previous TTI driving simulator studies and presentations made at the 2004 annual meeting of the Transportation Research Board in Washington, D.C., there was a concern about the possibility of subjects experiencing simulator-induced discomfort (SID) and being forced to prematurely end their participation. There is a belief by many simulator experts that older subjects and female subjects may be more likely to suffer from SID, although no evidence has been presented explaining this anecdotal relationship. Simulator conditions such as sharp turns, rapid acceleration, and rapid braking could rapidly bring the onset of SID in subjects. The following procedures were developed for use in a previous TTI research study and were used in this study to minimize the likelihood of SID occurrences.

- During subject recruitment the researchers asked 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 monitor the subjects for signs of SID.
- Five opportunities for rest breaks were provided 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.
- Researchers in the study observed the subjects through a closed-circuit television and watched for visual signs of SID.

- The presence of horizontal curvature was eliminated in the simulated driving environment.
- Lane changes and vertical curvature were minimized.

Eight of the 126 subjects tested complained of nausea despite the precautions taken for a dropout rate of six percent. In those cases the subjects were removed from the driving 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 C

DATA ANALYSIS AND PRELIMINARY RECOMMENDATIONS THE FIRST DATA COLLECTION PHASE

In this appendix, a review of the different analysis methods used is presented. First, an overview of analysis methods used in the first analysis method is presented. Second, a comparison of how the overall conclusions achieved from using PCSP button display studies compared to the driving simulator results. Third, the analysis methods that used differences in individual subject results as the means of comparison are presented. Fourth, analysis methods that used overall results of subjects as a group are presented.

Data Analysis and Summary of Findings

MOE #1: Numeric Differences in Reading Time Performance

During the self-paced segments of the study, the subjects were shown ten of the twenty messages, as shown in Table 7. Half of the subjects (those in groups A1 and A2) saw one set of ten; the other half (those in Groups B1 and B2) saw the other ten. Each subject viewed one display version of the messages listed from each message (Message M1 displayed in either flashing or static mode, Message M2 displayed in either flashing or static display mode, and so on until they had seen ten messages). The subjects were allowed to read each message for as long as they felt they needed, and this reading time was recorded.

Forty tests of hypothesis were then tested: one for the mean reading time for each of twenty CMS messages presented during the self-paced sessions for the 0.625 button/second display rate and another twenty for the 0.909 button/second display rate. The null hypothesis was rejected for a particular CMS message if the difference in reading time (PCSP reading time minus simulator reading time) was significantly different from zero.

The only difference between the two reading time measurements was the procedure used to impose mental workload on the subject (PCSP or driving simulator). If the procedures were truly comparable in imposing workload, then the difference in reading time (DRT) between the driving simulator reading time and the PCSP reading time should be zero, and the sum of all of the subjects DRTs should also be zero. A test was conducted to determine whether the average DRTs for all subjects was significantly different from zero for both of the display rates selected in the button display task. The following calculations were made:

$$DRT_{i,j} = (\text{PCSP Reading Time}_{i,j}) - (\text{Driving Simulator Reading Time}_{i,j}) \qquad \text{(C1)}$$

Where:

i = Subject Number (1 to 64), and

j = Message (1 to 20).

The following hypotheses were tested:

H_{0j}: $\mu_j = 0$, (mean reading times for a given message display j are equal) and

H_{1j}: $\mu_j \neq 0$ (mean reading times for a given message j are not equal).

Figure C1 shows a series of 95 percent confidence intervals for the sample reading time means, which were developed using Student's *t*-distributions. Those confidence intervals that are shaded in Figure C1 do not include zero, and so the null hypothesis can be rejected for that message.

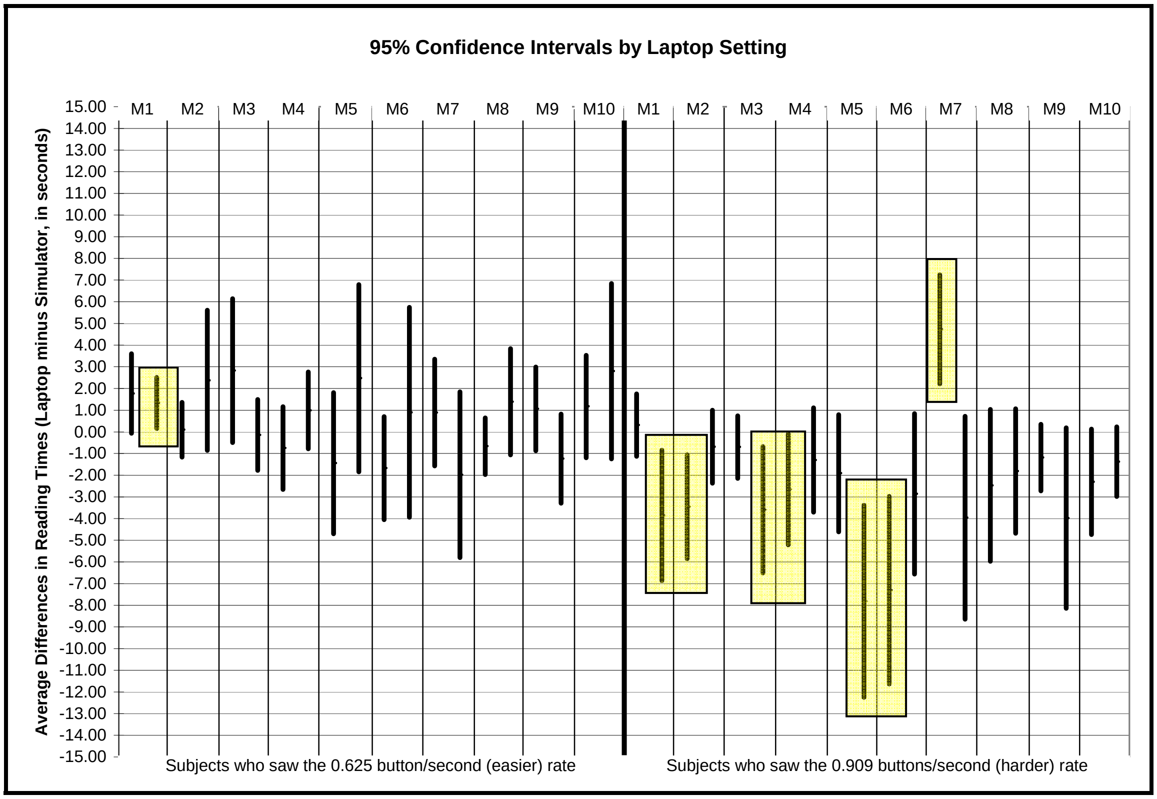

Figure C1. Ninety-Five Percent Confidence Limits of Differences in Reading Times (Shaded Boxes Indicate Messages where Difference in Reading Times were Different between the Driving Simulator and the Personal Computer Study Procedure Button Display Task)

The results showed that only one of 20 null hypotheses was rejected for the 0.625 button/second display rate, while seven were rejected for the 0.909 button/second display rate. Additionally, of the seven null hypotheses that were rejected for the 0.909 button/second PCSP display rate, one was found to have slower reading times than the driving simulator, and the other six had faster reading times. These faster results were unexpected, and may indicate that subjects became overwhelmed with both performing the button task as well as reading the CMS messages. If this is true then subjects may have stopped attending to the button task, allowing for the increased message-reading attention. This result is undesirable in any procedure that would replicate the workload of operating the driving simulator. The results indicate that the 0.625 button/second display rate may provide a better comparison with the driving simulator than the 0.909 button/second rate relative to average reading time.

MOE #2: Comparison of Comprehension Rates

The purpose of this MOE was to compare how well the two PCSP button display task display rates compared with the driving simulator results in terms of subject comprehension of the messages. Subjects were considered to have correct comprehension of a message if they were able to correctly recall all of the information presented on the message (3 lines of information for Messages M1 through M4 and M7 through M10, and; 4 lines of information for Messages M5 & M6). A PCSP display rate that is similar to the driving simulator should have few significant differences.

The message comprehension results were combined into ten message pairs (Messages M1 displayed in flashing mode and Message M2 displayed in flashing mode were combined for analysis, etc.,) and are shown in Table C1. The results were then examined with the Bernoulli Model to determine if any of the differences are statistically significant.

The Bernoulli Model tests the difference in proportions of two samples:

$$z = \frac{f_1 - f_2}{\sqrt{\frac{p_c(1-p_c)}{n_1} + \frac{p_c(1-p_c)}{n_2}}} \qquad \text{(C2)}$$

Where:

f_1 = the proportion of subjects that correctly recalled all of a message in the driving simulator,

f_2 = the proportion of subjects that correctly recalled all of a message within the PCSP,

n_1 = the number of subjects tested in the driving simulator,

n_2 = the number of subjects tested on a given PCSP display rate,

Table C1. Comprehension of Message Content during Self-Paced Display Reading Sessions

Message	Message Display Format	Number of Message Lines to Recall	Percentage of Subjects that Correctly Recalled all Units of the Message		
			Driving Simulator n = 64	0.625 button/second display rate n = 32	0.909 button/second display rate n = 32
M1 & M2	Flashing	3	80	81	78
	Static	3	89	81	72
M3 & M4	Flashing Line	3	59	63	66
	Static	3	64	59	63
M5 & M6	Alternating	4	64	52	59
	Non-Alternating	4	72	48*	51*
M7 & M8	No License Plate	3	92	91	91
	License Plate	3	33	53	31
M9 & M10	No Telephone Number	3	97	91	88
	Telephone Number	3	41	38	44

* The comprehension difference between the driving simulator and the PCSP button display task is significant at the 0.05 level of significance.

$$p_c = \frac{X_1 + X_2}{n_1 + n_2}, \quad \text{(C3)}$$

X_1 = the number of correct responses in the first sample, and

X_2 = the number of correct responses in the second sample.

Both the 0.625 button/second and the 0.909 button/second PCSP display rates had only one out of ten message pairs that were significantly different from the comprehension results from the driving simulator. Thus, with the exception of one message no differences in comprehension in comparison to the driving simulator results were found for either of the PCSP display rates.

An analysis was conducted to determine if there was a difference in comprehension during the fixed-time sessions presented using the PCSP versus the driving simulator. The same procedure was used as described for the self-paced comprehension data, and the results are shown in Table C2.

Both the 0.625 button/second and the 0.909 button/second PCSP display rates had zero out of ten message pairs that were significantly different from the comprehension results of the driving simulator. Thus, no differences in comprehension in comparison to the driving simulator results were found for either of the PCSP display rates.

MOE #3: Comparison of Stated Preference Rates

The purpose of this MOE was to compare how well the results with the two PCSP button display rates compared with the driving simulator results in terms of how subjects responded to preference questions. Each subject was asked to state which message format from each pair of messages they would prefer to see on the roadway. The

Table C2. Comprehension of Message Content during Fixed-Time Display Reading Sessions

Message	Message Display Format	Number of Message Lines to Recall	Percentage of Subjects that Correctly Recalled all Units of the Message.		
			Driving Simulator n = 64	0.625 button/second display rate n = 32	0.909 button/second display rate n = 32
M1 & M2	Flashing	3	88	78	88
	Static	3	89	78	94
M3 & M4	Flashing Line	3	75	66	69
	Static	3	72	53	69
M5 & M6	Alternating	4	67	47	59
	Non-Alternating	4	58	44	69
M7 & M8	License Plate	3	38	25	41
	No License Plate	3	92	88	97
M9 & M10	Telephone Number	3	33	25	31
	No Telephone Number	3	92	84	88

preference percentages collected using the PCSP were compared against those collected in the driving simulator. A PCSP difficulty display rate that was similar to the driving simulator should have few significant differences.

The message results were combined into ten message pairs (Message M1 displayed in flashing mode and Message M2 displayed in flashing mode were combined for analysis, etc.) and these results examined with the Bernoulli Model. These results are shown in Table C3.

Both the 0.625 button/second and the 0.909 button/second PCSP display rates had zero out of ten message pairs that were significantly different from the preference results of the driving simulator. Thus, no differences in preference were found between the two display rates and the driving simulator.

MOE #4: Comparison in Numeric Differences in Perceived Difficulty Rating Scale Ratings

When the subjects were finished in the driving simulator portion of the study they were asked to provide a 12-point Cooper-Harper rating on the relative difference between the driving simulator and their experiences driving real vehicles in similar driving circumstances. Subjects provided a numerical rating based on the following scale:

- 1 = "Much too easy when compared with real driving conditions;"
- 2 = "Too easy when compared with real driving conditions;"
- 3 = "A little too easy when compared with real driving conditions;"
- 4 = "Excellent comparison when compared with real driving conditions;"
- 5 = "Good comparison when compared with real driving conditions;"
- 6 = "Fair comparison when compared with real driving conditions;"
- 7 = "A little too hard when compared with real driving conditions;"
- 8 = "Too hard when compared with real driving conditions;"
- 9 = "Much too hard when compared with real driving conditions;" and
- 10 through 12 = "Failed comparison when compared with real driving conditions."

Table C3. Message Preference during Preference Session

Message	Message Display Format	Number of Information Units	Percentage of Subjects that Correctly Recalled all Units of the Message		
			Driving Simulator n = 64	0.625 button/second display rate n = 32	0.909 button/second display rate n = 32
M1 & M2	Flashing	3	39	38	44
	Static	3	61	63	56
M3 & M4	Flashing Line	3	45	47	50
	Static	3	55	53	50
M5 & M6	Alternating	4	52	53	47
	Non-Alternating	4	48	47	53
M7 & M8	License Plate	3	29	37	19
	No License Plate	3	71	63	81
M9 & M10	Telephone Number	3	17	26	19
	No Telephone Number	3	83	74	81

This process was repeated at the end of the PCSP portion of the study, so the ratings between the PCSP study could be could be compared with the driving simulator study. There was an interest to see if subjects were more likely to rate the button display task portion of the study as harder or easier based on the difficulty display rates (when compared to their ratings in the driving simulator). The differences between the button display rates rating and the simulator rating were determined for each subject. The differences in the individual responses, $D_{i,j}$, were calculated as follows and were tested for the difference in median values between two populations:

Where:

$D_{i,j}$ = The Cooper-Harper Rating for the PCSP minus the Cooper-Harper Rating for the driving simulator. (C4)

Confidence intervals were prepared to determine if the median value could be zero, in order to test the following hypotheses:

H_{0j}: $Median_j = 0$, (For the median subject, both the PCSP button display task and the driving simulator are equally rated), and

H_{1j}: $Median_j \neq 0$ (For the median subject, either the PCSP button display task or the driving simulator are rated harder than the other).

The differences in the individual responses were calculated and were tested for the difference in median values between the 0.625 button/second display rate and the 0.909 button/second display rate, and are shown in Table C4. The results were that the confidence intervals for the two display rates were identical (confidence intervals [-1,2]). Therefore, there was no indication of perceived difficulty between the two display rates and the driving simulator.

Table C4. Analysis of Cooper-Harper Rating Scale Differences by the Personal Computer Study Procedure Button Display Task Level of Difficulty

	Difference in Cooper-Harper Rating Scales, D_i	
	0.625 button/second n = 32	**0.909 button/second n = 32**
Median Difference, $D_{16,5}$	0	0
95% Confidence Interval of Median	[-1,2]	[-1,2]
Median Significantly Different than zero (α = 0.05)?	No	No

Summary of analysis results

Table C5 shows a summary of the analyses performed and comparisons of the results from the driving simulator and the PCSP studies for each MOE. The results of only one MOE, average reading time, showed a difference between the two PCSP display rates compared with the driving simulator results. The results indicated that the 0.625 button/second display rate provided performance more closely resembling the driving simulator than did the .909 button/second display rate.

It appears that the 0.909 button/second display rate may have crossed the threshold of difficulty where subjects cannot attend to the CMS message reading task and perform the button-pressing task. It is expected that testing a harder display rate would simply show a more severe trend.

Table C5. Summary of Results from Preliminary Analysis

Analysis Method	Number of Times Null Hypotheses were Rejected between the Driving Simulator and the PCSP Button Display Task (α= 0.05)		Indication of Which Display rate is Closer to the Driving Simulator
	0.625 button/second Display Rate	0.909 button/second Display Rate	
Numerical Differences in Reading Time Data	1 out of 20	7 out of 20	**0.625 button/second display rate.**
Numerical Differences in Comprehension Data during Self-Paced Display Sessions	0 out of 10	0 out of 10	No difference indicated.
Numerical Differences in Comprehension Data during Fixed-Time Display Sessions	1 out of 10	1 out of 10	No difference indicated.
Numerical Differences in Preferences given during Preference Session	0 out of 10	0 out of 10	No difference indicated.
Numerical Differences in Cooper-Harper Rating Scale Data	0 out of 1	0 out of 1	No difference indicated.

Considerations for How to Proceed to the Second Data Collection Phase

Based on these results, there does not appear to be a need to collect data on a display rate faster than the 0.909 button/second display rate:

- The individual performance data regarding differences in reading times (MOE #1) show that the 0.909 button/second display rate tends to provide less similar performance compared to the driving simulator than the 0.625 button/second display rate. Seven of the 20 (35 percent) CMS message reading times were found to be different from the driving simulator. This represents 35 percent of the CMS messages, and is considered a poor, especially compared to the 0.625

button/second display rate, where only one in 20 of the CMS messages (5 percent) were found to be different.

- The results of reading time data may indicate that when asked to perform the PCSP study using the 0.909 button/second display rate, subjects may focus instead on just reading the CMS messages, which would be an undesirable tendency. This was interpreted from the six out of 20 instances when the reading time difference indicated that the 0.909 button/second display rate provided *faster* reading times than the driving simulator, an unexpected result.
- From this, it appears that the 0.909 button/second display rate is approaching an extreme value in terms of unacceptable subject reading time performance in comparison to the driving simulator. It is expected that testing a faster display rate would simply show a more severe trend.

A new research question has arisen from this analysis: would a condition without any subject workload (no buttons to push) - an approach used in previous PC studies - provide comparable or better results to the 0.625 button/second display rate, or could even improved comparisons with the driving simulator be achieved.

Based on the data analysis presented and the discussion provided in this section, it is recommended that a number of subjects should be tested within the PCSP with no secondary task - a button display rate of 0 buttons/second. The condition with no secondary task is worth considering because it would provide information on the other extreme to the 0.909 button/second rate, and if determined to be comparable to the driving simulator could provide future researchers the option of having only a single-task experiment (reading CMS messages with no other task).

One of the purposes of this update is to decide on the button rates for second data collection phase. Based on the data analysis presented above, it is recommended that a number of subjects should be tested in the PCSP with no secondary workload. Thus, data will be available for three display rates.

By reallocating the remaining subjects evenly across the three alternatives, data will be available for the following distribution of subjects:

- 42 subjects with no secondary task,
- 42 subjects with the 0.625 button/second display rate, and
- 42 subjects with the 0.909 button/second display rate.

Figure C2 shows graphically how the study design was originally set up based on these recommendations. Those cells with check marks show the portions of the study that have been successfully completed as part of the first data collection phase. Figure C3 shows how the subjects can be reallocated to fit the recommendations made in this appendix.

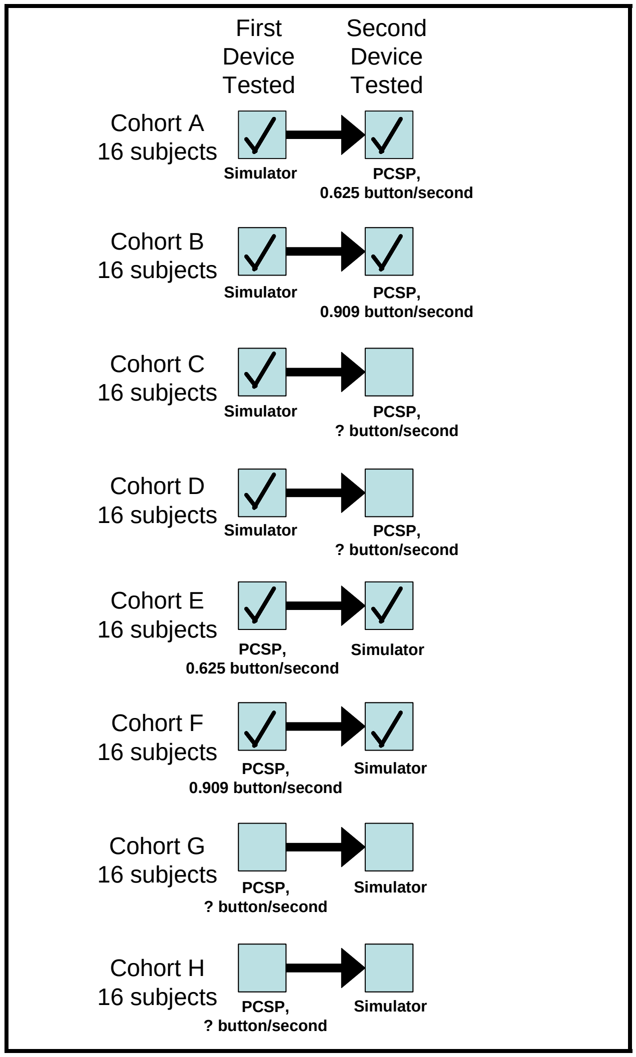

Figure C2. Original Data Collection Plan, Checks Showing Sections Completed to Date

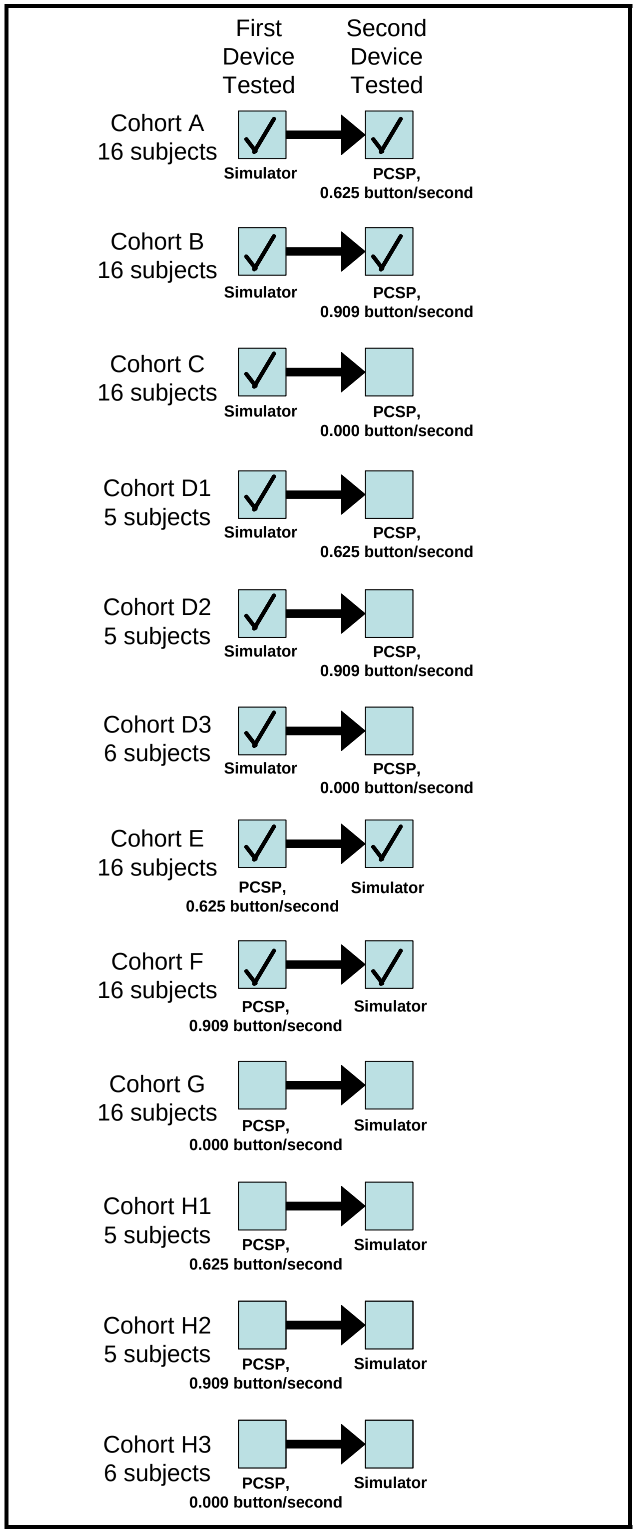

Figure C3. Revised Data Collection Plan, Checks Showing Sections Completed

APPENDIX D

PHYSIOLOGICAL CONDITION QUESTIONNAIRE ADMINISTERED BEFORE AND AFTER THE DRIVING SIMULATOR SESSIONS

Table D1. Simulator Induced Discomfort Questionnaire

Date_____________	Participant #_______________________			
Directions: Circle any symptoms below that apply to you right now				
General discomfort	None	Slight	Moderate	Severe
Fatigue	None	Slight	Moderate	Severe
Boredom	None	Slight	Moderate	Severe
Drowsiness	None	Slight	Moderate	Severe
Headache	None	Slight	Moderate	Severe
Eye Strain	None	Slight	Moderate	Severe
Difficulty Focusing	None	Slight	Moderate	Severe
Salivation increased	None	Slight	Moderate	Severe
Salivation decreased	None	Slight	Moderate	Severe
Sweating	None	Slight	Moderate	Severe
Nausea	None	Slight	Moderate	Severe
Difficulty concentrating	None	Slight	Moderate	Severe
Mental depression	None	Slight	Moderate	Severe
"Fullness of the Head"	None	Slight	Moderate	Severe
Blurred Vision	None	Slight	Moderate	Severe
Dizziness w/ eyes open	None	Slight	Moderate	Severe
Dizziness w/ eyes closed	None	Slight	Moderate	Severe
Vertigo *	None	Slight	Moderate	Severe
Visual flashbacks **	None	Slight	Moderate	Severe
Faintness	None	Slight	Moderate	Severe
Awareness of breathing	None	Slight	Moderate	Severe
Stomach awareness ***	None	Slight	Moderate	Severe
Loss of appetite	None	Slight	Moderate	Severe
Increased appetite	None	Slight	Moderate	Severe
Desire to move bowels	None	Slight	Moderate	Severe
Confusion	None	Slight	Moderate	Severe

Table D1. (Continued)

Directions: Circle any symptoms below that apply to you right now			
Burping	No	Yes	Number of times_____
Vomiting	No	Yes	Number of times_____
Other	____		

* Vertigo is experienced as loss of orientation with respect to vertical upright.
** Visual illusion of movement or false sensations similar to automobile dynamics, when not in the simulator or the automobile.
*** Stomach awareness is usually used to indicate a feeling of discomfort which is just short of nausea.

VITA

Steven Dale Schrock attended Williamsburg Community Schools in Williamsburg, Iowa, from kindergarten through high school, and graduated valedictorian of his class in May 1990. Mr. Schrock entered Iowa State University in Ames, Iowa, in August 1990 and graduated with a Bachelor of Science in Civil Engineering in December 1994. From January 1995 through July 1997 he worked as a consultant for the roof consulting firm Benchmark, Inc., in Cedar Rapids, Iowa. In August 1997 he left Benchmark and returned to Iowa State University to pursue a Master of Science in Civil Engineering with an emphasis in transportation engineering, which he received in August 1999. The title of his Master's thesis is: "Evaluation of Alternative Rural Interstate Work Zone Traffic Management Plans Using Simulation: A Case Study."

In September 1999 he enrolled at Texas A&M University in College Station, Texas, to pursue a Ph.D. in Civil Engineering with an emphasis in transportation engineering. While at Texas A&M University, Mr. Schrock also worked at the Texas Transportation Institute in the Work Zone and DMS Program, first as a Graduate Assistant Researcher, then as an Assistant Transportation Researcher, and finally as an Assistant Research Engineer. In August 2006 he began work as an Acting Assistant Professor in the Department of Civil, Environmental, and Architectural Engineering at the University of Kansas in Lawrence, Kansas. He received his Ph.D. from Texas A&M University in August 2007.

Mr. Schrock is a Registered Professional Engineer in Kansas and Texas. He is also a Member of the Institute of Transportation Engineers, and is actively involved with several committees of the Transportation Research Board. Mr. Schrock can be contacted at: The University of Kansas, CEAE Department, 2159B Learned Hall, 1530 15th Street, Lawrence, Kansas 66045, or at schrock@ku.edu.