Development of Human Factors Guidelines for Advanced Traveler Information Systems (ATIS) and Commercial Vehicle Operations (CVO): Driver Response to Unexpected Situations When Using an In-Vehicle Information System

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FOREWORD

This report is one of a series of reports produced as part of a contract designed to develop precise, detailed human factors design guidelines for Advanced Traveler Information Systems (ATIS) and Commercial Vehicle Operations (CVO). During the analytic phase of the project, research issues were identified and rated by 8 human factors experts along 14 separate criteria. The goal of the experimental phase was to examine the highest rated research issues that can be addressed within the scope of the project. The 14 experiments produced in that phase reflect the results of those ratings.

This report describes the results of a field study conducted to investigate the effects of using an In-Vehicle Information System (IVIS) when the driver is confronted with unexpected situations. The study examines issues regarding benefits of an integrated IVIS, information density, and the impact of driver age on system use.

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Director, Office of Safety
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This investigation is one of a series of studies aimed at investigating Advanced Traveler Information Systems (ATIS) and Commercial Vehicle Operations (CVO) applications and their effect on driver behavior and performance. A field experiment was conducted to investigate the benefits and detriments of using an In-Vehicle Information System (IVIS) when the driver is confronted with unexpected situations. The IVIS used in the present study included three in-vehicle subsystems: In-Vehicle Signing and Information Systems (ISIS), which provide redundant roadside information, In-Vehicle Routing and Navigation Systems (IRANS), and In-Vehicle Safety Advisory and Warning Systems (IVSAWS). This research focused on five primary areas: (1) the inclusion of unexpected situations, specifically external events and vehicle status warnings, (2) driver notification of these events and warnings via an IVSAWS, (3) situation awareness of the driver when confronted with unexpected situations, (4) the impact of IVIS display density on driver response to unexpected situations, and (5) older driver use of an IVIS when confronted with unexpected situations. Three research questions were posed and investigated, each involving the use of an IVIS and response to unexpected situations: (1) Do drivers derive a benefit from using an IVIS that has multiple subsystems, when confronted with an unexpected situation? (2) What impact does IVIS information density have on driver's behavior and performance? and (3) What impact does driver age have on system use and measures related to driver behavior and performance? The following conclusions and recommendations were derived from this field study: (1) results indicated a clear benefit for drivers responding to external events and vehicle status warnings when using an IVIS, (2) drivers are capable of safely switching attention from an IVIS to the forward roadway while responding to an external event, (3) older drivers behave more cautiously when using an IVIS and responding to unexpected situations, (4) limitations associated with older driver performance, such as longer response latency and more frequent navigation errors, may be reduced through the use of an optimally designed IVIS, (5) auditory cues for alerts should allow user control of intensity, and (6) drivers should be allowed to select "low urgency" messages and alerting cues from a bank of options that crosses sense modalities.</td></tr>
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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yards	0.836	square meters	m^2
ac	acres	0.405	hectares	**ha**
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
NOTE: Volumes greater than 1000 l shall be shown in m^3				
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5(F-32)/9 or (F-32)/1.8	Celcius temperature	°C
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.71	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
		TEMPERATURE (exact)		
°C	Celcius temperature	1.8C + 32	Fahrenheit temperature	°F
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

*SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380.

(Revised September 1993)

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LIST OF ABBREVIATIONS

AHS . . . . Automated Highway Systems
ANOVA . . . . Analysis of Variance
ATIS . . . . Advanced Traveler Information Systems
ATMS . . . . Advanced Traffic Management Systems
AVCS . . . . Advanced Vehicle Control Systems
CCFT . . . . Cold Cathode Fluorescent Tubes
CTR . . . . Center for Transportation Research
CVO . . . . Commercial Vehicle Operations
FOV . . . . Field of View
HUD . . . . Head-Up Display
IMSIS . . . . In-Vehicle Motorist Services Information Systems
IRANS . . . . In-Vehicle Routing and Navigation Systems
ISIS . . . . In-Vehicle Signing Information Systems
ITS . . . . Intelligent Transportation Systems
IVHS . . . . Intelligent Vehicle Highway Systems
IVIS . . . . In-Vehicle Information Systems
IVSAWS . . . . In-Vehicle Safety Advisory and Warning Systems
TFT . . . . Thin Film Transistor

EXECUTIVE SUMMARY

This experiment is one of a series of studies aimed at investigating Advanced Traveler Information Systems (ATIS) and Commercial Vehicle Operations (CVO) applications and their effect on driver behavior and performance. The ultimate goal of these studies is the development of a set of ATIS/CVO design guidelines.

A field experiment was conducted to investigate the benefits and detriments of using an In-Vehicle Information System (IVIS) when the driver is confronted with unexpected situations. The IVIS used in the present study included three in-vehicle subsystems: In-Vehicle Signing and Information Systems (ISIS), which provide redundant road sign information, In-Vehicle Routing and Navigation Systems (IRANS), and In-Vehicle Safety Advisory and Warning Systems (IVSAWS). This research focused on five primary areas:

- The inclusion of unexpected situations, specifically external events and vehicle status warnings,
- The notification of these events and warnings via an IVSAWS,
- The driver's situation awareness when confronted with unexpected situations,
- The impact of IVIS display density on driver response to unexpected situations, and
- Older driver use of an IVIS when confronted with unexpected situations.

To investigate these areas, three research questions were posed. Each question involved the use of an IVIS and response to unexpected situations:

- Do drivers derive a benefit from using an IVIS, which has multiple subsystems, when confronted with an unexpected situation?
- What impact does IVIS information density have on driver behavior and performance?
- What impact does driver age have on system use and driver behavior and performance?

Twenty drivers participated in this field experiment. One-half of the drivers were ages 18-24, and one-half were 65-75. A 1995 Oldsmobile Aurora was used as the data collection vehicle. Participants drove on a prescribed route, lasting approximately 2 hours, that took them through Virginia's Montgomery County, including urban areas of Blacksburg and Christiansburg. The route was divided into three sections. During each section, drivers were presented with a different IVIS display condition: no display, low density display, or high density display. During the route, drivers were administered five scripted external events and one planned vehicle status warning event. Each of the events was carried out by one or more confederate vehicles. The list of events consisted of:

- Car approaching from hidden entrance,
- One-lane tunnel,
- Disabled vehicle,
- Trunk open,
- Ambulance approaching, and

! Crash ahead.

To measure driver response, a number of dependent measures were collected to evaluate situation awareness, driving performance, and driver preference.

Considering each of the three primary research questions, the results of this experiment can be summarized as follows:

1. ***Do drivers derive a benefit from using an IVIS, which has multiple subsystems, when confronted with an unexpected situation?***

! No negative effects were observed for driver behavior when using an IVIS and responding to external events and vehicle status warnings.

! Response latencies for initiating responses to external events were shorter when drivers were driving a vehicle equipped with an IVIS.

! Significantly more appropriate responses occurred during vehicle status warnings for drivers using an IVIS.

! While using an IVIS, 18.2 percent of drivers responded to an ambulance approaching from the rear prior to seeing/hearing it.

! While using an IVIS, 27.3 percent of drivers responded to a crash scene prior to seeing/hearing it.

2. ***What impact does IVIS information density have on driver behavior and performance?***

! In the high density condition (with six to seven simple, well-designed symbols or phrases), extra information from the IRANS did not measurably hamper search time.

3. ***What impact does driver age have on system use and driver behavior and performance?***

! IVIS benefits were realized for both younger and older drivers.

! Both younger and older drivers preferred the auditory alert when it served as a redundant IVSAWS message for "high urgency" events. For some of the events, older drivers took more time to complete them than younger drivers.

! For the ambulance approaching event, older drivers took more time to shift their gaze from the forward roadway to the IVIS than younger drivers.

! More navigation errors were committed by older drivers.

! Younger drivers were quicker to respond to external events than older drivers.

! Most older drivers, but no younger drivers, preferred the auditory alert when it served as redundant ISIS and IRANS messages for "low urgency" events.

The following six design guidelines may be useful to ATIS/CVO system developers. Recommendations 1 and 2 are derived from the results of this research, while recommendations 3 to 6 are more speculative and are based on the methodology and the IVIS design characteristics used in this experiment.

(1) Driver response to unexpected events will benefit from well-designed IVIS displays that provide IVSAWS information.

(2) Auditory cues for alerts should allow user control of intensity.

(3) Five seconds is the recommended timing for IVSAWS information for external events, where a warning is presented 5 seconds prior to when the driver could perceive the external event without an IVSAWS. In this research, 5 seconds was enough time for the driver to look at the display, plan a response, and safely take remedial action.

(4) An IVSAWS can effectively integrate external event warnings and vehicle status warnings. With an IVIS, information for external event warnings and vehicle status warnings can be co-located in the same area designated for IVSAWS information.

(5) Limitations associated with older driver performance, such as longer response times and more frequent navigation errors, can be reduced through the use of an optimally designed IVIS.

(6) Drivers should be allowed to select preferred “low urgency” messages and alerting cues, including redundant messages and multiple cues. The rationale for this recommendation is based on the finding that younger drivers and older drivers differed in their desire for auditory alerts for ISIS and IRANS information (i.e., “low urgency”), but not in their desire for auditory alerts for IVSAWS information (i.e, “high urgency”).

CHAPTER 1: INTRODUCTION

IN-VEHICLE INFORMATION SYSTEM BACKGROUND

Intelligent Transportation Systems (ITS) encompass a wide range of technologies, including Advanced Vehicle Control Systems (AVCS), Automated Highway Systems (AHS), Advanced Traffic Management Systems (ATMS), Commercial Vehicle Operations (CVO), and Advanced Traveler Information Systems (ATIS). Under the umbrella of ATIS technologies, In-Vehicle Information Systems (IVIS) provide information to the driver while, as the name implies, the driver is inside the vehicle. This is in contrast to other transportation information systems that might provide traveler information at a kiosk or on the television screen of a hotel room. Currently available IVIS, such as the Bosch Travel Pilot, are typically mounted in the dashboard area. From the IVIS display, drivers have access to a variety of traveler information, including (1) redundant roadway and signing information, (2) routing and navigation information, (3) safety advisory and warning information, and (4) motorist services information. Taken separately, these systems can be categorized based on the information they provide. Subsystems that provide the information described above are known as: (1) In-Vehicle Signing Information Systems (ISIS), (2) In-Vehicle Routing and Navigation Systems (IRANS), (3) In-Vehicle Safety Advisory and Warning Systems (IVSAWS), and (4) In-Vehicle Motorist Services Information Systems (IMSIS).

Perez and Mast (1992) provide a clear description of the four ATIS subsystems. They define ISIS as a subsystem that provides non-commercial routing, warning, regulatory, and advisory information inside the vehicle. This includes information such as speed limit and highway markers that are currently posted on roadside signs. This information is not intended to take the place of roadside information, but is meant to supplement it or provide redundant information. IRANS are systems that help guide the driver from one location to another, as well as provide information on traffic operations and congestion. Moving map displays and turn-by-turn indicators are examples of guidance provided with IRANS. IVSAWS provide the driver with information about upcoming unsafe conditions/situations in order to allow the driver time to take remedial action. An example of an IVSAWS message is a warning to the driver that a rock slide has occurred and is blocking the roadway ahead. IMSIS are defined as systems that provide the driver with commercial logos and information about motels, restaurants, and similar traveler facilities. ATIS that employ these subsystems are currently commercially available and have been described in the literature. For example, the TravTek system incorporates IRANS and IMSIS, and has undergone an extensive operational field test (Dingus, McGehee, Hulse, Jahns, Manakkal, Mollenhauer, and Fleischman, 1995; Rillings and Lewis, 1991).

Optimally presenting information inside the vehicle, so that it is quickly understood and not distracting to the driver, is one Advanced Traveler Information Systems (ATIS)-related design issue outlined by ITS America (1995). Human factors research investigates this and other ATIS-related issues by collecting behavior and performance measures while the driver interacts with a system in a real-world driving environment. Through this type of research, an understanding of driver behavior can be realized, and recommendations for system design can be made. The ultimate goal of such investigation is the safe, efficient, and effective design and implementation of IVIS.

RECOMMENDED ATIS RESEARCH

Extensive laboratory, simulator, and field test research, such as that conducted on TravTek and more recently ADVANCE (Mollenhauer, McGehee, Dingus, Inman, and Neale, in press), provide insight into issues concerning interactions between drivers and IVIS. From this research, a better understanding of driver behavior can be gained and utilized in design guidelines for system developers. As outlined by Kantowitz, Dingus, Lee, Hulse, Barfield, Landau, Hanowski, Kantowitz, Ng, and McCauley (1994), a number of major issues require investigation for developing ATIS design guidelines, including:

- The cognitive demands placed on the driver by the need to transition from one ATIS function to another.
- How complex interactions among ATIS functions might affect driver understanding and response to the system.
- How the information drivers need and want from road sign (ISIS) and warning systems (IVSAWS) might influence behavior.
- How information reliability (e.g., false alarms) influences driver adaptation and enhances the potential for an improper response to ISIS/IVSAWS.
- How to display multiple ISIS and IVSAWS messages so that drivers can identify relevant information and react appropriately.
- Features that will benefit from/require standardization across many types of ATIS systems and functions.
- The performance differences associated with focusing all ISIS and IVSAWS information through either single or multiple display channels.
- The effectiveness of multi-modality displays, such as voice in combination with text.
- Specific concerns regarding how display formats and modality impact CVO driver workload.
- The effect of information reliability and inaccuracies on driver acceptance and use of ATIS/CVO systems.

Research on these issues has provided some insight (e.g., Kantowitz, Hanowski, and Kantowitz, 1997). The experiment presented here investigates another important issue related to ATIS: whether drivers' reliance upon cues provided inside the vehicle influences their observation of unexpected situations as compared with when they rely on cues presented solely outside the vehicle. There are five primary areas of focus in the present research: (1) the inclusion of unexpected situations, specifically external events and vehicle status warnings; (2) notifying drivers of these unexpected situations via an IVSAWS; (3) the driver's situation awareness when confronted with unexpected situations; (4) the impact of IVIS display density on driver response to unexpected situations; and (5) older driver use of an IVIS when confronted with unexpected situations.

EXTERNAL EVENTS AND VEHICLE STATUS WARNINGS

External events refer to unsafe conditions/situations that are outside the vehicle and require the driver to take remedial action. As noted previously, a rock slide in the roadway ahead is an example of an external event. External events involve a sense of urgency whereby the absence of remedial action may result in a crash. The severity of external events varies from case to case. However, all external events require immediate attention and, providing the hazard is still present when the driver reaches its location[1], remedial action. Vehicle status warnings are similar to external events in terms of required driver response. In the event of an emergency situation involving, for example, the mechanics of the automobile, the driver's immediate attention is required, along with an action to address the emergency. Examples of vehicle status warnings include dangerously low tire pressure and an unlatched hood.

Previous research has been conducted concerning external events and ATIS (Hulse, 1988; Dingus et al., 1995). Hulse (1988) found that while using an IRANS system (Etak), drivers appropriately focused their visual attention to the center of the roadway during the occurrence of an unexpected incident. Based on this result, it appears that in most circumstances, drivers can switch their gaze when necessary and respond appropriately when using an ATIS. When addressing other types of ATIS, no research has investigated the observation of external events during their use. Drivers could rely too heavily on information provided inside the vehicle. As a result, drivers might change their eye glance or attentional patterns and miss external events that would be detected without the presence of an ATIS.

IVSAWS MESSAGES

As outlined by Perez and Mast (1992), IVSAWS provide the driver with information about unsafe conditions/situations to allow the driver enough time to take remedial action. Different sensory modalities are available for providing IVSAWS information, including visual (e.g., text message, symbols/icons), auditory (e.g., tones, voice messages), and haptic messages (e.g., vibration). Recommendations for the presentation of warning messages are well documented (e.g., Campbell, Hooey, Carney, Hanowski, Gore, Kantowitz, and Mitchell, 1996; Deatherage, 1972; Edworthy, 1994; Lerner, Kotwal, Lyons, and Gardner-Bonneau, 1993; McCormick and Sanders, 1982; Wickens, 1992; Wolf, 1987). It is generally accepted that emergency alerts that require immediate attention should be presented aurally (e.g., Lerner et al., 1993) and that redundant communication can improve performance (Wickens, 1992). The results from recent research involving collision warning messages suggest that the redundant presentation of warning information in multiple modalities (auditory and visual) is preferred by drivers (Campbell et al., 1996).

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[1]Consider an ATIS that presents advanced warning information prior to reaching a hazard. Depending on how far in advance the information is presented, it is conceivable that the hazard may not be present when the driver reaches the location of the hazard. An example would be a traffic jam that dissipates prior to reaching it.

As discussed by Campbell et al. (1996), there are several considerations when presenting alerts to drivers. These include the sensory modality of the alert, the ambient noise level in the cab, and the timing of the alert. Obviously, the purpose of presenting an alert is to gain the attention of the driver. However, depending on when the alert is presented in relation to the occurrence of an event, the warning message may distract the driver from the event to which it is intended to alert them. Recent research efforts have examined issues related to IVSAWS message presentation: Lerner et al. (1993) developed a set of guidelines for collision avoidance systems; Campbell et al. (1996) outlined recommendations for the driver-vehicle interface of Side Object Detection Systems; and Hanowski and Kantowitz (in press) employed a driving simulator to investigate IVIS message comprehension and memory retention. However, investigations specific to IVSAWS messages and related driver behavior in a real-world environment are lacking from the body of ITS research. The primary benefit of such studies is that they allow direct observation of driver behavior and reaction to IVSAWS alerts under real conditions.

SITUATION AWARENESS

Events requiring a warning typically warrant a rapid analysis of a complex and dynamic situation; therefore, the operator's (driver's) situation awareness is critical for decision making and performance (Endsley, 1995). Endsley (1995) describes situation awareness in the flight environment and notes that "the safe operation of the aircraft in a manner consistent with the pilot's goals is highly dependent on a current assessment of the changing situation, including details of the aircraft's operational parameters, external conditions, navigational information, other aircraft, and hostile factors" (p. 33). Situation awareness can also be applied to the driving environment. Consider the rock slide event and the following scenario where, unbeknownst to the driver, a rock slide has occurred ahead and a large boulder is situated in the lane, around the next curve. As the driver approaches the slide, he/she is required to quickly analyze the situation and perform an action to avoid crashing into the boulder. The driver's situation awareness, as the pilot's in the flight environment, is critical to safely responding to this event. Warning the driver of the slide, in a timely and easily comprehendible manner, allows the driver to plan what actions to take, thereby reducing the urgency associated with the event. On the other hand, warnings that are either untimely or difficult to comprehend may add to the confusion and detract from the driver's ability to safely perform remedial actions. As noted, issues related to comprehension and memory retention of IVIS messages have recently been investigated in a driving simulator (Hanowski and Kantowitz, in press). The key, it seems, is to present clear, concise warning messages that provide adequate time to allow the driver to make an appropriate response.

DISPLAY DENSITY

One approach in developing ATIS guidelines for an optimal design is to assess what system characteristics or parameters might make for non-optimal design. Put another way, given that a driver has access to an IVIS that presents IVSAWS messages, what are some of the parameters that might detract from the driver responding appropriately? We might expect one such parameter to be information density, or the amount of information on the display screen. Tullis (1990) outlines and defines four characteristics of display density that affect alphanumeric display format: (1) overall density, (2) local density, (3) grouping, and (4) layout complexity. Overall density is the number of characters displayed or the percentage of total character spaces available. A general rule for overall density is to minimize the total amount of information on a single frame. Local density refers to the number of filled character spaces near each character. Jones (1978) and Stewart (1976) noted that spacing breaks up information into logical segments and provides structure. Grouping is the extent to which items form well-defined groups. Guidelines pertaining to grouping recommend that similar items be distinctly grouped. Finally, layout complexity is the extent to which items follow a predictable visual arrangement. Based on the location of some items on the screen, users should be able to predict the location of other items. Although developed for alphanumeric displays, these concepts seem applicable to the layout of an IVIS display. Consider an IVIS that incorporates multiple subsystems, such as TravTek. Depending on the driver's task, it may be difficult to locate pieces of information if issues related to the four outlined characteristics of display density are not addressed in the design. For example, a system that displays multiple subsystems on the same screen may violate guidelines related to grouping and layout complexity.

OLDER DRIVERS

As outlined by IVHS America (1992), "the objectives of intelligent vehicle highway systems (IVHS) technology include: improving safety, energy efficiency, and economic productivity, as well as reducing congestion and environmental impact." To meet these objectives, a thorough understanding of the user (driving) population is required. Statistics indicate that the demographics of the U.S. driving population are changing such that the number of older drivers is markedly increasing (National Safety Council, 1994; Stamatiadis, Taylor, and McKelvey, 1990). As such, a large percentage of the ITS user population is apt to be older drivers. Given this reality, the design of ITS must consider the needs, capabilities, and limitations of the older driver.

Hanowski, Bittner, Knipling, Byrne, and Parasuraman (1995) outlined a taxonomy for organizing research related to older driver crash involvement and safety interventions. Two issues were of importance to the development of ITS: (1) older drivers are at particular crash risk when their attentional and other dynamic information-processing capabilities are most challenged (e.g., during left turn maneuvers), and (2) in-vehicle crash avoidance and other systems have the potential of being "double-edged swords" that increase the demand on limited resources that the system was originally designed to augment. The inclusion of older drivers into research sample groups is imperative for a thorough understanding of driver behavior so that guidelines represent all segments of the driving population. For this reason, older drivers were included in the present research.

RESEARCH QUESTIONS

Three primary questions were posed in this research. First, do drivers derive a benefit from using an IVIS, which has multiple subsystems, when confronted with an unexpected situation? It is conceivable that event detection could be improved due to the increase in availability and timeliness of IVSAWS information, or that event detection could be reduced due to the shifting of attention from outside to inside the vehicle to gain information. However, interference with other IVIS subsystems (ISIS and IRANS) may impact the driver's ability to locate visual IVSAWS messages, thus slowing event response. This research question addresses the driver's situation awareness and his/her ability to respond to complex and dynamic events with and without the use of an IVIS. Second, what impact does IVIS information density have on driver behavior and performance? In a situation that requires an IVSAWS warning, having other information on the display, (i.e., IRANS) may interfere with a driver's ability to extract warning information and increase a driver's response time. The third research question examines system use by older drivers: What impact does driver age have on system use and driver behavior and performance?

CHAPTER 2: METHOD

PARTICIPANTS

Twenty drivers participated in the experiment and were divided into groups based on age. Ten subjects were between the ages of 18 and 25 (younger drivers), and 10 subjects were between the ages of 65 and 75 (older drivers). Within each age group, five subjects were male and five were female. Younger drivers were recruited through flyers posted on the Virginia Polytechnic Institute and State University campus. Older drivers were recruited through retirement communities, advertisements in local newspapers, and flyers posted at local merchants. Younger subjects were paid $10.00 per hour and older subjects were paid $15.00 per hour for approximately 3 hours of research time.

To determine participants' driving experience, data were collected on age and estimated total miles driven annually (table 1). Participants were also required to: (1) be a licensed driver, (2) drive a minimum of twice a week in Blacksburg, Virginia, or surrounding area, (3) pass a health questionnaire, (4) have a minimum 20/40 visual acuity, wearing corrective lenses if necessary, and (5) pass a hearing test.

Table 1. Participant grouping.

Age	Number	Estimate of Mean Miles Driven Annually
18-25	10	9,555
65-75	10	11,049

APPARATUS

Driver behavior was investigated on-road using an instrumented 1995 Oldsmobile Aurora four-door sedan (figure 1). The primary apparatuses used in the study were: (1) the automobile, (2) cameras and sensors, (3) an IVIS display, (4) software and hardware interfaces for information portrayal and data collection, and (5) the information portrayed and the portrayal format.

Automobile

The instrumentation in the vehicle provided the means to collect, record, and reduce a number of data items, including measures of attention demand, measures of navigation performance, safety-related incidents, and subjective opinions of the participants. The system consisted of video cameras to record pertinent events and eye movement data, an experimenter control panel to record time and duration of events and information on an IVIS display, sensors for the detection of variations in driving performance and behavior, and a custom analog-to-digital interface and computer to log the data in the required form for analysis.

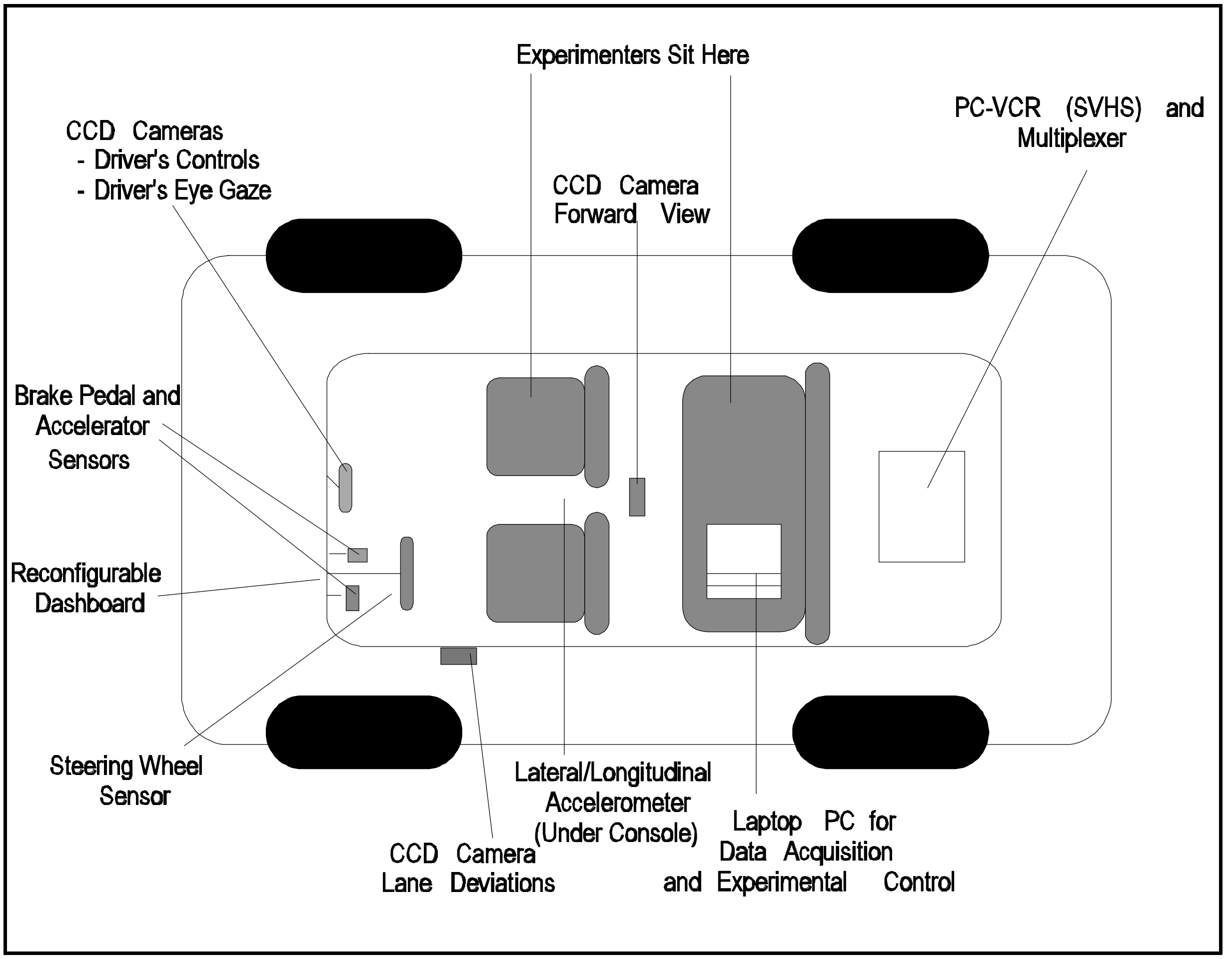


Figure 1. Diagram of the instrumented vehicle.

The vehicle's data collection system allowed for the collection and storage of several forms of data. The system provided the capability to store data on a computer in the form of one line of numerical data every 0.1 seconds during a data run. The videotape record provided by the cameras' view was time-stamped and synchronized with the computer data stream so that post-test data reduction and data set merging could occur in the laboratory. All data collection records were time-stamped to an accuracy of +/- 0.1 seconds.

Safety Requirements

The following safety measures were provided as part of the instrumented vehicle system. Such measures helped minimize risks to participants during the experiment:

- All data collection equipment was mounted such that, to the greatest extent possible, it did not pose a hazard to the driver in any foreseeable instance.
- Driver-side and passenger-side air bags were provided.
- Two trained in-vehicle experimenters were in the vehicle at all times. Emergency protocol was established prior to testing.

- A fire extinguisher, first aid kit, and cellular phone were located in the experimental vehicle.
- An experimenter's brake pedal was mounted in the front passenger-side.
- None of the data collection equipment interfered with any part of the driver's normal field of view (FOV).

Eye Glance Camera

The eye glance camera allowed monitoring of eye movements. Its FOV accommodated drivers of varying heights and seating positions. The view of the subject's eyes was clear and in focus, allowing eye movement classification in the laboratory. The eye glance camera was located in the center rear-view mirror and did not obscure the driver's view or impair his/her use of the mirror.

Forward-View Camera

The forward-view camera provided a wide view of the forward roadway without substantial distortion. The camera had an auto-iris and provided a high quality picture in all but the most severe daylight glare conditions. The forward-view camera was located in the center rear-view mirror and did not obscure any part of the driver's view of the roadway or impair his/her use of the mirror. The forward-view camera served to collect relevant data from the forward scene (e.g., traffic density, signs and markers, and headway).

Multiplexer and PC-VCR

A quad-multiplexer integrated up to four camera views and included a time stamp onto a single videotape record. A PC-VCR received a time stamp from the data collection computer and displayed the time stamp continuously on the multiplexed view of the videotaped record. In addition, the PC-VCR had the capability to read and mark event data provided by the data collection computer and perform high-speed searches for event marks. The PC-VCR operated in an S–VHS format so that each multiplexed camera view had 200 horizontal lines of resolution.

Data Collection Computer

The data collection computer provided reliable data collection, manipulation, and hard drive storage under conditions present in a vehicle environment. The computer had a 16-channel analog-to-digital capability, standard QWERTY keyboard, and a 9-inch diagonal color monitor. Computer memory and processing capabilities were: 12 megabytes RAM, 1.2 gigabyte hard drive, and Pentium processor.

Sensors

The steering wheel, speedometer, accelerator, and brake were all instrumented. The steering wheel sensor provided steering position data accurate to within +/- 1 degree. The brake and accelerator sensors provided brake position to within +/- 0.1 inch. An accelerometer provided acceleration readings in the lateral and longitudinal planes of the vehicle. The accelerometers provided values for vehicle acceleration and deceleration up to and including hard braking behavior, as well as intense turning. The sensor provided a signal that was read by the A/D interface at a rate of 10 times per second.

Experimenter Control Panel and Event Flagger

A custom experimenter control panel was located in the vehicle and allowed control of vehicle functions (e.g., releasing trunk latch) without driver notification or interference. A push-button input was used to record the occurrence of events in the data set.

Video/Sensor/Experimenter Control Panel Interface

A custom interface was constructed to integrate the data from the experimenter control panel, driving performance sensors, event flagger, and speedometer with the data collection computer. In addition, the interface provided a means to accurately read and log the time stamp from the PC-VCR to an accuracy of +/- 0.1 second. The time stamp was coded such that a precise location could be synchronized from any of the videotaped records to the computer data record for post-test laboratory reduction and file integration.

Audio Data Collection System

An audio track of the videotape record of the experiment contained the commentary of the experimenter, driver communication, and any system-generated audio.

Display

A display mounted in the dash provided information to the driver. The display was a Sharp TFT-LCD Module, Model No. LQ64D142. It was located 1.2 cm from the center of the dash, adjacent and to the right of the speedometer (figure 2). The dash configuration included an overhang, protruding 15.6 cm from a display cover, to help mitigate the effects of glare (figure 3).

Figure 2. IVIS display located in the dashboard area.

Figure 3. Driver view of IVIS through steering wheel.

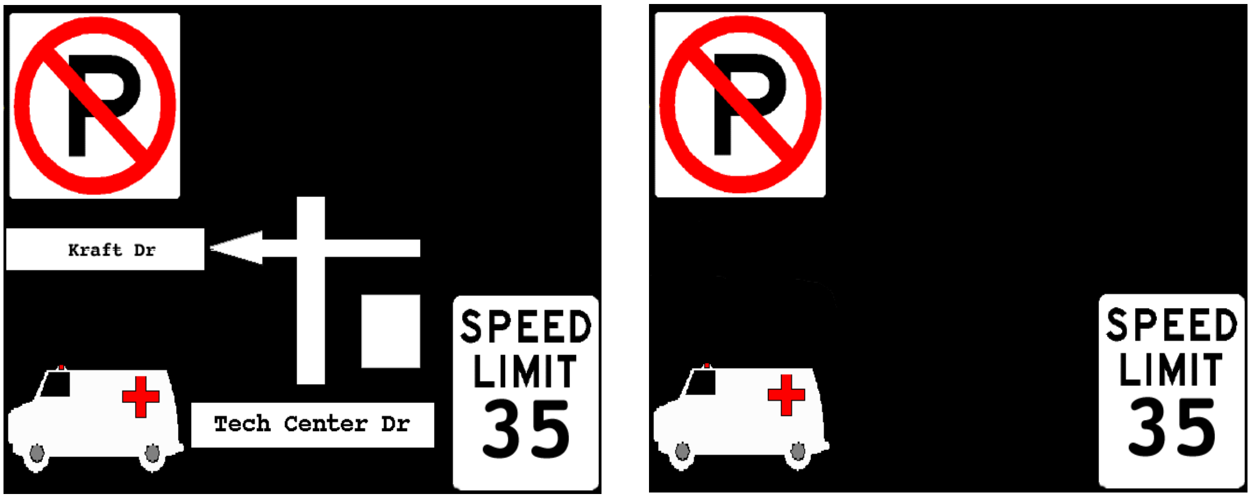
The Sharp TFT-LCD Module, Model No. LQ64D142 display is a color active matrix liquid crystal display incorporating an amorphous silicon thin film transistor (TFT). The back light system is an edge-lighting configuration with two cold cathode fluorescent tubes (CCFT). Lamp frequency of the CCFT is typically 35 KHz, with a range of 20 KHz to 60 KHz. Graphics and text can be displayed on a 640 x 480 pixel panel with up to 4,096 colors. Basic colors that can be displayed by module are black, blue, green, light blue, red, purple, yellow, and white. These basic colors can be displayed in 16 gray scales (from 4-bit data signals), therefore rendering a total of 4,096 possible colors because of the display's 12-bit data signals. Optical characteristics include a horizontal viewing angle range of 35° off perpendicular, to the left and right, retaining a contrast ratio of 10:1 or greater. Mechanical specifications for the display are listed in appendix A.

IVIS

The IVIS used in this study consisted of three subsystems: (1) ISIS, (2) IRANS, and (3) IVSAWS. ISIS provided supplementary notification and regulatory information that is currently depicted on external roadway signs. Notification information informed drivers of changes in the roadway, such as merge signs, advisory speed limits, chevrons, and curve arrows. Regulatory information included signs such as speed limits, stop signs, yield signs, and turn prohibitions. IRANS provided drivers with path information in order to get from one location to another. The route guidance system used in this study used turn-by-turn directional information that included the current street, upcoming turn street, directional change (right or left turn), and number of miles to next turn. IVSAWS provided warnings for external events and vehicle status warnings. Drivers were presented with an IVSAWS message for the following external events: car approaching from hidden entrance, one-lane tunnel, disabled vehicle, ambulance approaching, and crash ahead. The vehicle status warning used in this experiment was "trunk open."

The layout of the IVIS for the present study was modeled using the same "zone-format" that was used in a previous study (Lee, Dingus, Mollenhauer, and Brown, in press). Many of the ISIS and IVSAWS symbols were first used in a study that examined information organization and display (Hanowski and Kantowitz, in press). Refer to appendix B-1 for an actual size example of the IVIS display. Figure 4 shows examples of the high and low density displays. When new information was presented on the display for any of the subsystems, an alerting tone lasting 0.45 seconds was given. The location of the subsystems incorporated into the IVIS, and the density condition(s) that the subsystem was in, were as follows:

- IVSAWS messages, when appropriate, were located in the lower left-hand corner of the display (low and high density conditions).
- ISIS speed limits were always located in the lower right-hand corner, and symbols and other road notification information were located in the upper left-hand corner of the display (low and high density conditions).
- IRANS information was located in the center of the display (high density condition only).



High Density Display **Low Density Display**

Figure 4. IVIS display for the high and low density conditions.

The displays were created using Adobe Photoshop version 3.0. The image resolution was 768 pixels per inch, and the indexed color mode was used. Font styles and sizes used in creating information slides for IVIS were: speed limit — Courier, 90 pixels; current road — Courier, 20 pixels**;** next street to turn onto — Courier, 18 pixels.

EXPERIMENTAL DESIGN

A 2 x 6 x 3 x 2 mixed factor design was utilized for this study, consisting of two within-subjects variables (information density and event), and two between-subjects variables (age and gender). Three routes were chosen within the boundaries of Montgomery County, Virginia, and included the urban areas of Blacksburg and Christiansburg.

INDEPENDENT AND DEPENDENT VARIABLES

Independent Variables

- *Information Density*. Three levels of information density were included: (1) no density, (2) low density, and (3) high density. The no information density condition served as a baseline. The low density condition included ISIS and IVSAWS subsystems and displayed two to three information items. The high density condition included ISIS, IVSAWS, and IRANS subsystems and displayed six to seven information items. A Latin square design was used to balance the order in which the densities were presented to each driver (table 2). Due to inclement weather conditions, the last cell of each age/gender participant combination was not tested.
- *Event*. Six planned events were administered over the course of the test run. For safety, each planned event occurred in a rural area. Five were external events and one was a vehicle status warning. As noted previously, the five external events were: car

approaching from hidden entrance, one-lane tunnel, disabled vehicle, ambulance approaching, and crash ahead. The vehicle status warning was "trunk open."

! *Age*. Two age groups of drivers were used: younger drivers (18-25 years) and older drivers (65-75 years).

! *Gender*. An equal number of male and female drivers were assigned and tested with different display density patterns.

! *Route*. As shown in table 2, the entire drive was divided into three routes (1, 2, and 3). Two unexpected events were introduced in each route, such that a total of six unexpected events were introduced over the course of the entire drive. For each route, drivers used a different IVIS (i.e., either no display, low density, or high density). The Treatment Combination refers to the IVIS used for a particular route.

Table 2. Design matrix.

Gender	Younger				Older			
	Participant Number	Treatment Combination			Participant Number	Treatment Combination		
		Route 1	Route 2	Route 3		Route 1	Route 2	Route 3
Male	01	A	C	B	03	C	B	A
	05	B	A	C	07	A	C	B
	09	A	B	C	11	B	C	A
	13	C	B	A	15	B	A	C
	17	C	A	B	19	C	A	B
	none*	B	C	A	none*	A	B	C
Female	02	B	C	A	04	A	B	C
	06	C	A	B	08	B	C	A
	10	C	B	A	12	A	C	B
	14	A	B	C	16	C	A	B
	18	A	C	B	20	B	A	C
	none*	B	A	C	none*	C	B	A

A = no display condition; B = low density display condition; C = high density display condition
*none refers to no driver being tested for this Treatment Combination, due to inclement weather.

Dependent Variables

The dependent variables measured the impact of IVIS use and the potential system benefits. The specific measures collected were as follows:

- *Steering wheel position variance*. Research has shown that changes in driver steering behavior occur when driver attention changes (Wierwille and Gutman, 1978). In normal, low attention circumstances, drivers make continuous, small steering corrections to correct for roadway variance and driving conditions. These corrections typically range from 2 to 6 degrees. As attention or workload demands increase, the number of these corrections decreases, requiring a larger input to correct the vehicle's position. Therefore, an increase in the variance of steering wheel position indicates high attention or workload requirements.
- *Average vehicle velocity and velocity variance*. Vehicle speed can be considered a vehicle state that has to be held constant in most circumstances. Therefore, for the same reasons described for evaluating steering wheel position variance, variations in velocity were used to evaluate performance. Research has found velocity maintenance to be a sensitive measure to changes in the amount of attention demanded by secondary driving tasks (Monty, 1984).
- *Lateral acceleration measures*. Abrupt lateral maneuvers, such as large steering reversals, are indicative of a vehicle that is off the center lane track. Lateral acceleration measures are highly correlated to driver steering input and are therefore used to highlight large magnitude corrections.
- *Longitudinal acceleration/deceleration measures and braking data*. Braking behavior can also provide a sensitive measure of performance (Monty, 1984). If drivers are inattentive, the brake must be depressed harder and the resulting deceleration is greater.
- *Subjective acceptance and preference data*. A post-test questionnaire was utilized to assess participant acceptance and preference issues associated with the use of the display and display conditions.
- *Situation awareness and response appropriateness for external events and vehicle status emergencies*. External events and vehicle status emergencies were planned events requiring drivers to take remedial action. Criteria were developed for each type of external event that occurred. Participant reaction to these events was classified as appropriate or inappropriate.

PROCEDURES

Participant Screening and Training

Participants were initially screened over the telephone regarding age, gender, and driving experience (appendix B-2). If participants qualified, a time was scheduled for testing. Participants were instructed to meet experimenters at the Center for Transportation Research (CTR), Blacksburg, Virginia. After arriving at the CTR, the participant was given an overview of the study and was asked to complete the informed consent form (appendix B-3). Next, the participant was asked to answer a health screening questionnaire and was given a simple vision test (appendices B-4 and B-5, respectively). After these were completed, the participant was escorted to the test vehicle.

While the car was in park, the experimenter reviewed general information concerning the operation of the test vehicle (e.g., lights, seat adjustment, mirrors, windshield wipers; appendix B-

6). The participant was then asked to operate each control and set it for his/her own driving comfort. When the participant felt comfortable with the controls, the experimenter explained the IVIS displays. As a pre-test to familiarize drivers with the IVIS, 20 symbols were randomly presented on the IVIS display along with a text explanation (appendix B-7). This presentation included seven symbols that would appear en route, six of which corresponded to the IVSAWS messages that the driver would later encounter during the planned events. Additional symbols were included to help give the illusion that the system was actually sensing elements in the environment. The symbols were programmed to be consecutively displayed for 8 seconds each. After all 20 symbols were displayed, a recall test was administered. The symbols were re-presented on the display in random order, without the text explanation. The driver's task was to identify the meaning of each symbol. If the driver did not correctly identify the six symbols that were to serve as IVSAWS messages, the recall test was re-administered until all IVSAWS symbols could be identified.

Once the subject was comfortable with the vehicle controls and familiar with the IVIS display, a hearing test was administered to determine the participant's ability to understand verbal navigational commands and hear the auditory alert cues (appendix B-5).

Practice Route

For the next segment, part-task training was utilized. The drivers drove a practice route twice. The first time was designed to allow the participant to become familiar with the handling of the vehicle and no IVIS was used. During the second run, the IVIS was turned on and information was displayed in the high density format. An experimenter seated in the front passenger seat served as navigator and told the driver the names of streets on which to turn. For example, the experimenter would say "turn left on Cavers Street." The driver was required to locate and turn onto the appropriate street. Drivers were also asked to follow advisory signs displayed on the IVIS, such as 35 mi/h around a curve. Once the driver completed the practice sessions, he/she was asked to report whether he/she felt comfortable with the car and using the IVIS. If the answer was "no," then a third training run was given that was a repeat of the second run. Drivers were allowed as many training runs as desired in order to feel comfortable with the vehicle and the IVIS. Most of the drivers, both younger and older, required only two training runs. When drivers indicated that they felt comfortable with the car and the IVIS, the first test run began.

On-Road Data Collection

Two experimenters were in the vehicle with the driver. An experimenter in the front seat gave verbal navigational instructions, served as the safety officer using the emergency brake as needed, flagged events in the data set using the event flagger, and recorded the event corresponding to the flag on a data sheet. Both planned and unplanned external events were flagged. (Refer to appendix B-8 for front seat experimenter protocol.)

An experimenter in the rear seat controlled the presentation of information. The data set was flagged automatically when new information was presented on the IVIS display. IVIS information was stored in a "slide" format in a computer located in the trunk of the vehicle. The experimenter triggered the presentation of information for the IVIS when previously determined landmarks in the route were reached. The participants were not informed of this until after the study was completed.

There were three data collection routes that lasted approximately 40 minutes each, 20 minutes for the urban section and 20 minutes for the rural section (appendix B-9). Route 1 began at the CTR and ended at a gas station/convenience store. Route 2 began and ended at different gas station/ convenience stores. Route 3 began at a gas station/convenience store and ended at the CTR. Each route began where the other left off, and a 5-10 minute break was allowed between each route. If a wrong turn was made, the experimenter in the front seat would let the driver complete the turn and then direct him/her back to the prescribed route. Upon returning to the CTR, a preference questionnaire was administered (appendix B-10). After answering the questionnaire, drivers were debriefed and paid for their time.

External Events

External events were divided into two categories: planned events and unplanned events. Planned events were carried out using confederate drivers at the same point in the route for every participant. Unplanned events were naturally occurring events (e.g., car braking quickly in front of the participant, deer crossing road).

Planned Events

There were two planned events in the rural section of each route that utilized confederate drivers. The drivers communicated with the experimenter in the rear seat of the test vehicle via cellular phone. The cellular phone in the test vehicle did not use an audible ring; instead, the display and push buttons illuminated, indicating an incoming call. Communication between vehicles was done through a predetermined series of tones. The indicator light and tones were used to avoid the need for the experimenter to have to speak in the test vehicle. Hence, the subject was unaware of the communication taking place. For all planned events, the experimenter in the rear seat displayed the IVIS information approximately 5 seconds before the driver could see the event occurring on the roadway.

<u>Planned Event #1: Vehicle Approaching From Hidden Entrance</u>

When the test vehicle reached a specified location on Route 1, a confederate driver began approaching the road from a hidden entrance (driveway). In doing so, the confederate driver created the illusion of blindly moving into the roadway. However, for safety reasons, the confederate vehicle never entered the road. Refer to figure 5 for the IVSAWS symbol used for event #1.

Figure 5. IVSAWS message for the first planned event (first external event). Note that the text description at the bottom of the symbol was not provided during the test.

Planned Event #2: Vehicle in One-Lane Tunnel

When the test vehicle reached a specified location on Route 1, approximately 5 seconds prior to a one-lane tunnel, a confederate driver entered the tunnel from the opposite direction forcing the driver to stop and wait until the tunnel cleared. Refer to figure 6 for the IVSAWS symbol.

Figure 6. IVSAWS message for the second planned event (second external event). Note that the text description at the bottom of the symbol was not provided during the test.

Planned Event #3: Disabled Vehicle

A confederate driver situated his vehicle on the side of a two-lane road on Route 2. The car was parked partially in the roadway and partially on the shoulder, with its hazard lights on and the hood propped open to imitate a disabled vehicle. The confederate driver remained outside of the vehicle, appearing to work under the hood of the car. Refer to figure 7 for the IVSAWS symbol.

Figure 7. IVSAWS message for the third planned event (third external event). Note that the text description at the bottom of the symbol was not provided during the test.

Planned Event #4: Trunk Opening

When the test vehicle reached a specified location on Route 2, the experimenter in the rear seat unlatched the trunk using the experimenter's control panel. The driver was required to pull over and close the trunk. Refer to figure 8 for the IVSAWS symbol.

Figure 8. IVSAWS message for the fourth planned event (only vehicle status emergency). Note that the text description at the bottom of the symbol was not provided during the test.

Planned Event #5: Ambulance Approaching

When the test vehicle reached a specified location on Route 3, an ambulance approached from the rear with its emergency lights and siren on. A 1987 Ford Type II ambulance was used. The siren remained in the wail mode during the duration of this event.   During this section of the route, the road was a two-lane double line road; therefore, the subject had to decide if and when to pull over onto the shoulder, allowing the ambulance to pass. Refer to figure 9 for the IVSAWS symbol.

Figure 9. IVSAWS message for the fifth planned event (fourth external event). Note that the text description at the bottom of the symbol was not provided during the test.

Planned Event #6: Crash Ahead

At a specified location on Route 3, there was a one-car crash scene and an ambulance with all its emergency lights on. The confederate car (crash vehicle) was angled such that it appeared to have slid off the road. The confederate driver was hunched over the steering wheel appearing to be unconscious. The driver-side door was open and a medical attendant, situated outside the confederate car next to the driver, appeared to be administering first-aid treatment. Both the confederate vehicle and the ambulance were located on the shoulder of the road. Refer to figure 10 for the IVSAWS symbol.

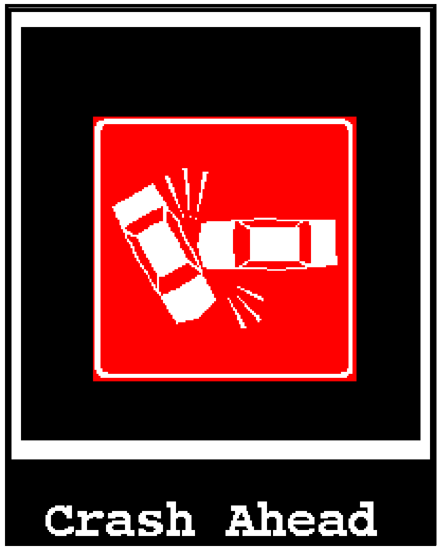


Figure 10. IVSAWS message for the sixth planned event (fifth external event). Note that the text description at the bottom of the symbol was not provided during the test.

Unplanned Events

In addition to the planned events, data were collected for unplanned events that occurred during the drive. Examples of external unplanned events caused by interaction with normal traffic include:

- Cross traffic approaching an intersection as the experimental vehicle approaches.
- Opposing traffic slowing and indicating a turn across the subject's lane.
- A preceding car slowing suddenly.
- A car pulling out in front of the experimental vehicle, requiring a rapid deceleration.
- Traffic in an adjacent lane, traveling in the same direction, moving into the lane of the experimental vehicle.

POST-TEST DATA COLLECTION (QUESTIONNAIRE)

At the conclusion of the third test run, drivers returned to the research building at the CTR and completed a preference questionnaire (appendix B-10). After completing the questionnaire, subjects were debriefed, thanked, and paid.

CHAPTER 3: RESULTS AND DISCUSSION

To investigate the benefits and costs associated with using an IVIS when confronted with an unexpected situation, three data sets were created: (1) situation awareness data, (2) driving performance data, and (3) driver preference data. The results of the analyses for each data set are outlined below, based on the three primary research questions. For details of analyses conducted, refer to appendix C, which includes the Analysis of Variance (ANOVA) tables. Due to missing data (typical of field experiments), analyses were conducted using the GLM model (Littell, Freund, and Spector, 1991).

IVIS BENEFIT ASSESSMENT

The primary question in this research was, “Do drivers derive a benefit from using an IVIS, which has multiple subsystems, when confronted with an unexpected situation?” Several of the results contained in the situation awareness data suggest that drivers responding to unexpected situations did benefit when their vehicle had an IVIS. Before outlining these results, it is worthwhile to review the dependent measures associated with the situation awareness data.

As outlined previously, Endsley (1995) points out that: (1) situation awareness is critical for decision-making and performance, and (2) events that require a warning typically warrant a rapid analysis of complex, dynamic scenarios. In the present study, all planned events required the driver to quickly assess the situation and initiate remedial action. For the low and high density display conditions, an IVSAWS message informed the driver of the event. In the no display condition, no warning was provided. To assess the driver’s situation awareness for these events, five dependent measures were collected: (1) event length, or time to complete an event, (2) time to notice the IVSAWS, or the time it took to glance down at the display after the message was presented, (3) time to notice the event, or the time it took to spot the event through the windshield or in a rear-view mirror, (4) time to respond to the event, or the response latency associated with a remedial action, and (5) response appropriateness, or the appropriateness of the remedial action.

Figure 11 provides an overview of the timing sequence of events for the three density conditions. For the high and low density conditions, drivers were presented with IVSAWS messages prior to the event occurring (approximately 5 seconds). In calculating the situation awareness dependent measures, the onset of the IVSAWS message initiated the event sequence. After the IVSAWS was on, the time to notice the IVSAWS was measured. As the driver drove down the road, he/she became aware of the event. For the display conditions, the time that the driver perceived the event was measured against the time the IVSAWS message was presented ($t = 0$). For the no display condition, the point in time where the driver perceived the event was marked as $t = 0$. For both the display and no display conditions, the event response dependent variable was measured against the time the event was perceived.

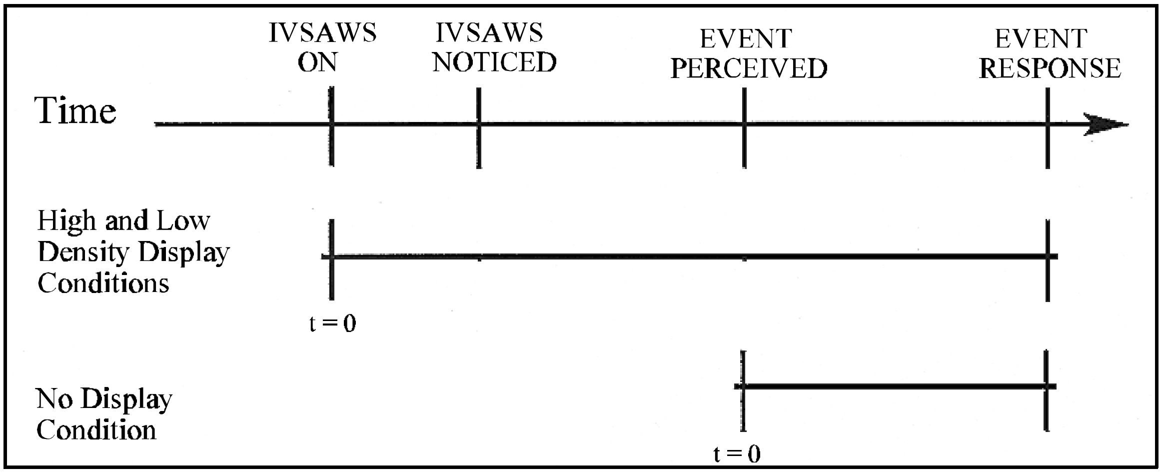


Figure 11. Timing sequence of IVSAWS messages for the three density conditions.

The analysis using the time to respond to event dependent measure, or event response latency, indicated a clear benefit for drivers using an IVIS. Figure 12 shows that drivers' mean time to respond to unexpected events when drivers did not have IVSAWS information was 2.98 seconds, compared with 1.05 seconds when IVSAWS information was presented. This result proved to be significant, $F(1, 17) = 5.25$, $p < .05$, and shows a dramatic advantage for drivers using an IVSAWS when responding to events.

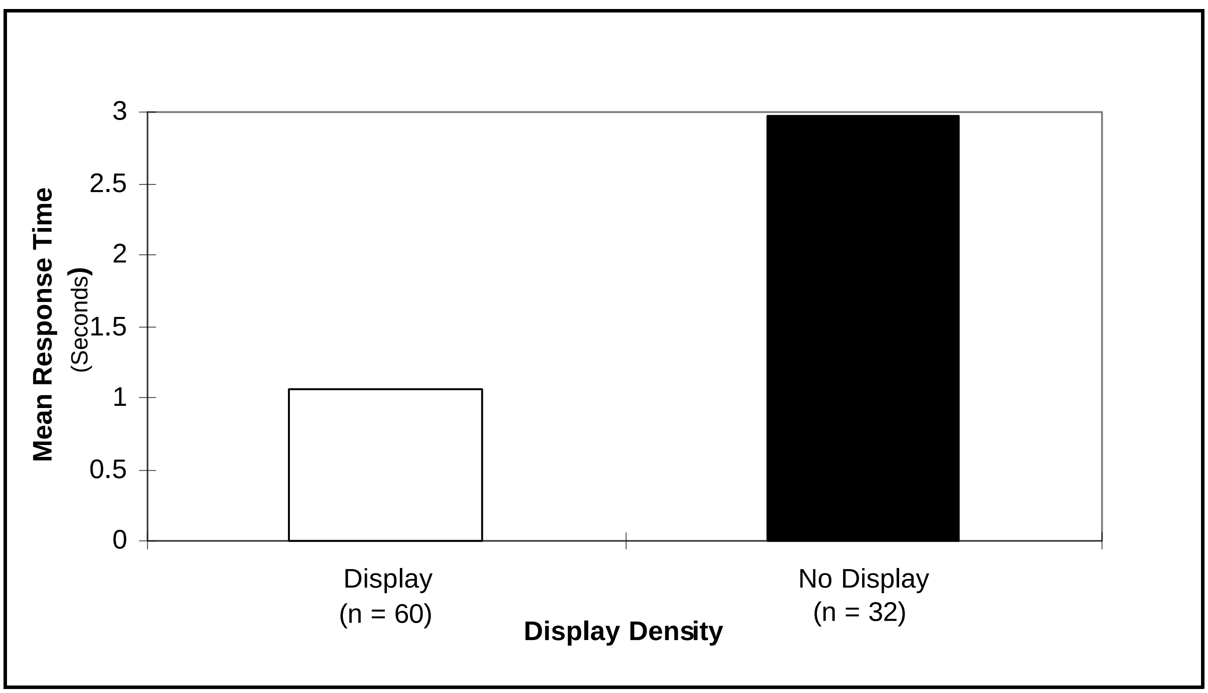


Figure 12. Event response latency as a function of display density.

Review of the raw data for event response latency uncovered a particularly interesting finding– there were instances of *negative* response latencies. That is, the driver responded to an event before seeing the event, but after seeing the IVSAWS message. Each of these instances occurred when the driver was using an IVIS. This result proved significant in a Chi-Square test on the frequency of negative response latencies (p = 0.005). Further examination of the data found that all of the negative response latencies occurred in the last two events ("ambulance approaching" or "crash ahead"). For the ambulance approaching event, 18.2 percent of the responses in the IVIS conditions were negative. For the crash ahead event, 27.3 percent of the responses were negative. No negative response latencies were found in the first four unexpected events. A Chi-Square confirmed this difference across events (p = 0.005). Two possible explanations for this result, explained in more detail in the Summary section, are that: (1) a learning effect was present such that driver trust in the system increased with prolonged exposure to the IVIS, and (2) the effect was event-specific and may be attributed to either the presence of emergency vehicles or the effectiveness of the IVSAWS symbols used in the last two events.

The negative response latency data are shown in table 3, which summarizes: (1) response percentages for viewing the IVIS, (2) responding to the event before seeing the event, (3) responding to the event after seeing the event, and (4) not responding to the event. Categories in the table are based on whether the driver was using an IVIS, and by the identification number of each unexpected event. Note that the number of observations in the display condition is approximately twice that of the no display condition because it includes both low density and high density displays.

Table 3. Response percentages, by event number, for display and no display conditions.

	Event Number	Number of Observations	Viewed IVIS (%)	Responded Prior to Event (%)	Responded After Event (%)	No Response (%)
IVIS Display	1	13	100	0	92	8
	2	13	100	0	92	8
	3	13	85	0	85	15
	4	12	100	N/A	42	58
	5	11	100	18	82	0
	6	11	100	27	73	0
	Mean		98	9	78	15
No IVIS Display	1	6	N/A	0	100	0
	2	7	N/A	0	100	0
	3	7	N/A	0	100	0
	4	8	N/A	0	12	88
	5	7	N/A	0	100	0
	6	7	N/A	0	100	0
	Mean		N/A	0	85	15

It is important to note that one older participant failed to see events #1 and #2. In both cases, the participant noticed the information displayed on the IVIS system but failed to see the events when they occurred. It might appear at first that there is some disadvantage of using an IVIS display because the data show that 8 percent of the participants failed to respond to an event during an IVIS condition versus 0 percent in the no IVIS display condition. However, there were approximately twice as many observations for the IVIS condition as compared with the no IVIS condition, and the "8 percent" referred to one driver. Therefore, it is probably more appropriate to treat this driver as an outlier rather than attribute the data to a dis-benefit of the IVIS.

Analyses conducted on the response appropriateness dependent variable also indicated a benefit to those drivers who used an IVIS. For many of the analyses, the "trunk open" event was not included because it was successfully completed by only eight of the 20 drivers. The appropriate response for this event was pulling off to the side of the road, stopping the car, and closing the trunk. In all density conditions, drivers received auditory feedback from activation of the trunk's solenoid (a faint "clunk"). In the low density and high density conditions, a symbol indicating that the trunk was ajar was presented as the trunk was opened. To investigate the benefit, if any, of the display to drivers' responses, a Fisher Exact Probability test was used that compared the frequency of appropriate vs. inappropriate responses. Of the eight subjects who responded appropriately to the trunk event, seven received information from the IVSAWS. This result proved to be significant, $p = .10$, and indicates the benefit of IVSAWS in providing timely vehicle status information to drivers.

IVIS INFORMATION DENSITY ASSESSMENT

Both the low density and high density display conditions incorporated an IVSAWS that alerted the driver to the planned events. The low density condition included an ISIS and an IVSAWS, while the high density display included an ISIS, IVSAWS, and IRANS. The previous section outlined the benefits associated with display versus no display; the analyses in this section assess the costs associated with the two display density conditions.

As outlined previously, one of the dependent measures included in the situation awareness data set was "time to complete the event." For the display conditions, this time was measured from IVSAWS onset until the driver had passed the event. For the no display condition, it was measured from the time the driver noticed the event until the driver passed the event. Given the way event length was measured, the durations of events in the no display condition were significantly less than those in either IVIS condition, $F(2, 30) = 5.86$, $p < 0.01$. As shown in figure 13, mean event lengths for the no IVIS condition, low density condition, and high density condition were 10.1, 15.2, and 15.2 seconds, respectively. The extra 5 seconds realized in the IVIS conditions were due to the advanced presentation of advisory/warning messages, which occurred approximately 5 seconds before the event came into view. Not surprisingly, no differences were found between the low and high density displays, suggesting that time to complete an event was not affected by display density.

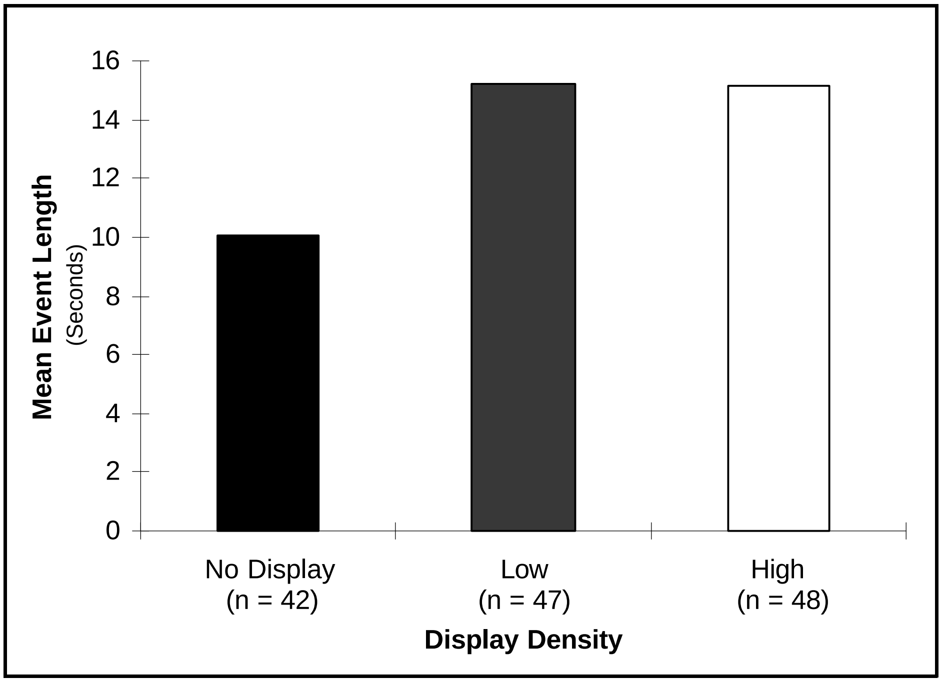


Figure 13. Mean event length for IVIS density conditions.

The amount of time it took a driver to glance down at the display after the IVSAWS message was presented was calculated for both low and high density display conditions. The results of an ANOVA indicated that time to notice the IVSAWS message was not affected by information density, $p > 0.05$. Time to notice the IVSAWS message was 0.76 seconds in the low density condition, and 0.64 seconds in the high density condition. This finding indicates that use of the IVIS for receiving IVSAWS messages was not affected by density.

Time to notice the event was determined to be the time it took the driver to spot the event through the windshield or see it in the rear-view mirror. Mean times to notice the event were 6.42 seconds for the low density condition and 7.63 seconds for the high density condition. This difference was not significant, $p > 0.05$, suggesting that noticing external events was not affected by additional information on the display.

Recall that the time to respond to an event, or event response latency, was measured from when the driver noticed an event until a response was initiated. As with the previous measures of situation awareness, no effect of display density was found, $p > 0.05$. Taken together, these results indicate that no observable costs were found to be associated with information density, and that drivers were not distracted by the additional information provided in the high density condition.

DRIVER AGE ASSESSMENT

The primary question posed concerning older drivers was, "What impact does driver age have on system use and driver behavior and performance?" To answer this question, several analyses were conducted using the situation awareness data set and the preference questionnaire data set.

Time to complete an event was one of the measures in the situation awareness data set. An analysis was conducted to determine if older drivers took longer to complete an event than did younger drivers. Not surprisingly, for some of the events, the time to complete events was shorter for younger drivers than for older drivers. As shown in figure 14, for the "one-lane tunnel" event, mean event completion times were 13.5 seconds for younger drivers and 16.7 seconds for older drivers. This difference proved significant, $F(1, 13) = 4.87$, $p < 0.05$. Figure 15 shows a similar result for the "crash ahead" event. Mean time to complete this event was 15.79 seconds for younger drivers and 16.19 seconds for older drivers. Again, this difference proved significant, $F(1, 13) = 8.09$, $p < 0.05$. As noted, the longer event completion times are not surprising and fit with previous research suggesting that older drivers are more cautious and/or have slower processing and reaction times than younger drivers (e.g., Tasca, 1992).

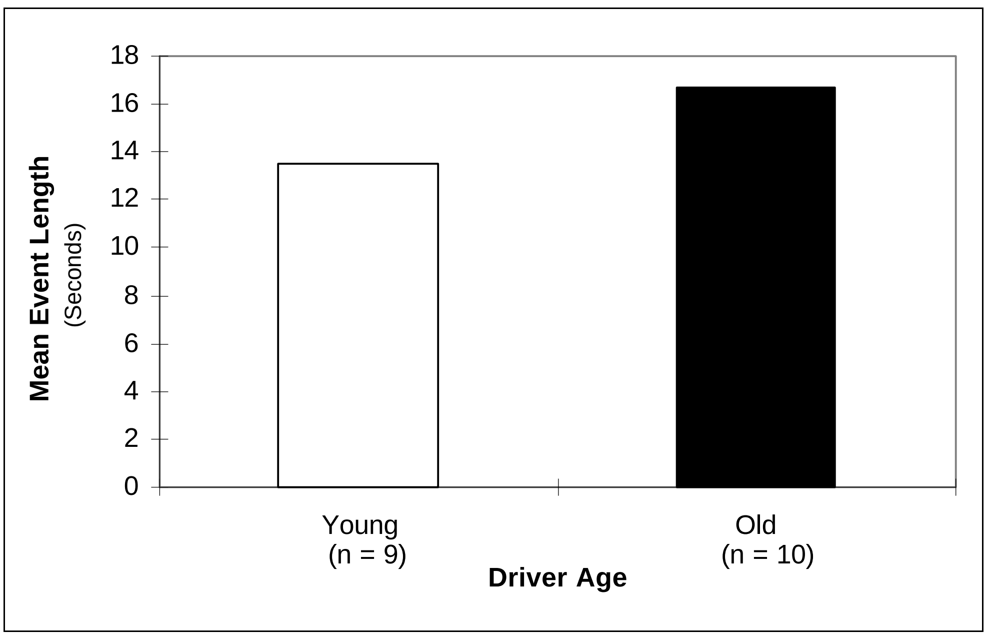


Figure 14. Mean event length for the one-lane tunnel event as a function of driver age.

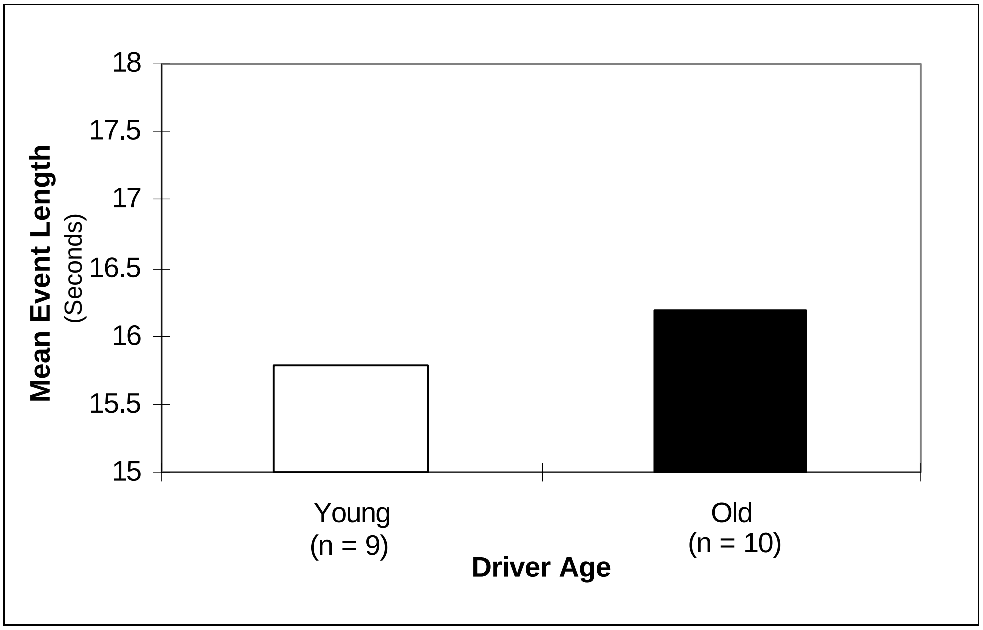


Figure 15. Mean event length for the crash ahead event as a function of driver age.

A second situation awareness measure was time to notice the IVSAWS. This was the time it took the driver to glance down at the IVIS after the IVSAWS message had been presented. One result related to driver age proved significant: for the "ambulance approaching" event, time to notice the IVIS was 0.22 seconds for younger drivers and 0.90 seconds for older drivers, $F(1, 8) = 17.1$, $p < .01$. This result is shown in figure 16. One possible explanation for this age difference is due to the dash-mounted placement of the display, which required drivers to take their eyes off the forward roadway. It must be noted that all of the older drivers were wearing glasses, and many had bi-focals. Therefore, shifting gaze from the forward roadway to the IVIS may have been a more difficult endeavor for older drivers, and one that was performed cautiously and in an unhurried manner. Literature suggests that older drivers know their limitations (e.g., Hanowski et al., 1995) and are typically cautious (e.g., Tasca, 1992), perhaps as a function of slower processing and reaction times. This factor may explain the longer time to shift attention to the dash. Follow-up studies are recommended that examine display placement of the IVIS to include head-up displays (HUDs). HUDs may allow drivers to retain their gaze on the forward road scene while receiving IVSAWS information. Such a placement may be particularly useful for older or other drivers using bi-focal glasses.

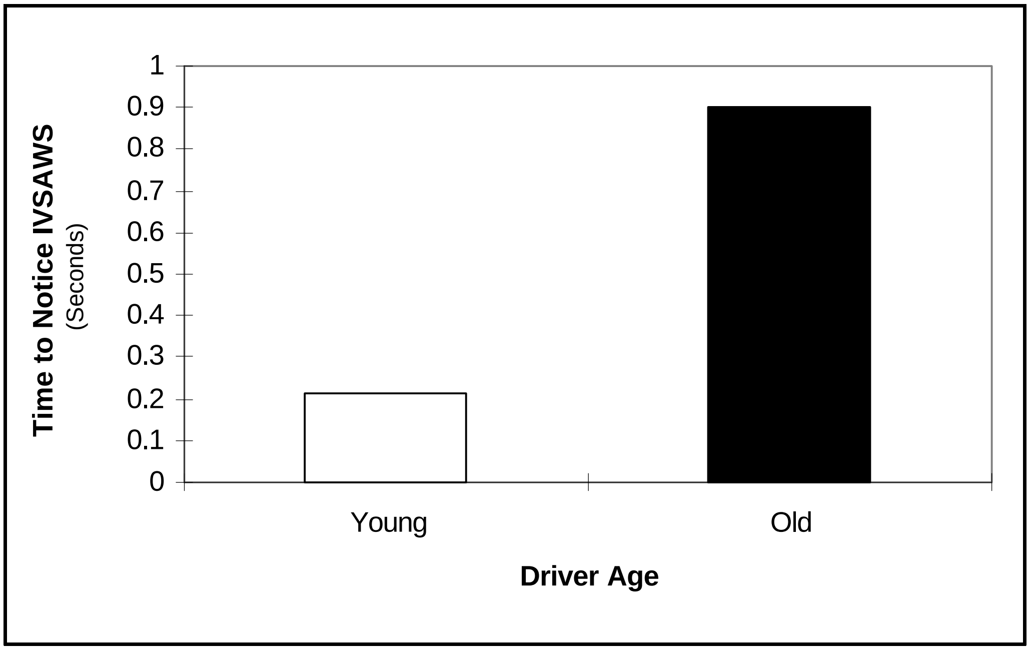


Figure 16. Time to notice the IVSAWS for the ambulance approaching event as a function of driver age.

Time to respond to an event, the primary measure of situation awareness used in this study, was measured from the time a driver noticed an event until a remedial action was initiated. Based on response latency data in the literature (e.g., Tasca, 1992), one would expect younger drivers to have faster response latencies. As shown in figure 17, this finding was supported in the present study, $F(1, 18) = 4.71$, $p < 0.05$. Mean response latencies were 2.57 seconds for older drivers and 1.79 seconds for younger drivers. This result suggests that any potential benefits from an IVIS regarding improved response times may be particularly valuable to older drivers.

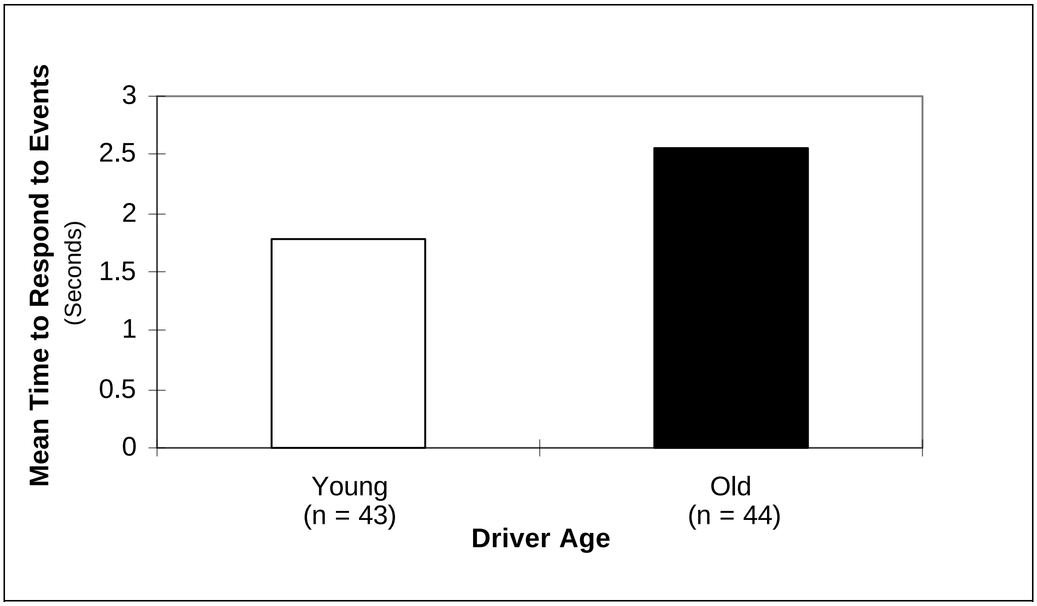


Figure 17. Mean time to respond to events as a function of driver age.

Drivers were required to navigate from one location to another. For all display conditions, the experimenter provided verbal navigational directions to the driver. In the high density display condition, the driver was also provided with turn-by-turn navigation information. A Chi Square analysis on the frequency of off-route deviations was conducted and found that older drivers went off route significantly more than did younger drivers, $p = 0.025$. There were 18 instances of older drivers off route, and six instances of younger drivers off route. This result suggests that, despite having a more difficult time in navigating the route, older drivers may derive relatively more benefit from a navigation system, provided that the system's design is optimized for them.

At the conclusion of the test route, drivers were administered a preference questionnaire to assess their opinions regarding the IVIS (appendix B-6). Eight of the questions were Likert-type and two were open-ended. Mean values for each question, by age, are provided in table 4a. As can be seen, opinions of the systems were favorable. Table 4b shows the frequency of alternative responses to a general system preference question (question #10).

Table 4a. Mean response value to seven-point Likert-type questions. Anchors and values shown in parentheses. Questions #6 and #8 were open-ended. Question #10 had four response choices, as indicated.

Question	Younger	Older
#1. How aware of the in-vehicle road sign and navigation information were you during the drive? (1 = Not Aware, 7 = Extremely Aware)	6.5	6.3
#2. How aware of the in-vehicle safety and warning information were you during the drive? (1 = Not Aware, 7 = Extremely Aware)	6.6	6.6
#3. How timely was the presentation of road sign/navigation/safety and warning information during the drive? (1 = Not Timely, 7 = Extremely Timely)	5.7	6.5
#4. How safe did you feel during the drive? (1 = Extremely Safe, 7 = Extremely Unsafe)	2.1	3.2
#5. How distracting was the road sign/navigation information during the drive? (1 = Not Distracting, 7 = Extremely Distracting)	3.8	2.2
#6. What was distracting? (Open-ended)		
#7. How distracting was the safety and warning information during the drive? (1 = Not Distracting, 7 = Extremely Distracting)	2.5	1.6
#8. What was distracting? (Open-ended)		
#9. Would you find these types of systems useful to you while driving? (1 = Very Useful, 7 = Not At All Useful)	2.7	1.9

Table 4b. Frequency of alternative responses for the general system preference question (Question #10).

Question	Younger	Older
#10. Of the two systems that you tested today, which, if any, did you prefer?		
1 = Did not like either system.	0	0
2 = Preference for systems about the same.	4	1
3 = Preferred system with less information.	1	2
4 = Preferred system with more information.	5	7

Of particular interest was the age difference in response to questions concerning “distraction.” Regarding the presentation of IVSAWS information (question #8), 70 percent of younger drivers indicated that nothing was distracting, compared with 90 percent of older drivers. However, regarding being distracted when road sign/navigation information (ISIS and IRANS) was presented, 100 percent of the younger drivers indicated that some aspect of the ISIS/IRANS was distracting, while 30 percent of older drivers indicated being distracted. Across both age groups, the most common responses were “nothing” and “the beep;” the beep was the auditory alert that accompanied a message when it was first presented on the IVIS. When examining these two responses, “nothing” and “the beep,” 80 percent of the younger drivers and 10 percent of the older drivers indicated that the beep was distracting when it accompanied ISIS/IRANS information.

A Fisher Exact Probability Test was conducted on these data using the 2 x 2 matrix shown in table 5. Regarding the ISIS/IRANS, eight younger drivers and one older driver indicated that they were distracted (by the beep). None of the younger drivers and seven older drivers indicated that they were *not* distracted at all. These differences proved reliable ($p < 0.001$). One possible explanation for this age difference concerns the degradation of hearing in the elderly, such that the volume of the tone was not distracting for older drivers. A second possible explanation is that, given their more cautious approach to driving (e.g., Tasca, 1992), perhaps as a function of slower processing and reaction times, older drivers spent more time focused on the forward road scene and less time scanning the IVIS. Given this scenario, older drivers may have benefitted from the auditory alert, which helped direct their attention to a new ISIS/IRANS message. Future research is recommended to investigate these possibilities.

Table 5. Frequency of responses to preference questionnaire question #6, "What was distracting (about the ISIS/IRANS)?"

	Younger	Older
Was Distracted by the Beep	8	1
Was Not Distracted at All	0	7

A second implication of these results is that both younger and older drivers seemed to appreciate the auditory alert when it accompanied IVSAWS information; recall that 70 percent of younger drivers and 90 percent of older drivers stated that nothing was distracting. Contrast this result with that for ISIS/IRANS information, where 100 percent of younger drivers and 30 percent of older drivers were distracted by some aspect of the ISIS/IRANS. These results seem to indicate that drivers are accepting of auditory alerts when information that requires immediate attention is presented.

DRIVING PERFORMANCE DATA

A number of driving performance measures were collected for this experiment. Dependent measures included velocity, steering, normalized braking, normalized acceleration, lateral acceleration, longitudinal acceleration, and duration of eye glances. Given that this study was "event driven," that the events were highly variable, and that the data of interest occurred in a relatively short time period, no meaningful differences relating to the hypotheses were found. For example, does a significant effect of normalized braking, taken for an event that only lasts 10 seconds, mean that the driver used the brakes because he/she was driving too fast, or a curve was coming up, or the hazard was detected? For confident interpretation, much more data would be required for each event.

CHAPTER 4: SUMMARY

IVIS BENEFITS GIVEN UNEXPECTED SITUATIONS

Hulse (1988) and Dingus et al. (1995) found evidence to suggest that drivers are capable of safely switching attention from an IRANS to the forward roadway. The present research echoed this result. Except for the trunk event, all events passed without incident and all subjects responded appropriately. In the trunk event, only eight appropriate responses were initiated, of which seven occurred when the driver was presented with an IVSAWS message. This result suggests that IVSAWS can provide benefit to drivers in both external events and vehicle status warning situations.

Across both display conditions (low and high information density), the results indicated a clear benefit for the IVIS as compared with the no display condition. Driver response to unexpected events was significantly faster when using an IVIS as compared with not using an IVIS. No observable negative effects were found in the IVIS conditions when responding to these events. However, it must be noted that IVSAWS messages were presented approximately 5 seconds before the planned event came into view. As such, the positive results found for the IVIS conditions should be considered in light of this 5-second advance presentation. Follow-up research questions arise pertaining to the optimal timing of warning information. Hanowski and Kantowitz (in press) found that very long recall intervals (50 seconds) negatively affect message identification, particularly for older drivers. However, no research that we are aware of addresses optimal timing for IVSAWS messages. It appears from these results that 5 seconds was enough time for the driver to look at the display, plan a response, and safely take remedial action. Whether a warning that precedes an event by more or less than 5 seconds would alter the positive results found in this study needs to be addressed.

Further evidence to suggest that the IVIS provided a benefit to drivers, when they were required to respond to an external event, was found in the response latencies. Within the IVIS conditions, 18.2 percent of the responses for the ambulance approaching event (second to last event), and 27.3 percent of the responses for the crash scenario event (last event) occurred *after* seeing the IVSAWS message, but *before* seeing the event. Recall that no instances of negative response latencies were found in any event prior to these two. Three hypotheses are proposed that might explain this result. First, there may have been a learning effect such that driver trust in the system increased as a function of exposure. Research related to trust in ATIS technology (Hanowski, Kantowitz, and Kantowitz, 1994) found that drivers' trust in an ATIS increased with exposure, as long as the presented information was reliable. This result is consistent with that of the present study, where all information presented on the IVIS was reliable. A second possible explanation for this result is related to the characteristics of the ambulance approaching and crash scenario events. That is, both planned events involved emergency vehicles. It is possible that the potential seriousness of these events affected driver response. A third possible explanation is related to the effectiveness of the IVSAWS message symbols; those symbols used in the last two events may have been more effective than those used in the first four events. Future research is required to explore these hypotheses.

It must be noted that the occurrence of responses prior to event stimuli being present, for the display conditions, provides further evidence to support the benefit of the IVSAWS on driver response to external events. Indeed, the IVSAWS warning led to driver awareness and provided ample time to perform an appropriate response. However, could there be events, not included in this study, where an early response might have a negative effect? A possible strategy to answer this question might consist of a taxonomy of events that details event characteristics and appropriate driver responses. In addition, the time required for appropriate driver response, given the parameters of the driving scenario, would be useful to determine the optimal timing of IVSAWS warnings. Future research is recommended to investigate these issues.

In summary, in response to the first research question, "Do drivers derive a benefit from using an IVIS, which has multiple subsystems, when confronted with an unexpected situation?," the following findings are relevant:

- No negative effects were observed for driver behavior when using an IVIS and responding to external events and vehicle status warnings.
- Response latencies for initiating responses to external events were shorter when drivers were driving a vehicle equipped with an IVIS.
- Significantly more appropriate responses occurred during vehicle status warnings for drivers using an IVIS.
- While using an IVIS, 18.2 percent of drivers responded to an ambulance approaching from the rear prior to seeing/hearing it.
- While using an IVIS, 27.3 percent of drivers responded to a crash scene prior to seeing/hearing it.

IMPACT OF INFORMATION DENSITY ON DRIVER RESPONSE

In the present research, display density was manipulated in two ways. First, the low density condition had ISIS and IVSAWS subsystems, while the high density condition had ISIS, IVSAWS, and IRANS subsystems. Second, the amount of information within each subsystem varied such that messages for the ISIS were located in the upper left and lower right corners of the display; the IRANS turn-by-turn guidance was located in the center of the display; and the IVSAWS messages were located in the lower left corner of the display. It is important to note that across density conditions, the ISIS and IVSAWS messages were presented in the same location. Across density conditions, therefore, it can be said that "layout complexity" (Tullis, 1990) was low with the goal of minimizing drivers' search time for information. With this noted, no significant differences were found between the low and high density conditions for time to respond to events. This suggests that the extra information in the high density condition (IRANS) did not hamper search time, or if it did, the effect was negligible for response time.

In response to the second research question, "What impact does IVIS information density have on driver behavior and performance?," the following research finding is noteworthy:

- In the high density condition (with six to seven simple, well-designed symbols or phrases), extra information from the IRANS did not measurably hamper search time.

AGE DIFFERENCES IN USING AN IVIS

There were several interesting results regarding driver age. For example, for three of the six planned events, older drivers took longer to complete the event than did younger drivers. This finding is consistent with data from published research (e.g., Tasca, 1992) that indicates that older drivers are more cautious than younger drivers, perhaps as a function of slower processing and reaction times.

In terms of looking down at the IVIS, for the "ambulance approaching" event, older drivers had longer response latencies than did younger drivers. One potential explanation for this result concerns the dashboard placement of the display. As noted in the results, all of the older participants wore glasses, and many had bi-focals. Shifting gaze from the forward roadway to a dash-mounted IVIS is apt to be a more difficult task for drivers wearing bi-focals. A more cautious approach taken by older drivers may account for the longer response latencies, where they delayed looking at the IVIS until they felt safe to change their gaze from far (roadway) to close (dash). Future research is recommended that will consider display placement as an independent variable. It is possible that a system that minimizes the shift in gaze, such as that in a HUD, may reduce time-to-notice-IVIS differences that were associated with age in this study.

As expected, significant age effects were found for event response times: younger drivers had lower response latencies as compared with older drivers. The analysis that compared the no density condition to the "low density + high density conditions" found a significant effect for density, where drivers were quicker to respond in the IVIS conditions, but not for age. These apparently contrasting results seem to suggest that older drivers may be slower to respond to external events, but benefits from the system were realized by both age groups. Interpreting this result requires caution as it is based on supporting the null hypothesis. Further research is recommended that will systematically examine this finding.

Analysis of the preference questionnaire data yielded a significant age difference related to system distraction. Recall that 70 percent of younger drivers and 90 percent of older drivers reported nothing distracting about the IVSAWS. However, for the ISIS/IRANS, 100 percent of younger drivers and only 30 percent of older drivers indicated being distracted. The most common response for the distraction was the auditory tone ("beep") associated with the presentation of a message. Based on related research involving Side Object Detection System alerts (Campbell et al., 1996), redundant auditory/visual warnings are preferred in high urgency situations, but not in low urgency situations. In the present study, IVSAWS messages might be classified as "high urgency" and ISIS/IRANS messages as "low urgency." By using this classification scheme, present study results support Campbell et al. (1996), where most drivers were distracted by the auditory alert in the ISIS/IRANS condition. However, what would explain the low distraction for older drivers in the "low urgency" situations? As noted in the Results and Discussion section, there are two possible explanations for this finding. First, older drivers used in this study may have had degraded hearing such that the intensity of the tone was not annoying or distracting. Although this is possible, this explanation does not seem likely since all drivers, young and old, were required to successfully complete a hearing test prior to beginning the study. None of the older drivers exhibited any difficulties with the hearing test or exhibited characteristics that would indicate that they were hard-of-hearing. A second possible explanation is that given their more cautious approach to driving (e.g., Tasca, 1992), older drivers may have spent more time focused on the forward road scene and less time scanning the IVIS. Given this scenario, older drivers may have benefitted from the tone, which helped direct their attention to a new ISIS/IRANS message. The differences found in the analysis of the preference data between age groups supports recommendations for user control of auditory alert intensity (Campbell et al., 1996; Lyons, Lerner, and Kotwal, 1994).

The benefits of redundant presentation of messages, and multiple cues, are also implied by these results. Differences in preference for the type of alert may be more a function of *perceived urgency* than age. It may be that this perception of urgency dictates the preferred characteristics of the alerting cues. For example, based on the current results, older drivers may have rated their navigation task with a higher degree of perceived urgency. Support for this assumption was found in the analysis of off-route frequencies; older drivers had significantly more instances of being off route as compared with younger drivers. As such, older drivers may have valued the IRANS auditory alert more so than did younger drivers. It is hypothesized that perceived urgency, rather than age, may dictate the characteristics of preferred alerting cues. For instance, a driver who is navigating through an unfamiliar environment may weigh perceived urgency greater than when that same driver is commuting to work in a familiar environment. Contrasting these scenarios, the driver's preferred alerting cues may change based on the perceived urgency of the situation. If this is the case, optimal IVIS designs may be those that include user selection of one or more alerting cues across modalities. Expanding this idea further, optimal designs may allow users to not only select preferred alerting cues, but also preferred message types. For example, an ATIS menu feature may be included that would allow drivers to select from a bank of message types (e.g., visual text, symbols, combinations of text and symbols, auditory/voice messages, auditory/tone messages, proprioceptive messages), allowing multiple or redundant messages as desired by the user. This design idea would allow drivers to select the modality and type of message, as well as the modality and type of related cues, based on their current driving scenario or level of urgency. Further research is required to explore these hypotheses.

Based on several results related to age, it appears that although benefits from IVIS can be seen for both younger and older drivers, *relatively* more benefit may be realized for older drivers. This was made apparent by the higher response latencies and more frequent navigation errors for older drivers. It is in these areas where IVIS benefits may be best realized (i.e., through IVSAWS and IRANS).

In summary, for the third research question, "What impact does driver age have on system use and driver behavior and performance?," the present research determined the following:

- Older drivers took more time to complete some of the events than did younger drivers.
- For the ambulance approaching event, older drivers took more time to shift their gaze from the forward roadway to the IVIS than younger drivers.
- More navigation errors were committed by older drivers.
- Younger drivers were quicker to respond to external events than older drivers.

- IVIS benefits were realized for both younger and older drivers.
- Both younger and older drivers preferred the auditory alert when it served as a redundant IVSAWS message for “high urgency” events.
- Most older drivers, but no younger drivers, preferred the auditory alert when it served as redundant ISIS and IRANS messages for “low urgency” events.

The following six design guidelines may be useful to ATIS/CVO system developers. Recommendations 1 and 2 were derived from the results of this research, and reference is provided to a figure or table in the Results section. Recommendations 3 to 6 are more speculative and are based on the methodology and the IVIS design characteristics used in this experiment. In addition to these six guidelines, the reader is directed to the bullets outlined in the preceding section. These bullets highlight the major findings of the present study and may also be useful to ATIS/CVO designers.

(1) Driver response to unexpected events will benefit from well-designed IVIS displays that provide IVSAWS information (see figure 12).

(2) Auditory cues for alerts should allow user control of intensity (see table 5).

(3) Five seconds is the recommended timing for IVSAWS information for external events, where a warning is presented 5 seconds prior to when the driver could perceive the external event without an IVSAWS. In this research, 5 seconds was enough time for the driver to look at the display, plan a response, and safely take remedial action.

(4) An IVSAWS can effectively integrate external event warnings and vehicle status warnings. With an IVIS, information for external event warnings and vehicle status warnings can be co-located in the same area designated for IVSAWS information.

(5) Limitations associated with older driver performance, such as longer response times and more frequent navigation errors, can be reduced through the use of an optimally designed IVIS.

(6) Drivers should be allowed to select preferred “low urgency” messages and alerting cues, including redundant messages and multiple cues. The rationale for this recommendation is based on the finding that younger drivers and older drivers differed in their desire for auditory alerts for ISIS and IRANS information (i.e., “low urgency”), but not in their desire for auditory alerts for IVSAWS information (i.e, “high urgency”).

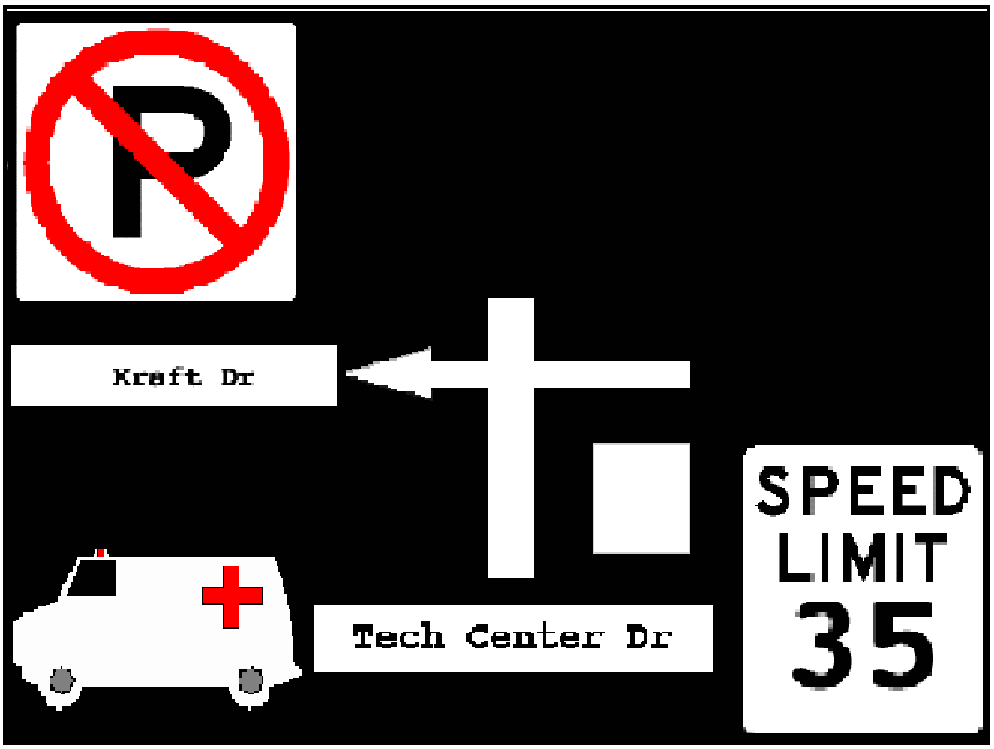
APPENDIX A: DISPLAY SPECIFICATIONS

Table 6. Mechanical specifications of the Sharp TFT-LCD Module, Model No. LQ64D142.

Parameter	Specification
Display size	16 cm diagonal (6.4 in.)
Active area	130.6 mm (H) x 97.0 mm (V)
Pixel format	640 pixels (H) x 480 pixels (V)
	(1 pixel = R + G + B dots)
Pixel pitch	0.204 mm (H) x 0.202 mm (V)
Pixel configuration	R, G, B, vertical stripe
Display mode	normally white
Unit outline dimensions*	175.0 mm (w) x 126.5 mm (h) x 9.5 mm (d)
Mass	235g ± 15g
Surface treatment	Anti-reflection, hard-coating (2H)
*Excluding back light cables. H = horizontal, V = vertical, w = width, h = height, d = depth.	

APPENDIX B: PROTOCOLS, QUESTIONNAIRES, AND STIMULI

APPENDIX B-1
Actual Portrayal Size of IVIS Information



APPENDIX B-2
Screening Questionnaire and Background Information

Participant's Name: ________________________________ Participant ID: ____

Participant's Phone: _________ Gender: ___ (0 = F, 1 = M) Age: ___

Pass: ______ Fail: ______

ADMINISTERED BY PHONE

NOTE TO INTERVIEWER: Ask the participant the following questions and record his/her responses. Participants are required to have a valid driver's license and drive at least twice a week.

PHONE INTERVIEWER: As part of the study, I need to ask you a few questions. Your answers will determine your eligibility for this study. This data will not be associated with your name, and will be treated confidentially.

1) Do you have a valid driver's license?

____________ Yes ______ No

2) How many times per week do you drive in Blacksburg or the surrounding area?

4 + 2 -3 X 1X <1X

3) Approximately how many miles do you drive per year?

1___Under 2,000
2___2,000 - 7,999
3___8,000 - 12,999
4___13,000 - 19,999
5___20,000 or more

PHONE INTERVIEWER: If passes...Now I'd like to schedule a time when you can come to the Center for the study. If fails...Thanks for your time; unfortunately you do not qualify for this particular study. Would you be interested on being put on a participant list for future studies?

* SCHEDULE A TIME DATE AND TIME________________________________

PHONE INTERVIEWER: Also, since you will be driving a car, I need to ask you to refrain from drinking any alcohol for the 24 hrs before the experiment. Is this all right with you?
YES____ NO____

Thank you, I'll see you? (DATE and TIME). Let me provide you with directions to the Center...

APPENDIX B-3
Informed Consent for Participant of Investigative Project

Title of Project: Evaluation of Drivers' Use of Cues Outside The Vehicle As Compared to Cues Presented Inside A Vehicle (by and ISIS and IVSAWS) for External Hazard Observation

Investigators: John Gallagher, Richard Hanowski, Dr. Vicki Neale, and Dr. Thomas Dingus

I. THE PURPOSE OF THIS RESEARCH/PROJECT

The purpose of this research is to evaluate how drivers perform when using an In-Vehicle Information System (IVIS). The results of this study will help engineers design effective, safe, and easy-to-use in-vehicle systems. The study involves twenty-four drivers of varying age and gender.

II. PROCEDURES

During the course of this study, you will be asked to perform the following tasks:

1. Read and sign an informed consent form.
2. Answer general and demographic questions.
3. Complete a vision test.
4. Complete a hearing test.
5. Complete a health screening questionnaire.
6. Read general information about the test vehicle.
7. Participate in a training session in which you will learn about specific features of the vehicle. The training will include a test drive to become familiar with the vehicle and practice using the IVIS.
8. Drive the vehicle over a pre-defined route for which data will be collected.
9. Answer questions regarding your preference of the data displayed in the vehicle.

After your drive, you will return to the Center for Transportation Research, be paid for your time, and have the chance to learn more about the research.

It is important for you to understand that we are evaluating the IVIS display in the vehicle, not you. Therefore, we ask that you perform to the best of your abilities. If you ever feel frustrated with the system, just remember that those are the things we need you to comment on when you complete the preference questionnaire. It is important that we know what you did and did not like. Your preferences provide information that is very important to this project.

III. RISKS

There are some risks and discomforts to which you are exposed in volunteering for this research. These risks are:

1. The risk of an accident normally associated with driving an automobile in light or moderate traffic, under clear conditions, and on straight and curved roadways.
2. The slight additional risk that an accident may occur while using the IVIS display. Previous research has indicated that this risk is minimal.
3. While you are driving the vehicle, you will be videotaped by cameras. Due to this, we ask that you not wear sunglasses. If, at any time, this impairs your ability to drive the vehicle, you are to notify the researcher immediately.

The following precautions will be taken to ensure minimal risk to you:

1. The researcher will monitor you during driving, and will ask you to stop if it is felt the risks are too great to continue. However, as long as you are driving the vehicle, it remains your responsibility to drive in a safe, legal manner.
2. You are required to wear the lap and shoulder belt restraint system any time the vehicle is being operated. The vehicle is also equipped with a driver's side airbag supplemental restraint system.
3. The vehicle is equipped with a fire extinguisher, first-aid kit, and a cellular phone which may be used in an emergency.
4. The researcher has a brake pedal to override the driver brake pedal to slow or stop the vehicle if necessary.
5. If an accident does occur, the researcher will arrange medical transportation to a nearby hospital emergency room. You will be required to undergo examination by medical personnel in the emergency room.
6. All data collection equipment is mounted such that, to the greatest extent possible, it does not pose a hazard to you in any foreseeable case.
7. None of the data collection equipment interferes with any part of the driver's normal FOV.

IV. BENEFITS OF THIS PROJECT

There are no direct benefits to you (other than payment). You may, however, find participation interesting. No promise or guarantee of benefits has been made to encourage you to participate. Your participation will make it possible to determine the benefits and hazards associated with IVIS use and assist in improving safety in vehicles.

V. EXTENT OF ANONYMITY AND CONFIDENTIALITY

The data gathered in this study will be treated with confidentiality. After you have completed the study, your name will be removed from the data. Only a code will be used to identify the data. You are allowed to see your data and may remove it from the study. You must immediately inform the researcher of this decision, as it will be difficult (or impossible) to track your data once the session is over. During the study, your eye movements will be videotaped by a camera. These video tapes will be stored in a locked filing cabinet at the Virginia Tech Center for Transportation Research, under the supervision of Dr. Thomas A. Dingus. Dr. Vicki Neale, as Project Manager, along with her research staff, will have access to the tapes for the purposes of analysis. The tapes will be destroyed three months after the data has been analyzed and the results documented (approximately July 1997). At no time will the researchers release the results of the study to anyone other than individuals working on the project without your written consent.

VI. COMPENSATION

You will receive $_____ per hour for your participation in this study. This payment will be made to you at the end of your voluntary participation for the portion of the study that you complete.

VII. FREEDOM TO WITHDRAW

You are free to withdraw from this study at any time for any reason. Further, you are free to not answer any questions or respond to any research situations without penalty.

VIII. APPROVAL OF RESEARCH

This research has been approved, as required, by the Institutional Review Board for projects involving human subjects at Virginia Polytechnic Institute and State University, and by the Department of Industrial and Systems Engineering.

X. SUBJECT'S RESPONSIBILITIES AND PERMISSION

I voluntarily agree to participate in this survey, and I know of no reason I cannot participate. I have read and understand the informed consent and conditions of this project. I have had all my questions answered. I hereby acknowledge the above and give my voluntary consent for participation in this project. If I participate, I may withdraw at any time without penalty. I agree to abide by the rules of this project.

Signature ____ Date __________

Name (please print) ________________________________

Should I have any questions about this research or its conduct, I may contact:

Dr. Vicki Neale, Project Manager	Phone: (540) 231-5578
Dr. Tom Dingus, Director, Center for Transportation Research	Phone: (540) 231-8831
T. H. Hurd, Director of Sponsored Programs	Phone: (540) 231-5281

APPENDIX B-4
Health Screening Questionnaire

1. Are you in good general health?	YES	NO

If no, please list any health-related conditions your are experiencing or have experienced in the recent past.

2. Have you, in the last 24 hours, experienced any of the following conditions?

Inadequate sleep	YES	NO
Unusual hunger	YES	NO
Hangover	YES	NO
Headache	YES	NO
Cold Symptoms	YES	NO
Depression	YES	NO
Allergies	YES	NO
Emotional upset	YES	NO

3. Do you have a history of any of the following?

Visual Impairment (If yes, please describe)	YES	NO

Hearing Impairment (If yes, please describe)	YES	NO

Seizures or other lapses of consciousness (If yes, please describe)	YES	NO

Any other disorders that would impair your ability to drive (If yes, please describe)	YES	NO

---

4. Please list any prescription or non-prescription drugs you are currently taking or have taken in the last 24 hours.

---

5. List the approximate amount of alcohol (beer, wine, fortified wine, or liquor) you have consumed in the last 24 hours.

---

6. Are you taking any drugs of any kind other than those listed above?

	YES	NO
7. If you are female, are you pregnant?	YES	NO

______________________ ______________________

Signature Date

APPENDIX B-5
Experimenter Protocol for Subject Suitability Assessment:
Proof of Valid Driver's License, Vision Test, and Hearing Test

SCREENING

After reading the consent form...

1) Show driver's license. Must be valid.

2) Administer "Health Screening Questionnaire"

NOTE TO EXPERIMENTER: Subject must be in general good health, not be taking any medication that would adversely affect his/her driving (e.g., antihistamine), not have been drinking, and not be pregnant.

3) Vision Test

EXPERIMENTER: "Follow me, and I'll administer a vision test that is required of all participants."

Take the subject to the Snellen chart in the ITS lab. Have the subject place his or her toes on the back edge of the tape line on the floor. Make sure the subject is wearing the glasses or contacts they wear while driving.

EXPERIMENTER: "Look at the chart on the wall and read aloud the smallest line you can comfortably make out."

If the subject reads every letter on the line correctly, have them try the next line down. Repeat this until they miss a letter, and record the acuity of the last line they got completely correct below. If the subject does not correctly read every letter on their first line correctly, move up a line and have them try again. Repeat as needed and record the acuity of the first line they get completely correct.

Acuity score: _____

4) Hearing Test

The next step is the hearing test. (Do this in the car, with the engine running. Have the subject sit in the driver's seat and the experimenter sits in the back seat directly behind the driver).

EXPERIMENTER: "I'm going to sit behind you and speak a list of words one at a time. After I say a word, I want you to repeat it back to me. Do you have any questions?"

Answer any questions, and then read the following list of words to the subject:

	Correct	Incorrect
STOP	_____	_____
TURN	_____	_____
LEFT	_____	_____
RIGHT	_____	_____
BEGIN	_____	_____
INTERSECTION	_____	_____

SCORING

To be a participant, the subject must:

1) Have a valid driver's license
2) Have a visual acuity of 20/40 or better.
3) Pass "Health Questionnaire." For Question 3, look for impairments that might adversely affect ability to drive.
4) Get all six words in the hearing test correct.

APPENDIX B-6
Experimenter's Instructions Script

1. INTRODUCTIONS and INSTRUCTIONS

A. Greet Participant

B. Informed Consent Form

! *Give participant a copy of the informed consent form to read.*
! *Answer any general questions the participant might have about the study.*
! *Have participant sign and date the informed consent form.*
! *Give participant a copy of the informed consent form.*

C. Health, Medication, and Drug Questionnaire

! *Give participant a copy of the health, medication, and drug questionnaire to complete.*
! *Have participant sign and date the health, medication, and drug questionnaire.*
! *Review questionnaire to ensure that participant is fit to take part in the study.*

D. Verify Driver's License

! *Have participant show a valid driver's license.*

E. Initial Briefing

EXPERIMENTER: "Do you have any additional questions at this point in time?"

! *Answer any general questions the participant might have.*

EXPERIMENTER: "Before we proceed, I'd just like to tell you that I will be reading from a script during much of our time together. This ensures that I won't forget to tell you anything. So, if I sound extremely formal at times, please understand that this is a requirement of the study."

"In order to make the experiment as objective and safe as possible, I'd like to go over a few points before we start driving."

"First, we will be driving over a prescribed course. This course will be in the Blacksburg/Christiansburg area."

"The vehicle you will be driving today is equipped with an in-vehicle information system (IVIS). The IVIS presents information inside the vehicle, in the dashboard area, that will

(1) help you navigate, (2) provide signing information, and (3) provide advisory and warning signs where extreme caution is required by you, the driver."

F. IVIS Orientation and Task Training

EXPERIMENTER: "There is a computer mounted in the trunk of the vehicle which runs the IVIS software. Using a positioning system, the IVIS can track your route, provide you with navigation information, and present signs. In addition, an in-vehicle safety advisory and warning system is present that will track a variety of events surrounding your car and warn you when action is required."

"The route that you will be driving has been pre-programmed into the IVIS. Please follow the route that the IVIS presents. That is, turn onto roads that the IVIS directs you to. The researcher will also help you navigate by providing directions on upcoming turns."

"You will also notice that the IVIS presents sign information, such as speed limit and other roadway signs. Please obey all speed limits and follow the directions associated with the roadway signs. For example, a pedestrian crossing sign means that you must be aware of pedestrians in the area and drive cautiously."

"Warning advisories may also be presented on the IVIS. The technology of the IVIS allows tracking of events around your vehicle and will warn you when a situation arises that requires your immediate attention or action. For example, an advisory that a "rock slide" has occurred may, in the rare event of a rock slide, be presented to you. If this happens, drive with extreme caution in the area and be prepared to take any necessary actions."

"During part of the route, the IVIS will display the number of miles to next turn; if there is less than .1 miles to the next turn, then the IVIS will display zero miles to next turn."

"Do you have any questions before we go out to the vehicle?"

! *Answer any general questions the participant might have.*

EXPERIMENTER: "Before we go out to the vehicle, I need to give you a vision test. This is a requirement of all participants of this study."

! *Administer vision test in "Flash Lab." If passes (at least 20/40), then go out to vehicle and continue with study. If fails, pay for time and excuse from study.*

2. ORIENTATION SESSION

A. Vehicle Briefing and IVSAWS Pre-test

! *Open front driver-side door for the participant and have them get into the front driver's seat.*

! *Get into front passenger's-side seat.*

EXPERIMENTER: "Before we begin today, I'd like to take a few moments to familiarize you with this vehicle."

"Since the controls in this car may be different from those in your car, I would like to give you a chance to familiarize yourself with the controls. When I point out the location of each, please operate it."

! *Say name of each control and have subject operate it.*

EXPERIMENTER and PARTICIPANT:

1. WINDSHIELD WIPERS
2. LIGHTS
3. HORN
4. TURN SIGNALS
5. DEFOGGER
6. DEFROSTER

EXPERIMENTER: "Please also note that, for your safety, this car is equipped with ABS brakes and a driver's side airbag. Are you aware of these technologies?"

! *If not, explain them*.

EXPERIMENTER: "In addition, and again for safety, the researcher riding in the front passenger's seat will have access to an emergency brake that they will use in case of an emergency. Do you have any questions about this safety feature?"

! *Answer general questions.*

EXPERIMENTER: "Now, I'd like you to adjust the seat and the steering wheel so that you are in a comfortable driving position. Make sure you can see the entire instrument panel through the steering wheel. It is in this area that the IVIS is located. Please fasten your seatbelt and turn on your headlights."

- *Show seat adjustments and have the participant adjust the seat and steering wheel. Then have them fasten their seatbelt and turn on headlights (kept on for duration of experiment).*

EXPERIMENTER: "Now, please adjust the side- and rear-view mirrors to your liking."

- *Have the participant adjust the side- and rear-view mirrors.*

- *Make sure the following system settings are achieved:*

  (1) Connect all computer cables
  (2) Power on display computer
  (3) Power up data collection computer
  (4) Load video cassette

- *Have subject start up the vehicle.*

EXPERIMENTER: "Now before we start out on the practice route, I am going to give you a roadway and warning sign recall test. For this test, 20 signs along with their meaning will be presented to you on the IVIS. After all 20 signs have been presented, they will be re-presented, this time without their meaning. It is your task to recall the meaning of the signs and call out the name of it to the researcher. For example, a picture of a stop sign with the word "stop" may appear. Later, that same sign will reappear without the sign's meaning. When it does, you tell the researcher that the sign's name is 'stop'."

"Do you have any questions before we begin?"

- *Answer general questions (note this task will become evident when it begins).*

- *Subject MUST correctly identify all IVSAWS used in the study ("Hidden Entrance," "Ambulance," "Car Crash," "One-Lane Tunnel," "Trunk Open," "Disabled Vehicle," "Railroad Crossing"). If pass, begin practice drive. If fail, re-do test.*

3. IVIS ORIENTATION

- *Boot up IVIS test screen (with IRANS, ISIS, and IVSAWS).*

EXPERIMENTER: "As we discussed, here is the IVIS with the different types of information on it. As you can see, there is navigation information that tells you which street you are on, the distance to the next turn, the direction of the next turn, and the name of the street that you will be turning onto. Signing information is also presented and includes speed limit, and other miscellaneous roadway signs. Finally, in the bottom left corner of the screen is where the safety advisory and warning signs will be presented."

"Do you have any questions about the IVIS display?"

! *Answer general questions.*

4. PRACTICE SESSION

EXPERIMENTER: "Now we will begin a practice drive to help you get familiar with operating the vehicle. During this drive, the IVIS will not be displayed."

! *Drive around block. Instruct subject on turns as follows, "Turn left on Tech Center Drive." "Turn Left on Pratt Drive." NOT "Turn left at the next street." If subject feels comfortable with operating the car, move on to IVIS practice. If not comfortable, repeat drive.*

EXPERIMENTER: "Now we will begin a practice drive to help you get familiar with operating the vehicle while the IVIS is on."

! *Drive around block. If subject feels comfortable with operating the car and IVIS, move on to first test route. If not comfortable, repeat drive.*

5. TEST DRIVE

EXPERIMENTER: "During your upcoming drive, you will be driving on a pre-determined route. There will be three sections to your route where a different IVIS will be presented. You will have a 5 to 10 minute break between route sections. In one of these sections, no IVIS will be presented. The other two sections will have an IVIS, but they will differ slightly."

"Your task is to drive the vehicle in a safe manner, obeying all traffic laws. Your primary responsibility is to safely operate the vehicle. Other responsibilities are: follow the navigation directions of the researcher and of the IVIS (when available); follow the directions of all signs presented on the IVIS (e.g., speed limit); follow the directions of all safety advisory and warning signs. There are no other tasks associated with this study."

"Do you have any questions about these tasks? Please note that neither I nor <name> (the other experimenter) will be allowed to answer questions while the drive is ongoing. Also, we will not be able to talk with you during the drive other than to provide navigation directions that will tell you what streets to turn on and the direction of the turn. Regarding these directions, for each turn I will tell you the road to turn on and the direction of the turn on two occasions; first when the street preceding the turn is first encountered, and second, approximately one block before the turn street."

! *Answer general questions.*

EXPERIMENTER: "Are you ready to begin the test drive?"

Data Collection

! *Begin preparing data collection equipment.*

(1) *Enter subject number.*
(2) *Enter experiment number.*
(3) *Enter input condition.*
(4) *Begin data collection.*

6. POST-TEST, DEBRIEFING, AND PAYMENT

! *Return to the CTR.*

! *Administer Preference Questionnaire.*

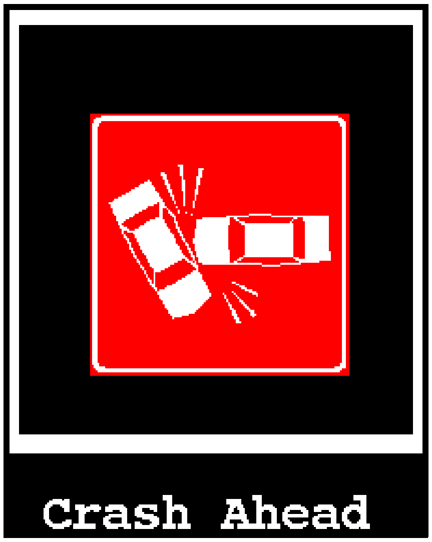
! *Answer any questions the participant has during the debriefing or about the study in general.*

! *Pay participant. Make sure that both you and the participant sign/date the payment log sheet.*

! *Thank participant for taking part in the study.*

APPENDIX B-7

Pre-test IVIS Symbols

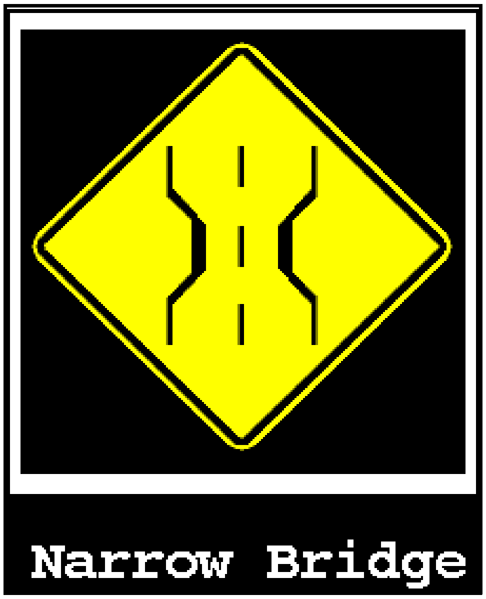

Crash Ahead

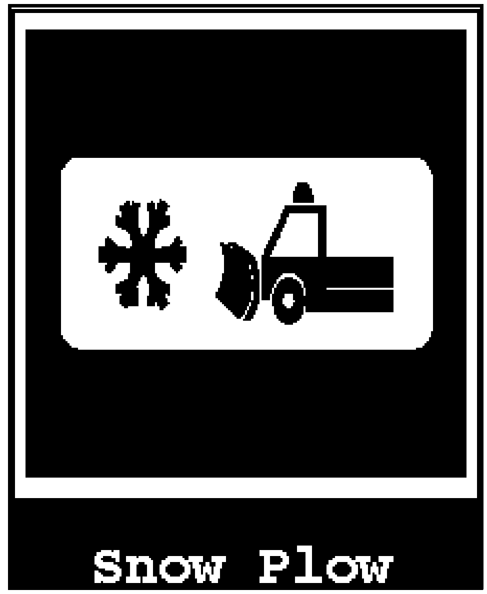

Car Fire Ahead


HIDDEN
ENTRANCE
Hidden Entrance


Low Tire Pressure

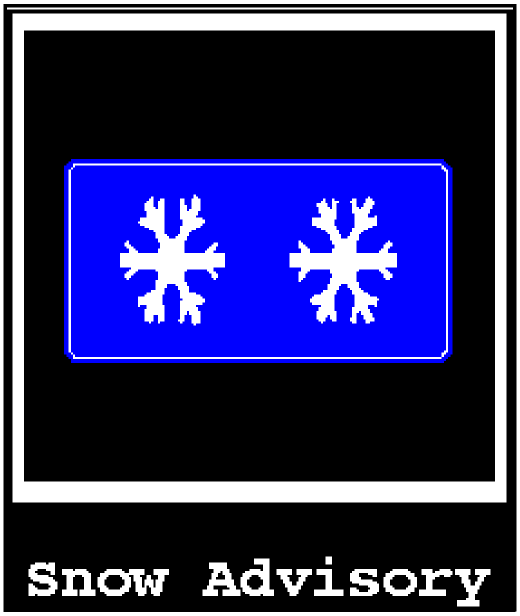

Slow Trucks/Incline Ahead

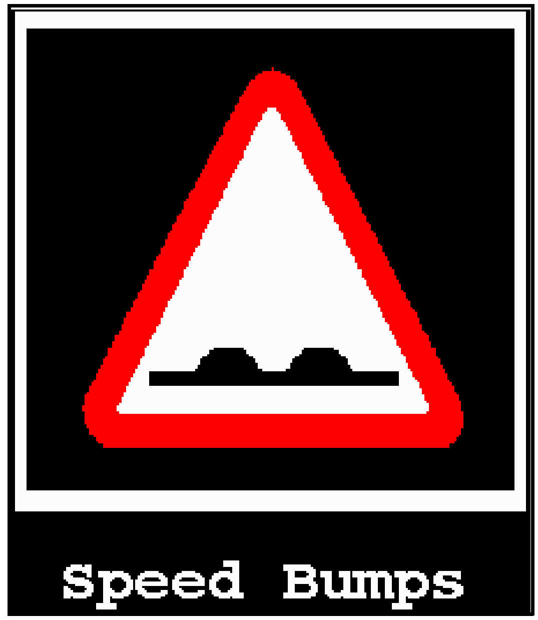

Narrow Bridge

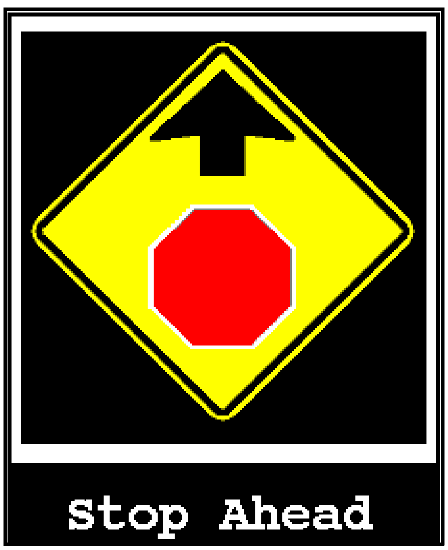

Snow Plow


R R
Railroad Crossing Ahead


School Crossing

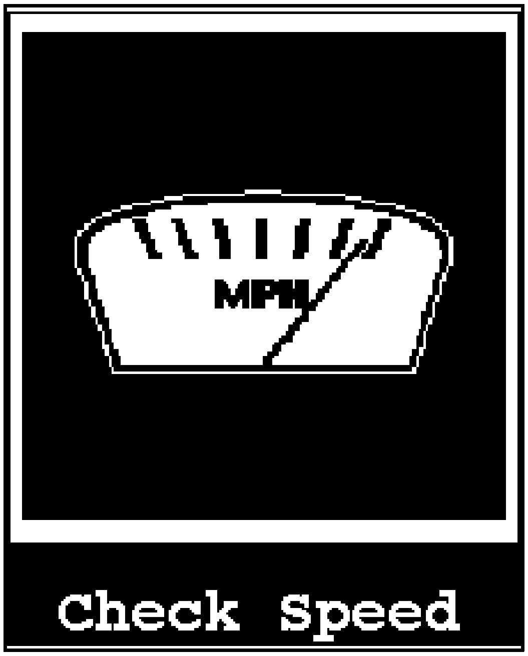

Snow Advisory


Speed Bumps


Stop Ahead


Disabled Vehicle Ahead


Trunk Open


MPH
Check Speed


Winding Road

APPENDIX B-8

Second Experimenter's Protocol

Tasks

The second experimenter (i.e., the experimenter who rides in the passenger seat) has three primary tasks. They are as follows:

1. Operate the safety brake—to be used only in case of emergency. The emergency brake is a foot brake located in the front passenger's area.

2. Flag data—of both planned and unplanned events. A cord with a button attached must be held by the second experimenter through the duration of the experiment. When a planned or unplanned event occurs, press down on the button and hold it down for the duration of the event. When the event is over, release the button. This will place a "flag" in the data for observation at a later time. Flag any events where the driver is required to react (or should react and neglects to). Planned events are those that involve the confederate vehicle and the trunk opening. Unplanned events are naturally occurring events that happen during the drive. Examples of unplanned events include a car braking sharply in front of the subject, a dog running across the road, a car merging toward the subject, a car traveling in the opposite direction, slowing in an intersection and initiating a left turn, etc.

In the case of multiple events, or when a second event begins before the first event ends, press the button for the first event, then again for the second even though the first hasn't finished yet.

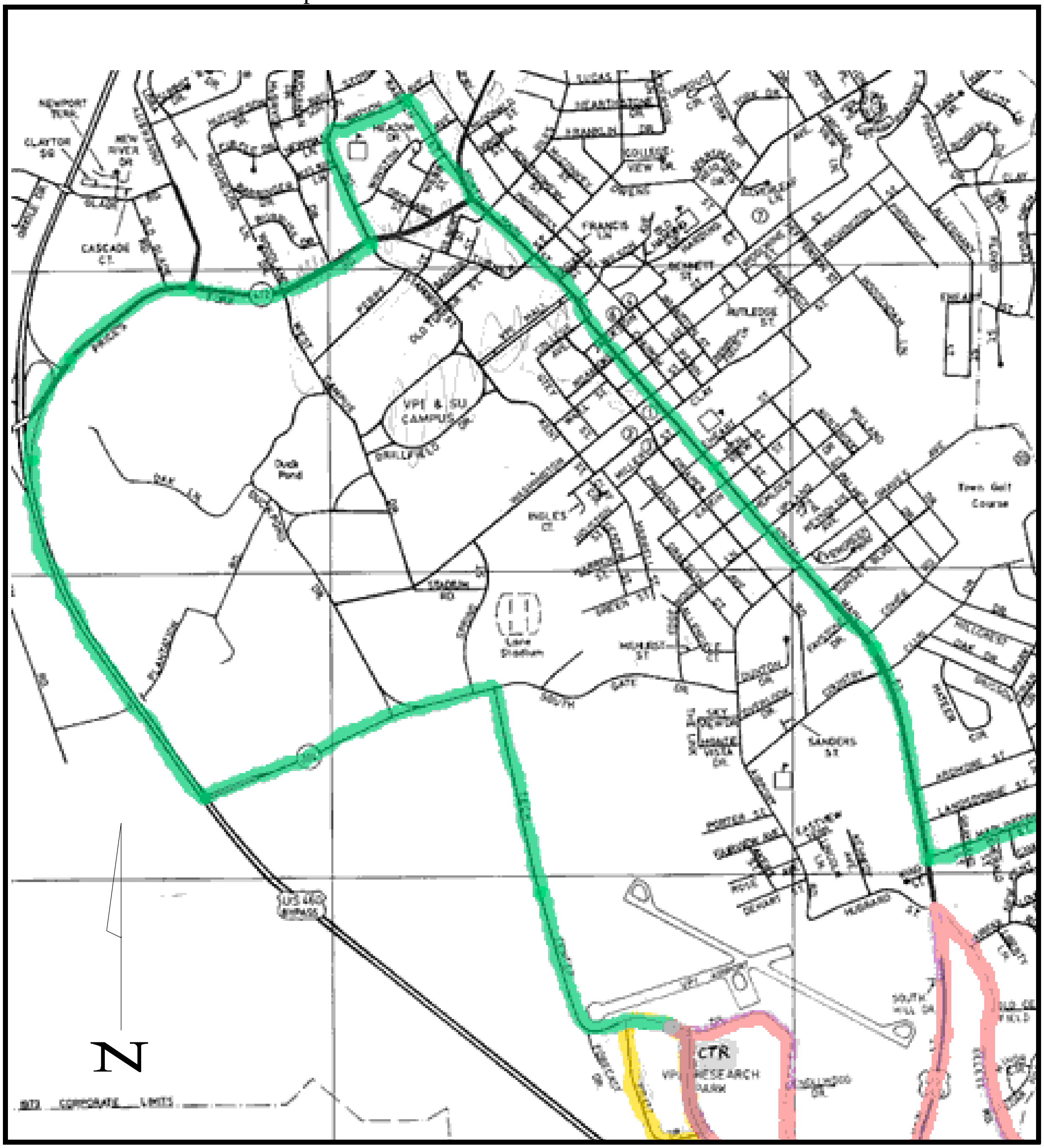
3. Provide direction information to the subject—during the drive. The second experimenter must have a thorough understanding of the route and list of all turns. Information for a given turn is provided on two instances: (1) when the subject enters the stretch of road preceding the upcoming turn, and (2) approximately one block before the upcoming turn. The method of presenting the information is as follows: As soon as the subject makes a turn, the upcoming navigation is stated as follows, "Your next turn is a right on Elm Street." Then, approximately 1/10th of a mile before the turn state, "Turn right on Elm Street." If the subject asks for more navigation information such as, "Do I turn right up here?," repeat the direction "Turn right on Elm Street." If the subject says, "What street was that again?," repeat the direction, "Turn right on Elm Street." This method will help ensure consistent directions are provided for all subjects. Note, in the directions do NOT say, "Turn right at next intersection." You need to say the street name so that the subject will be involved in the navigating and be looking at street signs.

APPENDIX B-9

Maps of Test Area with Highlighted Routes.

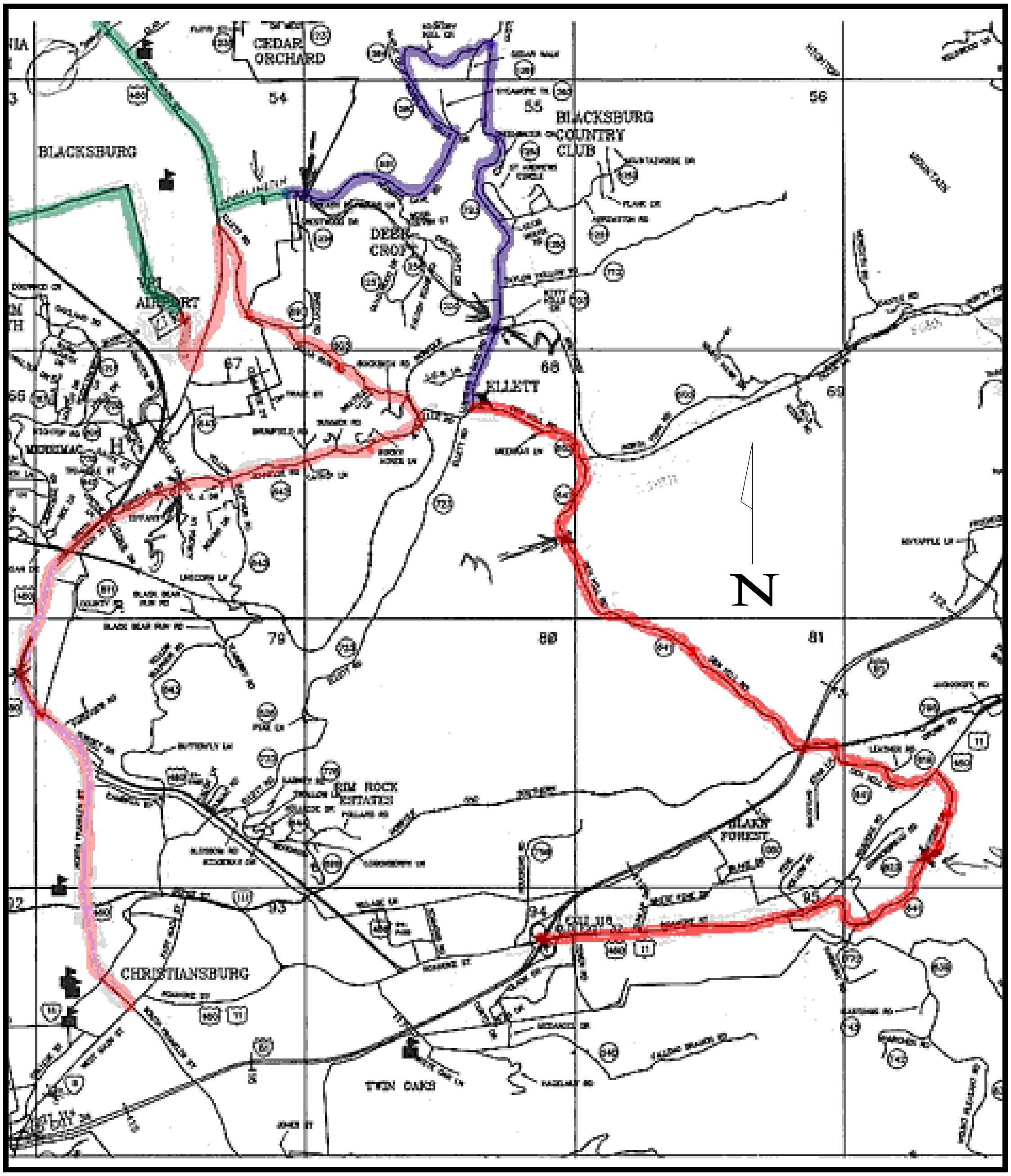
Blacksburg

Route 1 = Green and Purple **Route 2 =** Red and Yellow **Route 3 =** Brown and Pink



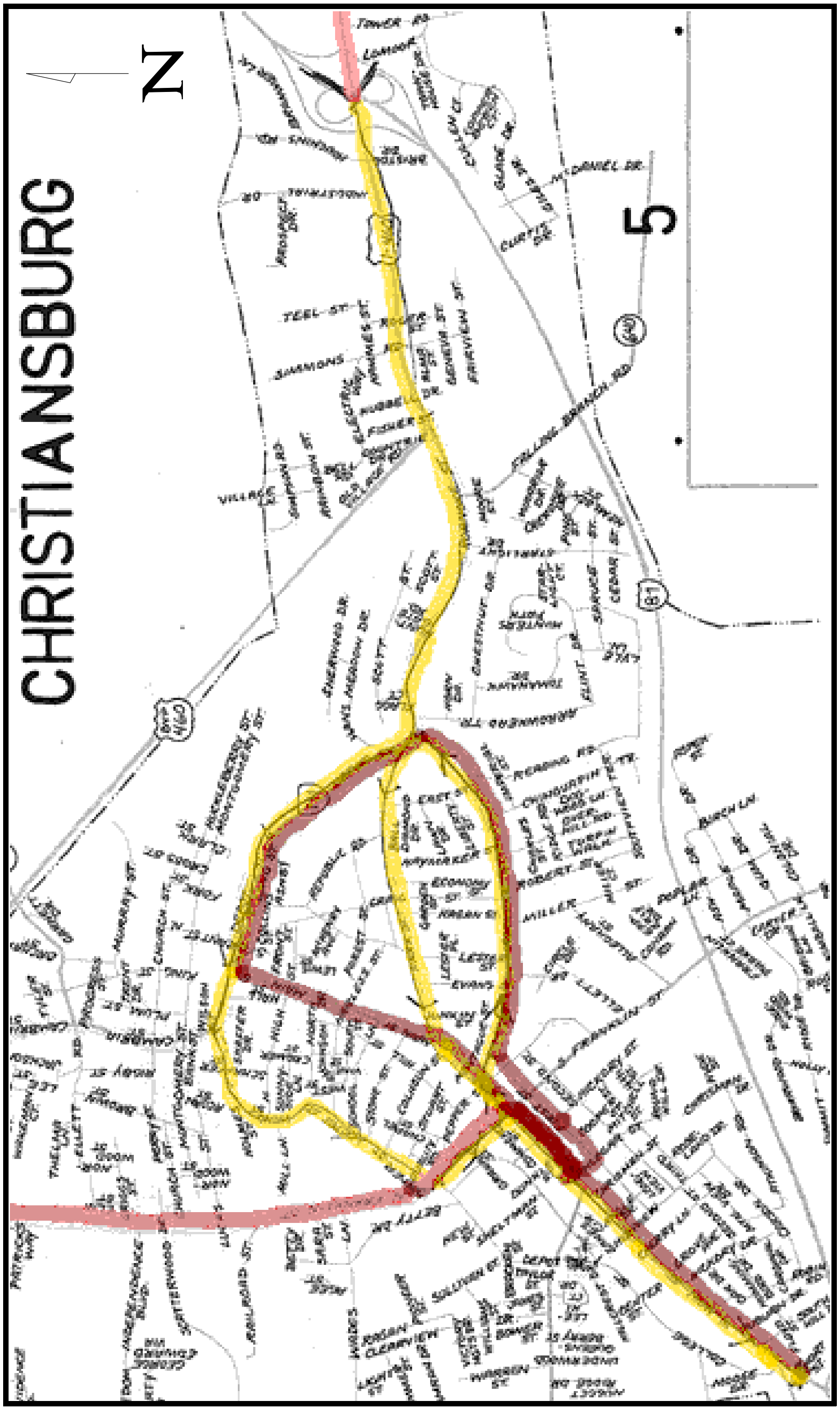
Montgomery County

Route 1 = Green and Purple **Route 2 =** Red and Yellow **Route 3 =** Brown and Pink



Christiansburg

Route 1 = Green and Purple **Route 2 =** Red and Yellow **Route 3 =** Brown and Pink



APPENDIX B-10

Preference Questionnaire

Please read the following questions and circle the number that best describes how you feel.

1. How aware of the in-vehicle road sign and navigation information were you during the drive?

1	2	3	4	5	6	7
Very Aware						Not at All Aware

2. How aware of the in-vehicle safety and warning information were you during the drive?

1	2	3	4	5	6	7
Very Aware						Not at All Aware

3. How timely was the presentation of road sign/navigation/safety and warning information during the drive?

1	2	3	4	5	6	7
Very Timely						Not at All Timely

4. How safe did you feel during the drive?

1	2	3	4	5	6	7
Very Safe						Not at All Safe

5. How distracting was the road sign/navigation information during the drive?

1	2	3	4	5	6	7
Very Distracting						Not at All Distracting

6. What was distracting? ____

7. How distracting was the safety and warning information during the drive?

1	2	3	4	5	6	7
Very Distracting						Not at All Distracting

8. What was distracting? ____

9. Would you find these types of systems useful to you while driving?

1	2	3	4	5	6	7
Very Useful						Not at All Useful

10. Of the two systems that you tested today which, if any, did you prefer?

Did Not Like Either System	Preference to Systems About the Same	Preferred System With Less Information	Preferred System With More Information

APPENDIX C: ANALYSIS OF VARIANCE TABLES

PREFERENCE QUESTIONNAIRE DATA

Table 7. Analysis of variance table for preference question #1, "How aware of the in-vehicle road sign and navigation information were you during the drive?"

Independent Variable	df	MS	F	p
Age	1	0.417	0.48	0.500
Gender	1	0.017	0.02	0.892
Age*Gender	1	0.417	0.48	0.500
Error	16	0.874		

Table 8. Analysis of variance table for preference question #2, "How aware of the in-vehicle safety and warning information were you during the drive?"

Independent Variable	df	MS	F	p
Age	1	0.087	0.26	0.616
Gender	1	0.022	0.07	0.802
Age*Gender	1	1.39	4.18	0.058
Error	16	0.333		

Table 9. Analysis of variance table for preference question #3, "How timely was the presentation of road sign/navigation/safety and warning information during the drive?"

Independent Variable	df	MS	F	p
Age	1	0.003	0.00	0.970
Gender	1	0.003	0.00	0.970
Age*Gender	1	0.248	0.12	0.735
Error	16	2.10		

Table 10. Analysis of variance table for preference question #4, "How safe did you feel during the drive?"

Independent Variable	df	MS	F	p
Age	1	4.12	0.71	0.411
Gender	1	2.52	0.44	0.519
Age*Gender	1	4.12	0.71	0.411
Error	16	5.78		

Table 11. Analysis of variance table for preference question #5, "How distracting was the road sign/navigation information during the drive?"

Independent Variable	df	MS	F	p
Age	1	7.25	2.77	0.116
Gender	1	0.034	0.01	0.911
Age*Gender	1	0.720	0.27	0.607
Error	16	2.62		

Table 12. Analysis of variance table for preference question #7, "How distracting was the safety and warning information during the drive?"

Independent Variable	df	MS	F	p
Age	1	0.007	0.00	0.952
Gender	1	0.559	0.31	0.591
Age*Gender	1	0.834	0.46	0.513
Error	9	1.8		

Table 13. Analysis of variance table for preference question #9, "Would you find these types of systems useful to you while driving?"

Independent Variable	df	MS	F	p
Age	1	2.02	1.04	0.322
Gender	1	2.34	1.21	0.287
Age*Gender	1	1.53	0.79	0.387
Error	16	1.93		

SITUATIONAL AWARENESS DATA

Table 14. Analysis of variance table for situational awareness dependent variable, "Event Length," and independent variables, "Age," "Gender," and "Density."

Independent Variable	df	MS	F	p
Age	1	106.2	1.14	0.302
Gender	1	231.5	2.48	0.135
Age*Gender	1	2.84	0.03	0.864
S(Age Gender)	16	93.4		
Density	*2*	*336.7*	*5.86*	*0.007*
Age*Density	2	1.80	0.03	0.969
Gender*Density	2	53.4	0.93	0.405
Age*Gender*Density	2	1.53	0.79	0.387
Density*S(Age Gender)	30	57.4		

Table 15. Analysis of variance table for situational awareness dependent variable, "Event Length," and independent variables, "Age," "Gender," and "Event."

Independent Variable	df	MS	F	p
Age	1	63.2	0.82	0.377
Gender	1	142.1	1.85	0.192
Age*Gender	1	2.84	0.00	0.991
S(Age Gender)	16	76.7		
Event	*6*	*533.0*	*11.1*	*0.0001*
Age*Event	6	1.80	0.30	0.926
*Gender*Event*	*6*	*149.1*	*3.10*	*0.009*
Age*Gender*Event	6	23.5	0.49	0.815
Event*S(Age Gender)	76	48.04		

Table 16. Analysis of variance table for situational awareness dependent variable, "Time to Notice IVSAWS," and independent variables, "Age," "Gender," and "Density" (only Low and High density conditions included).

Independent Variable	df	MS	F	p
Age	1	0.50	0.48	0.497
Gender	1	0.49	0.47	0.501
Age*Gender	1	0.001	0.00	0.972
S(Age Gender)	16	16.5		
Density	1	0.158	0.27	0.608
Age*Density	1	0.154	0.27	0.612
Gender*Density	1	2.39	4.16	0.059
Age*Gender*Density	1	0.041	0.07	0.794
Density*S(Age Gender)	15	8.61		

Table 17. Analysis of variance table for situational awareness dependent variable, "Time to Notice IVSAWS," and independent variables, "Age," and "Event."

Independent Variable	df	MS	F	p
Age	1	0.478	0.45	0.512
S(Age)	18	1.07		
Event	4	0.521	0.81	0.530
*Age*Event*	*4*	*1.75*	*2.71*	*0.047*
Event*S(Age)	33	0.646		

Table 18. Analysis of variance table for situational awareness dependent variable, "Time to Notice Event," and independent variables, "Age," "Gender," and "Density" (only Low and High density conditions included).

Independent Variable	df	MS	F	p
Age	1	70.0	2.39	0.142
Gender	1	5.83	0.20	0.662
Age*Gender	1	0.018	0.00	0.981
S(Age Gender)	16	29.4		
Density	1	5.41	0.18	0.682
Age*Density	1	31.8	1.03	0.328
Gender*Density	1	17.7	0.57	0.462
Age*Gender*Density	1	17.3	0.56	0.467
Density*S(Age Gender)	15	30.9		

Table 19. Analysis of variance table for situational awareness dependent variable, "Time to Notice Event," and independent variables, "Age," and "Event."

Independent Variable	df	MS	F	p
Age	1	76.8	3.33	0.085
S(Age)	18	23.1		
Event	*4*	*54.4*	*2.71*	*0.046*
Age*Event	4	3.57	0.18	0.948
Event*S(Age)	34	20.0		

Table 20. Analysis of variance table for situational awareness dependent variable, "Time to Respond to Event," and independent variables, "Age," and " Density" (with two levels: no display and Low +High density).

Independent Variable	df	MS	F	p
Age	1	0.107	0.02	0.894
S(Age)	18	5.82		
New Density	*1*	*90.8*	*5.25*	*0.035*
Age*New Density	1	1.03	0.06	0.810
New Density*S(Age)	17	17.3		

Table 21. Analysis of variance table for situational awareness dependent variable, "Time to Respond to Event," and independent variables, "Age," and "Event."

Independent Variable	df	MS	F	p
Age	*1*	*16.3*	*4.71*	*0.044*
S(Age)	18	3.47		
Event	*4*	*45.0*	*14.2*	*0.000*
Age*Event	4	1.47	0.46	0.763
Event*S(Age)	59	3.18		

Table 22. Analysis of variance table for situational awareness dependent variable, "Event Length," and independent variables, "Age," and "Density," for the first planned event, "Car approaching from side street."

Independent Variable	df	MS	F	p
Age	1	8.60	2.85	0.115
Density	*2*	*227*	*75.3*	*0.000*
Age*Density	2	3.38	1.12	0.357
S(Age Density)	13	3.02		

Table 23. Analysis of variance table for situational awareness dependent variable, "Event Length," and independent variables, "Age," and "Density," for the second planned event, "One-lane tunnel."

Independent Variable	df	MS	F	p
Age	*1*	*50.5*	*4.87*	*0.046*
Density	*2*	*219*	*21.1*	*0.000*
Age*Density	2	10.7	1.03	0.385
S(Age Density)	13	10.4		

Table 24. Analysis of variance table for situational awareness dependent variable, "Event Length," and independent variables, "Age," and "Density," for the third planned event, "Disabled vehicle."

Independent Variable	df	MS	F	p
Age	1	69.0	3.58	0.079
Density	2	18.8	0.97	0.402
Age*Density	2	9.50	0.49	0.621
S(Age Density)	13	19.3		

Table 25. Analysis of variance table for situational awareness dependent variable, "Event Length," and independent variables, "Age," and "Density," for the fourth planned event, "Trunk open."

Independent Variable	df	MS	F	p
Age	1	0.65	0.00	0.971
Density	2	208.8	0.48	0.645
Age*Density	1	23.8	0.05	0.825
S(Age Density)	5	435		

Table 26. Analysis of variance table for situational awareness dependent variable, "Event Length," and independent variables, "Age," and "Density," for the fifth planned event, "Ambulance approaching."

Independent Variable	df	MS	F	p
Age	1	0.30	0.00	0.951
Density	2	241	3.12	0.078
Age*Density	2	0.76	0.01	0.990
S(Age Density)	13	77.4		

Table 27. Analysis of variance table for situational awareness dependent variable, "Event Length," and independent variables, "Age," and "Density," for the sixth planned event, "Crash ahead."

Independent Variable	df	MS	F	p
Age	*1*	*98.5*	*8.09*	*0.014*
Density	*2*	*52.3*	*4.3*	*0.037*
Age*Density	2	23.1	1.90	0.189
S(Age Density)	13	12.17		

Table 28. Analysis of variance table for situational awareness dependent variable, "Time to Notice IVSAWS," and independent variables, "Age," and "Density" (using Low and High only), for the first planned event, "Car approaching from side street."

Independent Variable	df	MS	F	p
Age	1	0.083	0.33	0.580
Density	1	0.522	2.08	0.184
Age*Density	1	0.003	0.01	0.911
S(Age Density)	9	0.251		

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Table 29. Analysis of variance table for driving performance dependent variable, "Velocity," and independent variables, "Age," "Gender," and "Eye Position" (where driver was looking).

Independent Variable	df	MS	F	p
Age	1	14148	3.52	0.134
Gender	1	272	0.07	0.807
Age*Gender	1	924	0.23	0.657
S(Age Gender)	4	3642		
Eye Position	*3*	*9842*	*4.44*	*0.026*
Age*Eye Position	3	2820	1.27	0.328
Gender*Eye Position	3	1529	0.69	0.576
Age*Gender*Eye Position	3	2828	1.28	0.327
Eye Position*S(Age Gender)	8	2216		

Table 30. Analysis of variance table for driving performance dependent variable, "Velocity," and independent variables, "Age," "Gender," and "Baseline" (where time surrounding an event was divided into pre-event, during-event, and post-event windows).

Independent Variable	df	MS	F	p
Age	1	15105	5.48	0.079
Gender	1	240	0.09	0.783
Age*Gender	1	986	0.36	0.582
S(Age Gender)	4	2757		
Baseline	*2*	*22997*	*5.17*	*0.036*
Age*Baseline	2	1531	0.34	0.719
Gender*Baseline	2	1867	0.42	0.671
Age*Gender*Baseline	2	494	0.11	0.896
Baseline*S(Age Gender)	8	4445		

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