Development of Human Factors Guidelines for Advanced Traveler Information Systems and Commerical Vehicle Operations: Components of the Intelligent Transportation Systems: Designs Alternatives for In-Vehicle Information Displays

Publication No.: FHWA-RD-96-147 **October 1997**

U.S. Department of Transportation
Federal Highway Administration

Federal Highway Administration
Turner-Fairbank Highway Research Center
6300 Georgetown Pike, McLean, VA 22101

The original format of this document was an active HTML page(s). The Federal Highway Administration converted the HTML page(s) into an Adobe® Acrobat® PDF file to preserve and support reuse of the information it contained.

The intellectual content of this PDF is an authentic capture of the original HTML file. Hyperlinks and other functions of the HTML webpage may have been lost, and this version of the content may not fully work with screen reading software.

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). The contractual effort consists of three phases: analytic, empirical, and integration. This report is a product of the empirical phase. The empirical phase will also address topics such as: ATIS function transition, display channels, multi–modality displays, CVO driver fatigue, display formats and workload, and head–up displays. Among the analytic topics discussed in the series are a functional description of ATIS/CVO, comparable systems analysis, task analysis of ATIS/CVO functions, alternate systems analysis, identification and exploration of driver acceptance, and definition and prioritization of research studies.

This report describes an experimental examination of In–Vehicle Safety Advisory and Warning Systems (IVSAWS) and In–Vehicle Signing Information Systems (ISIS) characteristics and their effect on driver performance. The study examines the impact of display modality, message style, and display location on driver compliance with warning messages and driving safety.

A. George Ostensen, Director
Office of Safety and Traffic
Operations Research and Development

NOTICE

Technical Report Documentation Page

1. Report No. FHWA–RD–96–147	**2. Government Accession No.**	**3. Recipient's Catalog No.**
4. Title and Subtitle Advanced Traveler Information Systems and Commercial Vehicle Operations Components of the Intelligent Transportation Systems: Design Alternatives for In–Vehicle Information Displays		**5. Report Date** October 1997 **6. Performing Organization Code**
7. Author(s) J. D. Lee, S. Stone, B. F. Gore, C. Colton, J. Macauley, R. Kinghorn, J. L. Campbell, M. Finch, G. Jamieson		**8. Performing Organization Report No.**
9. Performing Organization Name and Address Battelle Human Factors Transportation Center 4000 NE 41st Street P.O. Box 5395 Seattle, WA 98105–0395		**10. Work Unit No. (TRAIS)** 3B2C1012 **11. Contract or Grant No.** DTFH61–92–C–00102
12. Sponsoring Agency Name and Address Office of Safety and Traffic Operations R&D Federal Highway Administration 6300 Georgetown Pike McLean, VA 22101–2296		**13. Type of Report and Period Covered** Technical Report April 1995 – August 1996 **14. Sponsoring Agency Code**
15. Supplementary Notes Contracting Officer's Technical Representative (COTR): Joe Moyer, HSR–30; Thomas Granda, SAIC		
16. Abstract This report describes the results of an experiment that examines the effect of Advanced Traveler Information Systems (ATIS) devices. Specifically, it examines how In–Vehicle Safety and Warning Systems (IVSAWS) and In–Vehicle Signing and Information Systems (ISIS) characteristics affect driver compliance with warning messages and driving safety.		

These characteristics include display modality, message style, and display location. A general issue facing ATIS designers is the concern that ATIS warning messages may go unheeded by drivers. Therefore, a critical element of ATIS design concerns is making information easily accessible and compelling so drivers comply with the warnings. The results show converging evidence that ATIS warnings can generate greater compliance compared to road signs. Another general issue that faces ATIS designers is the potential for ATIS devices to undermine driving safety. The results of this experiment show that ATIS devices can undermine driving safety by fostering an overreliance on ATIS information. The results also show how particular ATIS design characteristics can minimize the overreliance and its negative effects on driving safety.			
17. Key Words ATIS, ISIS, ITS, IVSAWS, warning compliance, driving safety.		**18. Distribution Statement** No restrictions. This document is available to the public through the National Technical Information Service, Springfield, Virginia, 22161.	
19. Security Classif. (of this report) Unclassified	**20. Security Classif. (of this page)** Unclassified	**21. No. of Pages** 86	**22. Price**

Form DOT F 1700.7 (8-72)

Table of Contents

List of Figures

List of Tables

List of Acronyms

ATIS Advanced Traveler Information Systems

BAS Battelle Automobile Simulator

BMDP Bio–Medical Data Processing

CRT Cathode Ray Tube

CVO Commercial Vehicle Operations

EL Electroluminescent

HOV High–Occupancy Vehicle

HUD Head–Up Display

ISIS In–Vehicle Signing Information Systems

IVSAWS In–Vehicle Safety Advisory and Warning Systems

LCD Liquid Crystal Display

RMS Root Mean Square

SA Situational Awareness

SAGAT Situation Awareness Global Assessment Technique

SD Standard Deviation

STI Systems Technology, Inc.

EXECUTIVE SUMMARY

While the technical capability exists to display In–Vehicle Signing Information Systems (ISIS) and In–Vehicle Safety Advisory and Warning Systems (IVSAWS) information in a variety of ways, little human factors research exists to guide the selection of a preferred display design from among the range of potential design alternatives. Key human factors considerations associated with selecting Advanced Traveler Information Systems (ATIS) display alternatives include the accessibility, legibility, and understandability of ATIS information; the potential for ATIS information to facilitate driver decision–making; and the potential for ATIS information to distract the driver from the primary task of controlling the vehicle. A wide range of display design parameters are relevant to these human factors considerations as well. This experiment examines the effect of display modality, message style, and display location on driver compliance with warnings and driving safety. These design parameters must also be considered in the context of characteristics of the driving population (i.e., age and gender) and the environment (i.e., existing ATIS and road–sign infrastructure).

In this experiment, ATIS warning messages were presented to drivers using a low–fidelity automotive simulator equipped with an easily reconfigurable ATIS. The simulator is equipped so that ATIS messages can be presented visually, through liquid crystal display (LCD) panels, or auditorially through speakers. The visual scene can also be controlled to present drivers with roadway information in a form similar to the changeable–message signs found on many highways.

Driving safety and compliance with warning messages were estimated directly with several measures. In addition, several intervening variables were measured to provide a deeper understanding of the cognitive processes that mediate the effect of ATIS design characteristics on driver behavior, given particular driver and roadway characteristics.

A general issue facing ATIS designers is the concern that ATIS warning messages may go unheeded by drivers. A critical element of ATIS design concerns is to make information easily accessible and compelling so the drivers comply with the warnings. The results show converging evidence that ATIS warnings can generate a greater compliance compared to road signs; however, they may adversely affect trust and self–confidence. Certain ATIS designs may place drivers in a double–bind situation where they do not trust the ATIS, but they also feel that they cannot gather the required information themselves. This double bind may lead to dissatisfaction with the ATIS. The results also show that ATIS design characteristics can be manipulated to affect the level of driver compliance.

Another general issue that faces ATIS designers is its potential to undermine driving safety. Based on the information processing and mental workload paradigm, many have suggested that an improperly designed ATIS device could jeopardize driving safety by overloading drivers. Multiple–resource theory predicts this will be particularly critical for devices that force drivers to share their visual resource between reading ATIS warnings and the driving task. This investigation hypothesized another safety concern. An improperly designed ATIS device might jeopardize safety by leading drivers to favor in–vehicle information sources and ignore critical roadway information. The results of this experiment show that ATIS devices can undermine driver performance by fostering an overreliance on ATIS information. Their effects on workload, situational awareness, and driving safety measures all support this assertion. The results also show that ATIS design characteristics can exacerbate the overreliance and its negative effects on driving safety.

Not surprisingly, driver age emerged as an important variable that moderates the effectiveness of the ATIS. Although the overall driving performance of older drivers was worse than that of younger drivers, the presentation of ATIS messages had a less pronounced negative impact on safety for the older drivers than for the younger drivers. In addition, older drivers seem more likely to trust the capabilities of the ATIS, particularly when it is not entirely reliable.

Gender interacted with driver age and message style to influence the effectiveness of ATIS messages. Similar results for several dependent variables suggest that younger women assimilate ATIS notification messages more effectively than command messages. The opposite is true for older women, who assimilate command messages more effectively. For example, older women perceived less mental effort with command messages such as "Merge left," compared to younger women, who perceived less mental effort for notification messages such as "Accident ahead in right lane." In general, men assimilate notification messages more easily than command messages. These results show that complex sociological trends might complicate the design of ATIS devices.

An important design implication concerns the implementation of ATIS devices relative to the infrastructure of standard and changeable–message road signs. Providing drivers with only ATIS information leads to a high level of compliance, but it can also compromise safety. Providing ATIS information with redundant road–sign information generates a high level of compliance without the associated decline in safety.

Message style (command versus notification messages) emerged as a critical ATIS design characteristic, influencing both compliance and safety. Although message style has not been widely studied, results suggest that it has a more powerful effect on driver behavior than more commonly studied characteristics, such as display modality. Results of this study show that command messages promote greater compliance, but they reduce safety. Given the consequences for safety and compliance, command messages should be reserved for situations where an immediate and rapid response is required to preserve driver safety. This is particularly true for situations where redundant roadway information is not available.

CHAPTER 1. INTRODUCTION

Advanced Traveler Information Systems (ATIS) are intended to provide travelers with real–time information on traffic and roadway conditions, vehicle navigation, roadway hazards, weather conditions, and motorist services. In–Vehicle Signing Information Systems (ISIS) and In–Vehicle Safety Advisory and Warning Systems (IVSAWS) are key components of the broader ATIS program, and have the potential to provide drivers with a wide variety of information via an in–vehicle display. ISIS is intended to provide drivers with information that is currently depicted on external roadway signs, such as non–commercial routing, warning, regulatory, and notification information (McCallum, Lee, Sanquist, & Wheeler, 1995). IVSAWS is intended to warn drivers of hazardous or unsafe conditions on the roadway ahead, including accidents, construction zones, and the presence of emergency vehicles (Erlichman, 1992).

While the technical capability exists to display ISIS and IVSAWS information in a variety of ways, little human factors research exists to guide the selection of a preferred display design from among the range of potential design alternatives. Key human factors considerations associated with selecting ATIS display alternatives include the accessibility, legibility, and understandability of ATIS information; the potential for ATIS information to facilitate driver decision–making; and the potential for ATIS information to distract the driver from the primary task of controlling the vehicle. A wide range of display design parameters are relevant to these human factors considerations. These design parameters must also be considered in the context of characteristics of the driving population and the environment. Driver characteristics include age and gender, and environmental characteristics include the existing ATIS and road–sign infrastructure. Figure 1 shows how driver attitudes and information–processing capabilities mediate the effect of ATIS design characteristics on driving safety and warning compliance. This figure also shows the range of variables selected for investigation. The general categories of ATIS design and driving context include only a few of the many possible variables. ATIS availability has been included as a design characteristic and as part of the driving context. ATIS availability can depend on design decisions and it may also depend on the roadway infrastructure.

In this study, we examine the effect of message style, the physical grouping or location of ATIS displays, the use of visual as opposed to auditory messages, the availability of the ISIS and IVSAWS information presented through an ATIS, and the availability of roadway information. This study will investigate how these factors affect driver compliance with warning messages, and whether particular ATIS message characteristics degrade driving safety.

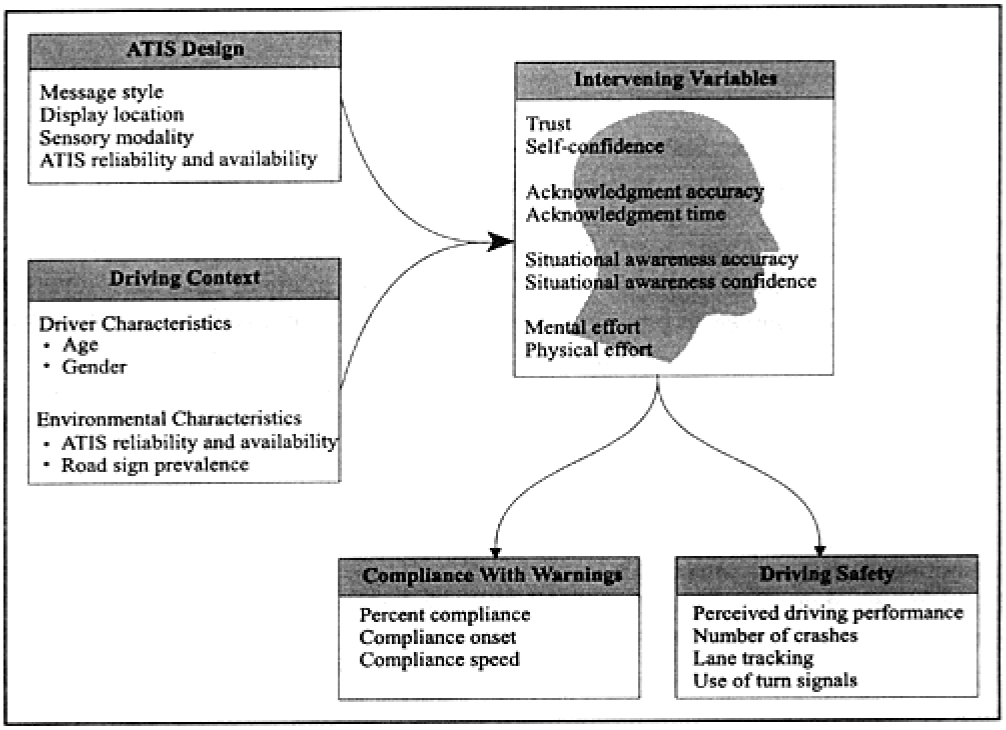


Figure 1. Factors moderating the effect of ATIS design characteristics on driving safety and warning compliance.

MESSAGE STYLE

One way to describe message style is by the degree to which it directs a driver to perform a specific action. At one extreme, messages might simply advise drivers of a particular roadway condition (e.g., "Icy Road Ahead"). At the other extreme, messages might command drivers to take specific actions in response to the condition (e.g., "Slow Down"). In the context of this discussion, we will refer to the endpoints of this dimension of ISIS and IVSAWS message design as the distinction between *notification* and *command* warning information. Notification information advises the driver of a particular condition, although the driver still maintains complete autonomy with respect to both interpreting the condition and deciding how to respond to it. Alternatively, command information suggests a course of action to the driver that if not followed, could adversely affect the driver. Giving information in the form of commands might require some automated integration of information. Such a system would evaluate existing roadway conditions, real–time traffic data, and vehicle data, and suggest an appropriate action to the human driver, although the driver is still free to either adopt or ignore the suggestion (see also Sheridan, 1982). While command information can reduce certain information–processing requirements of the driving task (e.g., perception of relevant information, integration of multiple sources of driving information, and complex decision–making), it also has the potential to misdirect drivers when the command fails to consider all the relevant factors, for example, a command to change lanes when the lane is occupied by another car.

Although message style has not been investigated empirically in the context of the driving task, studies in other domains have examined similar questions. For example, researchers have investigated the effects of mothers' message styles (directive or suggestive) on children's compliance. Suggestive styles have been found to lead to higher compliance in normal children (Crockenberg & Litman, 1990; Lytton, 1977; Rocissano, Slade, & Lynch, 1987), although the reverse is true for children with Down's Syndrome (Landry & Chapieski, 1989; Landry, Garner, Pirie, & Swank, 1994; Maurer & Sherrod, 1987). Extrapolating this result to the driving context suggests that notification information might induce greater compliance.

Research on the effect of directive and non–directive leadership style on performance and compliance is extensive. Generally, a directive style of leadership has been found to increase compliance (Lippitt, 1940), but reduce both group performance and satisfaction (Brollier, 1984; Hendrix & McNichols, 1982; Miller & Monge, 1986), especially when measured in field, as opposed to laboratory, studies. Simpler tasks (which are more common in the laboratory) are frequently performed better under directive leadership, while more complex tasks are best performed under a more democratic style (Becker & Baloff, 1969; Rudin, 1964). A less directive style seems to lead to better performance with highly anxious subjects (Misumi & Peterson, 1985). Extrapolating these results to the current study suggests that the command style would promote compliance, but that it might undermine driving safety and the driver's satisfaction and trust in the system.

The effectiveness of authoritarian leadership seems to be related to the amount of knowledge possessed by the leader. If the autocratic leader knows more than the other members of the team, authoritarian leadership leads to the most effective performance. If, however, the authoritarian leader knows less, or is given misinformation, the team will do much worse than if led by a less knowledgeable or misinformed democratic leader (Blyth, 1987; Cammalleri, Hendrick, Pittman, Blout, & Prather, 1973; Fiedler & Garcia, 1987; Shackleton, Bass, & Allison, 1975). This suggests a notification style for unreliable systems, or for messages that require interpretation and integration with other information sources.

Given the complexities and uncertainties associated with extrapolating these findings to ATIS design, it is difficult to draw firm conclusions. However, these findings suggest that a command style would promote greater compliance as compared to a notification message style. These benefits might be outweighed if drivers follow the ATIS commands blindly and ignore important roadway information. Thus, we might expect a trade–off for compliance and safety. This study will directly examine the differences in these two message styles and their effect on driver safety and warning compliance.

DISPLAY LOCATION

Another important dimension of ISIS and IVSAWS message design is the physical grouping or location of displays and displayed information. At one extreme, ISIS and IVSAWS information might be centralized on a single cathode ray tube (CRT) screen. At the other extreme, ISIS and IVSAWS information might be distributed across several locations using several display modalities (e.g., head–down instrument panel, center–mounted CRT, and head–up display (HUD)). For auditory displays, a centralized approach might refer to the concurrent use of all speakers in the vehicle, while a distributed approach might use individual speakers to localize sound and provide directional cues.

In the context of our discussion here, we will refer to this dimension of ISIS and IVSAWS message design as the distinction between *centralized* and *distributed* warning information. The literature on attention and time–sharing do not provide unequivocal guidance on the relative merits of a centralized versus a distributed approach. At issue is which approach to the display location makes the most effective use of available attentional resources and supports the most efficient time–sharing between assimilating warning information and the primary task of driving.

In this regard, the centralized display option may be a somewhat simpler and more parsimonious approach because it reduces driver requirements to attend and visually scan more than a single in–vehicle display. Specifically, attentional resources associated with instrument scanning can be focused on a single display, rather than "spread out" across numerous displays. There is some support for this approach in the literature. For example, Shaw (1984) reported that signal detection performance for simple stimuli decreases as the number of display locations increases. Similarly, Konrad, Kramer, and Watson (1994) compared multiple displays to a single sequential display using a simple monitoring task. They found that both response time and response accuracy performance were better with the single (centralized) display. Also, a centralized approach may address the tendency of people to engage in less–than–optimal scanning strategies when multiple displays must be monitored (Moray, 1981).

In contrast, a distributed display could use display location as an alternate code to the urgency or type of the displayed information. Thus, the location of the information can serve as a cue that may reduce processing time and aid driver interpretation, decision–making, and response associated with the information. For example, information requiring an immediate response from the driver can be presented on a HUD (which generally minimizes eye and head movement requirements), while less urgent information can be presented on one or more head–down CRTs. Although poor time–sharing will take place if the spatial separation across displays is too great (Wickens, 1984), the fixed and consistent nature of distributed displays may lead to parallel processing of visual information (Schneider & Shiffrin, 1977), resulting in automatic processing of the different information sources.

In sum, both the centralized and the distributed approach are associated with a number of theoretical and operational trade–offs. The centralized approach may be more effective with relatively simple stimuli and responses, and minimizes the number of displays that must be attended to by the driver. The distributed approach may be more effective with more complex tasks involving real–world decisions and demanding psychomotor responses. The distributed approach also uses display location as a redundant code to facilitate the interpretation of displayed information.

SENSORY MODALITY

For many travel–related information displays (e.g., speed–limit signs and traffic signals), designers have little choice regarding the sensory modality used to convey the information. However, with ATIS information, designers have the option of using either auditory or visual displays to present ISIS and IVSAWS information. From the perspective of driver acceptance and performance, the most effective display modality is not always obvious and there are a number of design trade–offs and considerations associated with auditory and visual displays. The auditory channel can have an advantage over the visual channel due to its attention–getting qualities (McCormick & Sanders, 1982). In addition, auditory messages are an attractive option since driving already places high visual demands on drivers. The use of auditory messages might allow better time–sharing of limited processing resources, i.e., time–sharing between two sensory resources may be superior to sharing within a single resource (Wickens, 1984). However, the visual channel is the more traditional mode for the presentation of driving information, is associated with relatively higher information rates (Sorkin, 1987) than the auditory channel, and is less likely to startle the driver than auditory messages. While components of sounds such as speed, fundamental frequency, repetition units, and inharmonicity have been successfully manipulated to vary the perceived urgency of sounds (Hellier, Edworthy, & Dennis, 1993), relative urgency is but one component of ISIS and IVSAWS messages that auditory displays will need to communicate to drivers. The relative salience and urgency that can be conveyed by an auditory message may depend on message style and the dimension of directiveness. Command messages may be more compelling when delivered in an auditory, rather than a visual, format. Another concern with auditory displays is that they are frequently disabled by users due to an increase in frustration and subjective workload (King & Corso, 1993).

Although the selection of auditory versus visual displays depends upon a number of situation–specific variables, Deatherage (1972, p. 124) has provided general guidelines for selecting sensory modalities. These guidelines are presented in table 1. This table demonstrates the uncertainty regarding the most appropriate use of auditory and visual displays for ISIS and IVSAWS information. Either the exact nature of the ISIS/IVSAWS message is unclear (e.g., does it call for immediate action?), or the guideline is ambiguous (e.g., what if the message deals with both events in time and location in space?). Although table 1 does not provide a definitive answer, its guidelines suggest that an auditory display may be best suited to ISIS/IVSAWS information. This study will investigate this option directly.

Table 1. General guidelines for the selection of auditory versus visual forms of information presentation (Deatherage, 1972).

Use Auditory Presentation If:	Use Visual Presentation If:
1. The message is simple	1. The message is complex
2. The message is short	2. The message is long
3. The message will not be referred to later	3. The message will be referred to later
4. The message deals with events in time	4. The message deals with location in space
5. The message calls for immediate action	5. The message does not call for immediate action
6. The visual system of the person is overburdened	6. The auditory system of the person is overburdened
7. The receiving location is too bright or dark-adaptation integrity is necessary	7. The receiving location is too noisy
8. The person's job requires him to move about continually	8. The person's job allows him to remain in one position

ATIS AND ROADWAY INFORMATION AVAILABILITY

Related to these display design issues is the availability of the ATIS and roadway information and the corresponding level of trust that the driver places in this information. ATIS information cannot be assumed to be consistently available, especially during initial implementation of ATIS. ATIS information may be inaccurate or non–existent. When ATIS information is not readily available, drivers may ignore the ATIS and use roadway or other information to guide their decisions. If driver trust in the system is low due to the lack of ATIS information associated with past experience, drivers may spend additional time verifying the accuracy of the information. In general, users are reluctant to rely upon equipment that they do not trust (Lee & Moray, 1992).

As ATIS becomes more widespread, drivers may encounter ATIS messages paired with redundant roadway information, roadway signs alone, and ATIS messages alone. In these situations, the driver must adapt his or her own knowledge of the roadway situation and available signage to the information provided by the ATIS and act accordingly. While chronic ATIS failures may lead drivers to disregard ATIS completely, intermittent failures will require drivers to adapt to the availability of ATIS information, following the ATIS when available and using roadway information otherwise. An ATIS that provides warning information intermittently may also undermine drivers' trust. This effect may depend on the message style. Command messages will be more useful to drivers and will be associated with higher levels of driver trust and acceptance when ATIS information is consistently available. With command messages, drivers are not given the underlying reason for the warning, while notification messages describe the situation and provide drivers with a better basis for making a decision if the information is unreliable. Thus, the command message style may be most appropriate for high levels of information availability, while the notification message style may be appropriate for lower levels of information availability.

Drivers using ATIS will be required to adapt their sampling of roadway and ATIS information as the availability of ATIS and roadway information varies. Trust in the ATIS and self–confidence are likely to be important factors mediating their sampling strategy (Lee & Moray, 1992). Factors such as the amount of driving experience and the costs associated with the missing information will affect this decision. For example, if the ATIS system does not display the speed limit of a section of highway that has been raised from 35 to 45 mi/h (56.3 to 72.4 km/h), the cost of the missing information is relatively low. However, if we reverse the situation, with the system not having the information that the speed limit has been reduced from 45 to 35 mi/h (72.4 to 56.3 km/h), the cost may be higher. That is, the driver may be driving at a speed that is unsafe for that section of highway and may risk getting a costly speeding ticket. This experiment will examine how drivers' trust in the ATIS interacts with their self–confidence to influence compliance with ATIS messages.

The redundancy of ATIS and roadway information is an important consideration for ATIS implementation. One option for ATIS implementation is to present ATIS messages without corresponding roadway messages such as changeable–message signs. Another option is to augment signs with redundant in–vehicle messages. Redundant information might enhance driver compliance with the warnings, but it might also overload the driver with too much information. The redundancy of ATIS and roadway information, and the associated information processing load, may depend on ATIS message style (notification versus command), display locations (centralized versus distributed), and sensory modality (auditory versus visual).

Considering different levels of ATIS and roadway infrastructure development, the three dimensions of ATIS display design generates four issues of particular importance: (1) the effect of notification versus command message style on compliance and driving performance, (2) the effect of centralized versus distributed display location on compliance and driving performance, (3) the effect of auditory versus visual ISIS and IVSAWS information on compliance and driving performance, and (4) the interaction of these issues in the context of potentially unavailable ATIS information and/or unavailable roadway information. ATIS information must facilitate rapid and accurate response; however, it must not degrade driving safety by interfering with drivers' ability to consider roadway information.

OBJECTIVES AND HYPOTHESES OF THIS STUDY

The overall objective of this study is to develop general guidelines for addressing ISIS/IVSAWS displays. This study examines three important dimensions of ISIS and IVSAWS design: message style (notification versus command), display location (centralized versus distributed), and sensory modality (auditory versus visual). In the context of inaccurate information from the roadway and the ATIS, the study examines how these dimensions affect drivers' ability to comprehend ISIS and IVSAWS information and combine it with roadway information to make appropriate decisions.

This experiment investigates how ATIS design characteristics combine with environmental and driver characteristics to influence compliance with warning messages and driving safety. In general, ATIS messages should enhance drivers' reaction to roadway events by encouraging greater speed reductions and faster lane changes. Furthermore, certain ATIS message formats may be more effective than others. While ATIS messages may encourage faster and more effective responses to roadway hazards, they may degrade driving safety. ATIS messages may degrade driving safety by overloading drivers. Alternatively, ATIS messages may encourage overreliance on the ATIS and draw a driver's attention into the vehicle and away from the roadway. The aim of this experiment is to identify the relationship between ATIS design characteristics, message compliance, and driving safety.

To examine the effect of different ATIS design characteristics on warning compliance and driving safety, several dependent measures were collected. In addition, this experiment examines several intervening variables to better understand the cognitive processes underlying the influence of ATIS designs on safety and compliance. Trust and self–confidence have been shown to underlie reliance on automation and information systems (Lee & Moray, 1992; Lee & Moray, 1994). Factors influencing trust and self–confidence are likely to influence compliance with ATIS warnings. Similarly, situational awareness, workload, and information assimilation measures should reflect the factors underlying how ATIS messages might compromise driving safety. Specifically, measures of workload should reflect the information overload that might accompany the additional information provided by the ATIS. Situational awareness and message acknowledgment should indicate whether ATIS draws attention away from the roadway. These considerations are reflected in a series of general hypotheses and a set of more specific hypotheses. The general hypotheses include:

- ATIS messages will encourage greater compliance with warnings.
- ATIS messages will degrade driving safety through information overload or by drawing drivers' attention away from the roadway into the vehicle.
- Manipulating ATIS design characteristics will generate a trade–off between warning compliance and driving safety.

The following specific hypotheses guided the analysis:

WARNING COMPLIANCE

- Presenting ATIS messages will promote higher compliance.
- The command message style will promote higher compliance.
- Auditory messages will promote greater compliance.
- Mode and style will interact to promote the highest level of compliance for auditory command messages.

DRIVING SAFETY

- The presence of ATIS information will reduce drivers' attention to roadway information.
- The presence of ATIS information will overload the driver.
- The command message style will promote overreliance on the ATIS and draw attention away from the roadway.
- Auditory information will promote overreliance and draw attention away from the roadway, while text messages will tend to overload the driver.
- Mode and style will interact to induce the lowest level of safety for auditory command messages, depending on whether the ATIS tends to overload or distract the driver.

TRUST IN ATIS AND SELF–CONFIDENCE

- Trust will be enhanced when ATIS information is available and self–confidence will be enhanced when roadway information is available.
- Trust in ATIS systems with the command message style will be fragile and will drop more when ATIS information is missing, compared to the notification message style.
- Self–confidence will be greatest with notification message styles.
- Self–confidence will be more robust with the notification message style and it will drop less when ATIS information is missing.

SITUATIONAL AWARENESS, WORKLOAD, AND INFORMATION ASSIMILATION

- Situational awareness will decline as drivers' attention is drawn into the vehicle when they receive only ATIS information without redundant road signs.
- The text–based ATIS messages will increase workload.
- Redundant sign information will increase driver workload.
- Auditory messages will capture attention, resulting in shorter latencies for message acknowledgment.
- Centralized displays will facilitate information assimilation, as indicated by shorter latencies for message acknowledgment.

Beyond these specific hypotheses, figure 2 provides a general framework for approaching the analyses. This figure places the dependent variables in a context that shows the relationship among dependent variables and between the independent and dependent variables. This figure highlights the four primary analyses. The hypotheses provide a starting point for each analysis and this figure provides a framework for considering the more exploratory data analyses.

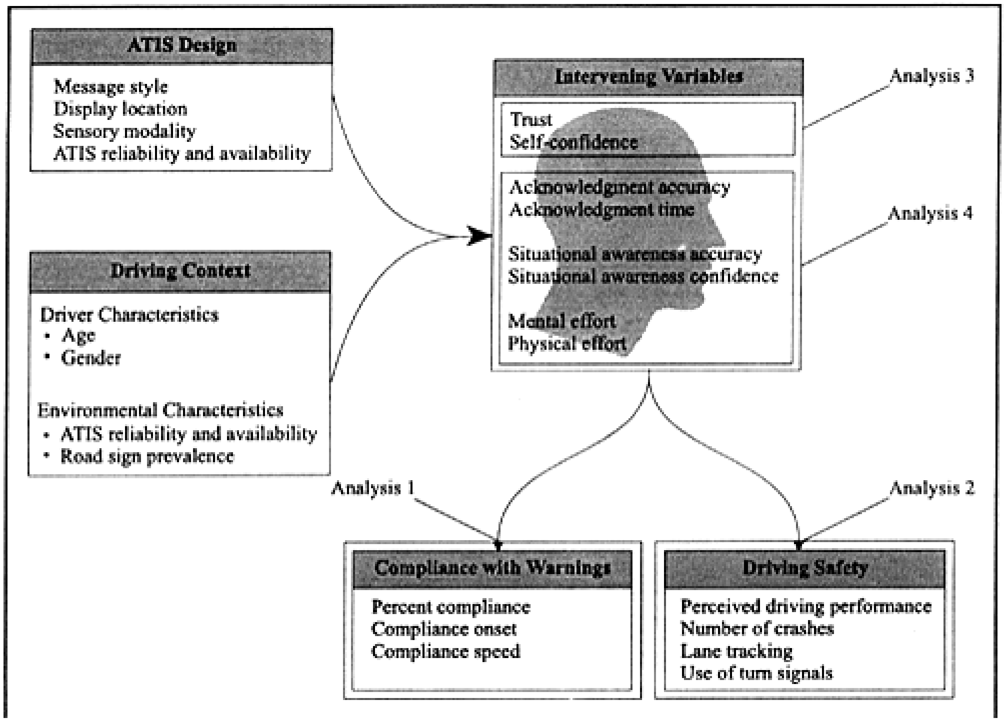


Figure 2. The relationship between the independent and dependent variables and the focus of the data analysis.

CHAPTER 2. METHOD

This experiment examined the effect of ATIS message characteristics and availability of ATIS and roadway information on driving safety and compliance. ATIS warning messages were presented to drivers using a low–fidelity automotive simulator equipped with an easily reconfigurable ATIS. The vehicle was equipped so that ATIS messages could be presented visually, through liquid crystal display (LCD) panels, or auditorially through speakers. The visual scene of the simulation could also be controlled to present drivers with roadway information in a form similar to the changeable–message signs found on many highways.

Driving safety and compliance with warning messages were estimated directly with several measures. In addition, several intervening variables were measured to provide a deeper understanding of cognitive processes that mediate the effect of ATIS design characteristics on driver behavior, given particular driver and roadway characteristics.

SUBJECTS

Sixteen male and sixteen female subjects participated in this experiment for a total of 32 subjects. Eight male and eight female subjects were under the age of 30, with ages ranging from 18 to 29 (mean (M) = 22.4, standard deviation (SD) = 3.3). Eight male and eight female subjects were over the age of 64, with ages ranging from 66 to 83 (M = 74.4, SD = 4.7). All subjects had a valid driver's license, drove at least twice per week, and had no problems with motion sickness. Younger drivers were recruited from the University of Washington, while older drivers were recruited from local church, volunteer, and retirement groups. Each driver was paid $5 per hour, for approximately 3 hours of research time.

APPARATUS

Driver behavior was investigated using the Battelle Automobile Simulator (BAS). The major components of the simulator include: (1) the automobile test buck, (2) the simulation software, and (3) the simulated ATIS.

Automobile Test Buck

The buck was constructed using a 1986 Ford Merkur XR4Ti automobile. The original side and top body work, from 12 in (30.5 cm) in front of the firewall to 20 in (50.8 cm) behind the driver's seat, have been maintained to preserve the feel of a real automobile. The dash of the automobile has been modified to allow multiple configurations, including combinations of active matrix LCD touchscreens and electroluminescent (EL) displays, and a completely analog instrument panel. The configuration used in this experiment replaced the standard instrument panel with electroluminescent displays. A small fan was also included in the instrument panel to provide air circulation to the driver. The steering column is that of the Merkur with no modifications. The steering wheel has been modified to include a push–button switch on each side of the wheel at approximately 130 and 240 degrees. The steering shaft is also connected to a torque motor that produces accurate roadway feedback to the driver. Interior lights are located in the center of the vehicle's roof near the front windshield and can be aimed by the driver as needed. The rear of the vehicle is open to allow access to the rear speakers. Both doors are operational and have side–view mirrors. The buck also has adjustable driver and passenger seats.

The front "windshield" is completely enclosed. The left side of the windshield houses a 20–in (50.8–cm) MultiSync color monitor providing a simulated roadway display for the various driving scenarios. The monitor is covered with a black wooden hood and the right side of the windshield is covered with a black piece of plastic to reduce the ambient background lighting.

Simulation Software

A closed–loop, low–fidelity driving simulator developed by Systems Technology, Inc. (STI) (Version 8.01) was used for the experiment. Running on an IBM–compatible computer, the simulator produced visual scenes and sound relevant to driving. The fully interactive STI simulator includes the following features: five–speed automatic transmission, variable vehicle dynamics, simulated road noise (engine and drive train), tire squeal to signal loss of control on high–speed turns, and wire–framed rendering of displayed objects. The simulation updates visual scenes at approximately 10 to 20 Hz, providing relatively smooth apparent motion. The STI software allows for full driver interaction; the driver is able to steer, change lanes, accelerate, and brake. For this experiment, the vehicle dynamics were adjusted to represent a typical passenger vehicle.

Simulated ATIS

The BAS has a range of display alternatives to simulate many potential ATIS designs. Messages were displayed on one of two in–vehicle EL displays or auditorially through a speaker system. The viewing area of the EL display was 4.8 in (12.2 cm) by 7.0 in (17.8 cm). Messages can also be transmitted through a pair of speakers located behind the driver on either side of the vehicle.

In addition, BAS has the capability to present various questions to the drivers. This capability was used to collect situational awareness (SA) measures and subjective estimates, such as trust and self–confidence. Questions were displayed on a 9.4 inch (23.9 cm) diagonal Active Matrix Color LCD display. This display was centered on the transmission channel of the vehicle. The LCD display was a touchscreen and so subjects could answer questions by making selections from choices presented on the display. The touchscreen used resistive technology with a serial controller. The displays were driven by a 486–based computer that was interlinked with the simulation computer using a digital input/output card.

EXPERIMENTAL DESIGN

The experiment was a 2x2x2x2x2x4 mixed factorial design. Table 2 shows the within–subjects variables distributed in a Latin square design. The experiment considered three dimensions of ATIS design: (1) display location (centralized versus distributed), which was a between–subjects variable, (2) message style of ATIS information (command versus notification), which was a within–subjects variable, and (3) mode of presentation (auditory versus visual), which was a within–subjects variable. The order of these variables was counterbalanced in a Latin square design. Each row in table 2 represents the experimental conditions that a driver experiences. Each driver experiences 16 scenarios and, during each scenario, 4 roadway events occur. The letters and numbers represent levels of independent variables.

Table 2. The combination of events within–subjects variables in a Latin square design.

Scenario 1–4	Scenario 5–8	Scenario 9–12	Scenario 13–16
Tc_{1234}	Tn_{1234}	An_{1234}	Ac_{1234}
Tn_{1234}	Tc_{1234}	Ac_{1234}	An_{1234}
An_{1234}	Ac_{1234}	Tn_{1234}	Tc_{1234}
Ac_{1234}	An_{1234}	Tc_{1234}	Tn_{1234}
T = Text display modality; A = Auditory display modality; c = Command message style; n = Notification message style; 1 = ATIS and roadway information; 2 = Only ATIS information; 3 = Only roadway information; 4 = Neither roadway nor ATIS information.			

Each line represents a series of 16 scenarios with each scenario representing a separate experimental condition. A scenario is defined as a sequence of four driving events lasting approximately 6 min. A driving event is defined as a circumstance that requires a driver decision and action. When ATIS information is available, drivers are notified of the upcoming events by ATIS warning messages. Each subject experienced 16 scenarios. The design was constructed so that each set of 16 scenarios was experienced by 4 subjects: 1 young male, 1 older male, 1 young female, and 1 older female. This pattern of experimental conditions was replicated so that 16 drivers experienced the scenarios in table 2 with a centralized display and 16 drivers experienced these conditions with a distributed display.

Independent Variables

Table 3 summarizes the independent variables examined in this experiment. The independent variables included the availability of roadway and ATIS information, display location, message style, display modality, and driver age. The availability of information was a within–subjects variable with four different levels: (1) ATIS and roadway information, (2) ATIS information only, (3) roadway information only, and (4) neither. Roadway information was presented as a changeable–message sign in a style that matches most standard warning signs. The style of all the roadway signs is similar to the notification style for the ATIS messages. During a scenario with the information availability condition "ATIS and roadway information," drivers receive four ATIS messages and see four changeable–message signs, one for each roadway event they encounter. During the "ATIS only" condition, drivers receive four ATIS messages and see only one changeable–message sign. During the "Roadway only" condition, drivers receive only one ATIS message and see four changeable–message signs. During the "Neither" condition, drivers receive only one ATIS message and see only one changeable–message sign. In the "Neither" condition, drivers encounter two events without any warning, they receive an ATIS message for one, and they see a changeable–message sign for the remaining event. This was done to mimic the fact that a completely unreliable ATIS or road–sign system is not realistic. Table 3 summarizes the independent variables.

Table 3. Independent variables included in the experiment.

Variable	Type	Levels
Age	Between	Under 30, 65 and over
Gender	Between	Male, Female
Display Location	Between	Centralized, Distributed
Message Style	Within	Command, Notification
Message Modality	Within	Visual Text, Auditory
Information Availability	Within	Both ATIS and Roadway, ATIS only, Roadway only, and Neither

For each scenario, drivers experienced a random selection of four of the events shown in table 3. Table 4 shows the ATIS warnings for each of six different events. Depending on the experimental condition, drivers received a message from table 1 either as a command or as a notification message, formatted as an auditory or visual warning.

Table 4. ATIS warnings for each of six different events.

Event	ATIS Messages
1. Curve	Reduce speed (Command) Curve ahead (Notification)
2. Crosswalk	Reduce speed (Command) Pedestrian crossing (Notification)
3. Icy roadway	Reduce speed (Command) Icy roadway (Notification)
4. Road construction	Merge left (Command) Lane closed for construction (Notification)
5. Accident in lane	Merge left (Command) Lane blocked by accident (Notification)
6. High-Occupancy Vehicle (HOV) lane	Merge left (Command) HOV lane ahead (Notification)

Dependent Variables

This experiment collected data on two types of dependent measures. One type included direct measures of driving safety and compliance with warnings. The other type included intervening variables that may illuminate the cognitive processes that influence the direct measures of compliance and driving performance. The intervening dependent variables measured drivers' attitudes, situational awareness, and message acknowledgment.

Drivers' attitudes were measured by subjective ratings given at the end of each scenario. Subjective scales measured drivers' attitudes, including: (1) trust in the ATIS system to identify and notify them of roadway events and hazards, (2) self–confidence in their ability to accurately identify roadway conditions and hazards, (3) mental effort, (4) physical effort, and (5) perceived driving performance. Mental and physical effort were included to estimate the influence of display characteristics on driver workload. The scales were presented on a touchscreen display at the end of each 6–min trial.

Subjects' situational awareness was measured once during each scenario using the Situation Awareness Global Assessment Technique (SAGAT) (Endsley, 1995a). Situation awareness has been defined by Endsley (1995a, p. 36) as "the perception of the elements in the environment within a volume of time and space, the comprehension of their meaning, and the projection of their status in the near future." SAGAT has been studied extensively and has proven to be a valid and effective measure of SA (Endsley, 1995b). Using this technique, the simulation was "frozen" while the subjects responded to the questions. Examples of questions include: "What is your current speed?," "What product was the last billboard advertising?," "In the next 30 seconds, which action will you perform?" For each question, the drivers' were given two choices from which to select their answer (forced choice). Four questions were randomly drawn for each query from a pool of 14 questions (see appendix C for a complete list). After each question, subjects rated their confidence in their answer on a 0–100 scale. Each situation awareness query contained four questions and was presented once in each 6–min trial.

Drivers were asked to acknowledge each ATIS and roadway warning by pressing a steering–wheel button. Drivers used the button on one side of the steering wheel to acknowledge ATIS messages and the button on the other side to acknowledge roadway signs. The acknowledgment latency and accuracy were measured to estimate the focus of the drivers' attention. If drivers focus attention on the ATIS, then acknowledgment latency and accuracy should favor the ATIS acknowledgment. The acknowledgment side was counterbalanced to guard against any right/left bias. To avoid learning effects, acknowledgment side was introduced as a between–subjects variable.

Measures of driving safety included:

- Lane position (root mean square (RMS) deviation from lane and center line).
- Speed control (RMS speed).
- Number of crashes per hour.
- Use of turn signals.

These measures began 5 s before the time that the drivers received the ATIS message or roadway information and lasted until 5 s after the event had ended. For driving performance, lane position, speed, brake and accelerator actuation, turn–signal actuation, steering–wheel use, and crashes were all collected during this time. The purpose of collecting these data was to determine how ATIS messages might distract from the primary task of driving.

For this study, warning compliance has been defined as the degree to which drivers correctly respond to messages. For example, drivers who move to the left lane after a message instructing them to merge left would have a higher level of compliance compared to a driver who fails to comply with the message and stays in the right lane. Similarly, if a driver slows from 45 to 25 mi/h (72.4 to 40.2 km/h), compliance would be greater than one who remains at 45 mi/h (72.4 km/h). Complete compliance with the warning is rated at 100 percent. It is possible to be more than 100 percent compliant, such as when a driver swerves to the far side of the left lane to avoid an accident in the right lane.

Figure 3 shows several measures of compliance. The analysis addressed three measures of compliance. The first measure is the time to 10 percent of maximum compliance, shown on the left side of figure 3. The second measure reflects how quickly compliance increases and is labeled rise time. Rise time is the time it takes compliance to change from 10 percent of maximum compliance to 90 percent of maximum compliance. The third measure of compliance, known as integrated compliance, represents the area under the curve in figure 3. It is calculated by numerically integrating the level of compliance from the onset of the message to the end of the event.

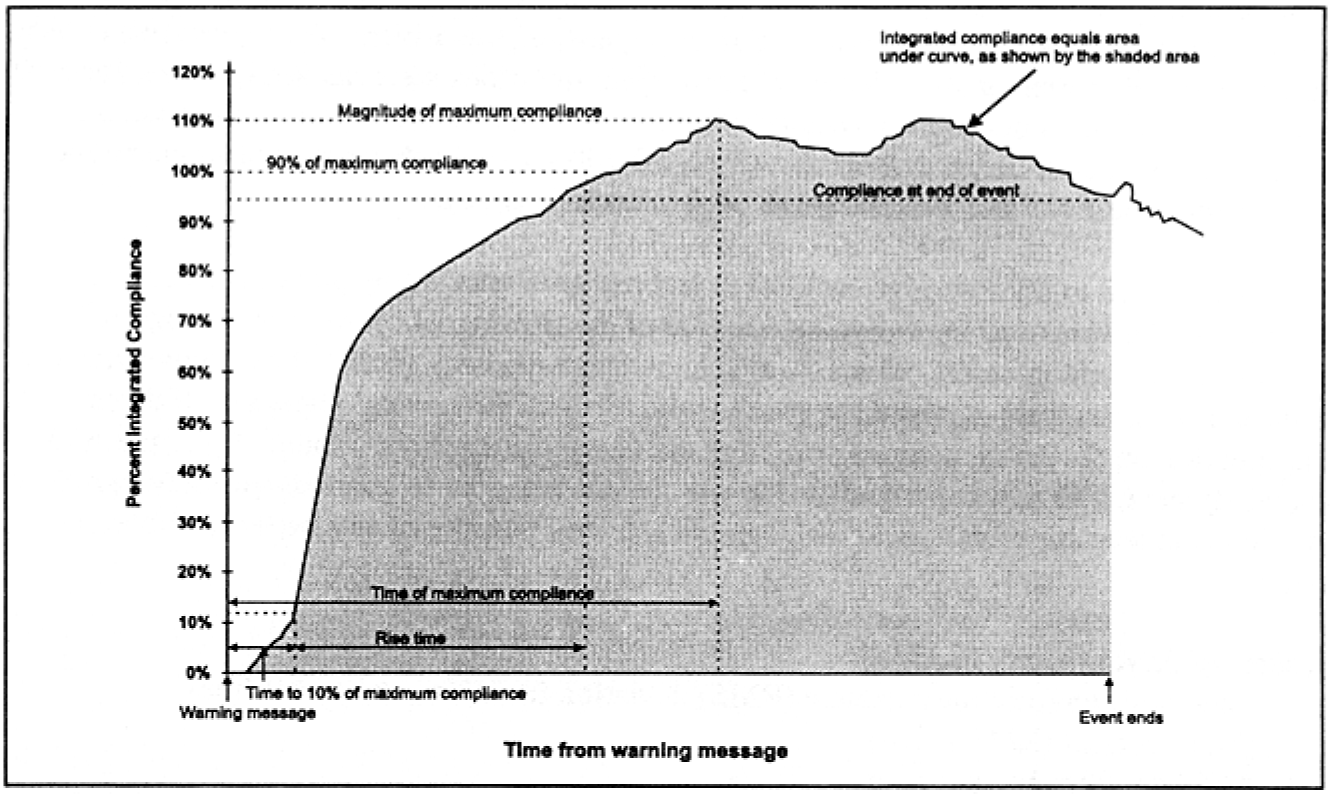


Figure 3. A hypothetical trace of a driver's compliance with a warning message.

Procedure

Figure 4 shows the experimental protocol. When subjects first arrived, they were briefed on what they would be asked to do and were then asked to sign an informed consent form if they chose to participate. Subjects were then given a brief pre–test that evaluated their general attitudes toward technology. Following the pre–test, drivers were trained on the experimental procedures. To ensure that the drivers understood the instructions, they were given a short test. The experimenter reviewed any questions that were answered incorrectly. During the training, drivers were told to drive normally and obey speed limits. They were also instructed to respond to ATIS and roadway warnings by pressing the appropriate steering–wheel buttons. Subjects who failed to respond accurately to more than 25 percent of the events repeated the training scenario. If after two repetitions they were not able to respond accurately, they were paid and escorted out of the laboratory.

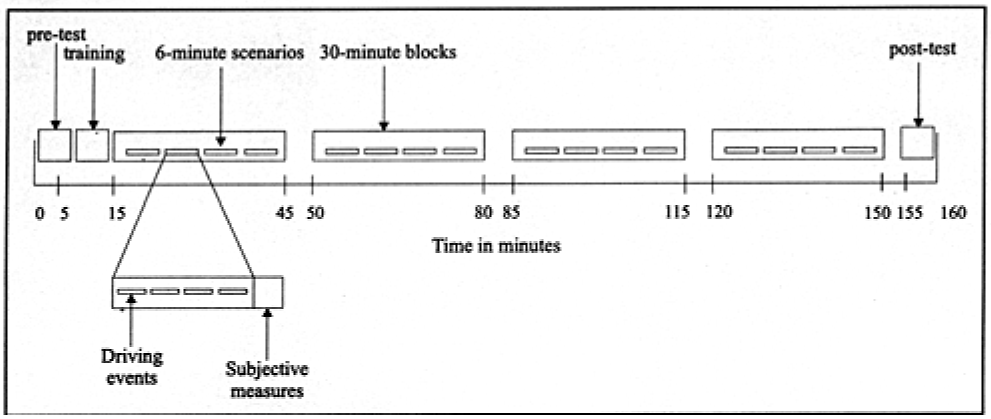


Figure 4. The timeline of the experiment showing the distribution of driving activity.

The training scenario was followed by four 30–min "blocks" composed of four 6–min scenarios and a short break. This generated data for a total of sixteen 6–min scenarios. Each 6–min scenario contained four main driving events. These events included: disabled vehicles, pedestrian zones, high–occupancy vehicle (HOV) lanes, accidents, and construction zones. Drivers experienced a random selection of four of these events during each 6–min scenario.

During each scenario, the subjects were in control of steering, acceleration, and braking. Since the subjects were in complete control of the vehicle during the scenarios, the scenario length varied slightly depending on the driver. In each scenario, ATIS and roadway information was presented to alert drivers to each of the four roadway events. Other roadway characteristics that drivers might typically see while driving (traffic lights, pedestrians, billboards, etc.) were also displayed. Drivers also faced typical driving hazards. They faced oncoming traffic and passing traffic. As they drove in the right lane of a two–lane rural road, cars approached and passed in the left lane.

Two sets of questions were administered during each scenario. One set, concerning drivers' situational awareness, was presented randomly during one of the four roadway events and the other set, containing subjective measures of the drivers' experiences, was presented at the end of each scenario. After completing the 16 scenarios, the subjects were given a post–test identical to the pre–test that evaluated subjects' attitudes toward technology. Subjects were then debriefed, paid for their participation, and escorted out of the laboratory.

CHAPTER 3. RESULTS

The results will be described in four sections: (1) warning compliance, (2) driving safety, (3) trust in ATIS and self–confidence, and (4) situational awareness, workload, and message acknowledgment. The first two sections address how ATIS design characteristics influence compliance with warning messages and driving safety and the final two sections investigate the intervening variables and cognitive processes that govern compliance and safety.

WARNING COMPLIANCE

Three repeated measures analysis of variance were used to evaluate the factors influencing the measures of compliance (time to 10 percent compliance, rise time, and integrated compliance). The analyses included age, gender, information availability, message style, message mode, and message location as independent variables. The significant results will be considered first in terms of the hypotheses and then in terms of the more general framework. The specific hypotheses include:

- Presence of ATIS messages will promote higher compliance.
- Command message style will promote higher compliance.
- Auditory messages will promote greater compliance.
- Mode and style will interact to promote the highest level of compliance for auditory command messages.

The first hypothesis states that ATIS messages will promote a higher level of compliance compared to the roadway signs. Table 5 shows the three measures of compliance (see figure 3) for each of the four conditions of information availability. The units for 10 percent compliance and rise time are seconds, and integrated compliance is measured as a percentage. The effect of information availability is not significant for time to 10 percent compliance, $F(2.6, 42.2) = 0.90$, $p>0.05$.(1) The effect is significant for rise time and integrated compliance, $F(2.8, 46.2) = 3.69$, $p<0.05$, and $F(2.8, 45.1) = 46.24$, $p<0.0001$, respectively. Since rise time reflects the time to progress from 10 to 90 percent of the maximum compliance, lower values correspond to a faster increase in compliance. The longer rise time suggests that drivers who receive both roadway and ATIS information are able to act on this information gradually over time, while drivers who receive neither roadway nor ATIS information are forced to react rapidly to avoid approaching hazards. Integrated compliance follows the hypothesized pattern showing higher levels of compliance when the ATIS information is present.

Table 5. Measures of compliance for the four levels of information availability with standard deviations in parentheses.

Measure of Compliance	Road & ATIS	ATIS	Road	Neither
Time (seconds) to 10% compliance (NS)	4.6 (2.1)	4.8 (2.5)	4.9 (2.3)	4.5 (1.9)
Rise time* (seconds)	10.4 (5.2)	9.6 (4.6)	9.8 (3.5)	8.8 (5.0)
Integrated compliance** (percent)	57.1 (19.5)	59.0 (19.9)	44.3 (18.3)	39.0 (20.0)

* $p<0.05$, ** $p<0.001$, NS = non-significant results.

The second hypothesis states that the command message style will promote greater compliance compared to the notification message style. Message style refers only to the ATIS messages, the roadway sign style was not manipulated. The analysis does not uniformly support this hypothesis. Only the integrated compliance measure shows significance. The effect of message style on integrated compliance is consistent with the hypothesis. Integrated compliance with the command message is 52.0 percent compared to 47.7 percent for the notification message, $F(1, 16) = 3.06$, $p<0.10$. Considering only those cases when ATIS messages are presented shows a much stronger effect of message style, $F(1, 16) = 19.51$, $p<0.001$. When only ATIS messages are present, compliance with the command–style messages is 64.8 percent and 53.2 percent for notification–style messages.

The third hypothesis states that auditory messages will promote a higher compliance compared to text messages. This hypothesis is not supported by the analysis. None of the three measures showed a significant effect of message modality.

The final hypothesis states that the effects of message mode and style will interact, with drivers complying most fully with auditory command messages. This hypothesis is not supported.

Beyond the effects associated with specific hypotheses, several effects associated with driver age are also significant. A two–way interaction between display location and age indicates that a distributed display promotes greater integrated compliance with older drivers (54.4 percent versus 44.8 percent), but a centralized display promotes greater compliance for younger drivers (50.1 percent versus 48.5 percent), $F(1, 16) = 5.81$, $p<0.05$. Older drivers also showed longer rise time compared to younger drivers, $F(1, 16) = 5.18$, $p<0.05$. Older driver compliance rose from 10 percent to 90 percent in 10.5 s, compared to 8.9 s with younger drivers.

The surface similarity of the different measures of compliance suggests a high correlation between each of the three measures; however, the correlations between the measures are all relatively weak. Table 6 shows that the highest correlation is less than 0.2.

Table 6. Correlation matrix of measures of compliance.

Measure of compliance	Time (seconds) to 10 percent	Rise time (seconds)	Integrated compliance (percent)
Time (seconds) to 10%	--		
Rise time (seconds)	0.067	--	
Integrated compliance (percent)	0.068	0.185	--

The higher correlation between the rise time and integrated compliance may reflect a greater stability in these measures. Both the rise time and the integrated compliance draw upon a greater sample of driver behavior and so are likely to be more stable measures. The number of significant effects for each of the measures may also reflect this stability and resulting sensitivity. The low correlation between the measures may also reflect the fact that the three measures reflect different characteristics of compliance. The time to 10 percent compliance and the rise time both reflect the response time of the driver, while integrated compliance is a more holistic measure of compliance that reflects speed, magnitude, and duration of the compliance.

The effect of age is consistent with this interpretation of the differences between these measures. Rise time shows that younger drivers respond more quickly than older drivers. Time to 10 percent compliance shows a similar pattern with older drivers reaching 10 percent of their maximum compliance in 4.9 s, compared to 4.5 s for younger drivers; however, the difference is not significant, $F(1, 16) = 1.20$, $p>0.05$. Integrated compliance does not reflect response time and it suggests an opposite effect for older drivers. The integrated compliance for older drivers is 52.0 percent compared to 47.7 percent for younger drivers; however, this effect is not significant, $F(1, 16) = 2.50$, $p>0.05$. Although not significant, the direction of these effects suggests that integrated compliance reflects the conservative nature of drivers and the rise time and time to 10 percent compliance reflect the speed of a driver's reaction.

The effects of ATIS and driver characteristics on driver compliance are summarized in table 7.

Table 7. The effects of the independent variables on three measures of driver compliance.

Effects	Time to (seconds) 10 percent	Rise time (seconds)	Integrated compliance (percent)
Age (A)		*	
A x L (Location)			*
Information Available (I)		*	**

* $p<0.05$, ** $p<0.001$, blank, unshaded cells = non–significant results.

DRIVING SAFETY

Five repeated measures analysis of variance were used to evaluate the factors influencing five measures of driving safety. Each analysis included age, gender, information availability, message style, message mode, and message location as independent variables. These measures included:

- Perceived driving performance.
- Mean number of crashes in each hour of driving.
- Percentage of correct use of the turn signal.
- Root mean square of lane position.
- Root mean square of velocity.

Perceived driving performance is a subjective measure collected at the end of each scenario, with a maximum of 100 and a minimum of zero. The average number of crashes per hour is calculated by normalizing the number of crashes in each scenario by the scenario duration. Turn-signal use is calculated as a percentage and is based on whether or not drivers used the turn signal as they changed lanes. The RMS measures of lane position and velocity were calculated for the period immediately after the message was presented until the point where the drivers acknowledged the message. To enhance the sensitivity of the RMS measures, the analysis uses the RMS for the period just prior to the message presentation as a covariate.

- A general concern is that the ATIS messages might undermine driving safety. This might occur in two ways. First, an ATIS might overwhelm the driver with information. This is particularly true when the ATIS competes for visual attention. Second, the ATIS might promote overreliance and drivers may allow their attention to be drawn away from the roadway and into the vehicle. These two general alternatives will be considered throughout the discussion. The significant results will be considered first in terms of the hypotheses and then more generally. The specific hypotheses include:
- The presence of ATIS information will reduce drivers' attention to roadway information.
- The presence of ATIS information will overload the driver.
- The command message style will promote overreliance on the ATIS and reduce attention to roadway information.
- Auditory information will draw attention away from the roadway, while text messages will tend to overload the driver.
- Mode and style will interact to induce the lowest level of safety for auditory command messages or text notification messages, depending on whether the ATIS tends to overload or distract the driver.

The first hypothesis states that ATIS messages will reduce attention to the roadway and the second hypothesis states that ATIS messages will overload the driver with too much information. These hypotheses will be evaluated simultaneously by examining the effect of information availability on the measures of safety. Table 8 shows that information availability significantly affects three out of five measures of driving safety.

Table 8. The effect of information availability on driving safety.

Measure	ATIS & Roadway	ATIS	Road	Neither	Significance Test
Perceived Driving Performance	77.0	68.6	78.2	73.7	$F(2.19, 35.1) = 7.37$, $p<0.001$
Crashes per hour	3.4	8.5	2.7	2.9	$F(2.71, 43.38) = 15.73$, $p<0.0001$
Lane Position (RMS)	0.52	0.39	0.51	0.78	$F(3, 47) = 2.48$, $p>0.05$
Velocity (RMS)	0.58	0.42	0.46	0.55	$F(3, 47) = 5.33$, $p<0.005$
Turn–Signal Use (percent)	84.4	87.6	87.3	81.7	$F(2.39, 38.17) = 2.46$, $p>0.05$

The first two variables in this table suggest that driving safety is lower when the ATIS is the only information source. The effect of information availability on RMS velocity shows a different pattern of effects that is not consistent with either hypothesis. The lower level of safety when only ATIS information is available, compared to when ATIS and roadway information are both available, supports the hypothesis that ATIS information draws attention from the roadway into the vehicle. The effects of messages on lane position and velocity could be consistent with the hypothesis that ATIS information, particularly when paired with redundant roadway signs, will overload the driver. However, the pattern of results for compliance, situational awareness, and workload data suggests that information overload is not the primary contributor to the degraded safety associated with ATIS messages.

The third hypothesis states that the command messages will draw attention away from the roadway, leading to lower levels of driving safety. The main effect of message style for several variables shows modest support for this hypothesis. Table 9 shows that perceived driving performance and RMS velocity indicate that command messages tend to erode driving safety. To enhance the sensitivity of the RMS data, the RMS data from the time period just prior to the message onset was used as a covariate. This reduces the degrees of freedom from 16 to 15. Because command messages are generally shorter, they transmit less information and should impose less mental workload on the drivers. This suggests that the negative effect of command messages stems from their tendency to encourage overreliance on the ATIS. This overreliance draws drivers' attention from the roadway, leading to unsafe maneuvers and collisions with other vehicles.

Table 9. The effect of message style on driving safety.

Measure	Command	Notification	Significance Test
Perceived Driving Performance	72.2	76.6	$F(1, 16) = 5.70$, $p<0.05$
Crashes per hour	8.0	6.5	$F(1, 16) = 2.35$, $p>0.05$
Lane Position (RMS)	0.49	0.44	$F(1, 15) = 4.22$, $p>0.05$
Velocity (RMS)	0.54	0.46	$F(1, 15) = 5.33$, $p<0.005$
Turn–Signal Use (percent)	84.3	86.1	$F(1, 16) = 1.04$, $p>0.05$

The fourth hypothesis states that auditory messages will draw attention away from the roadway and text messages will tend to overload the driver. None of the safety–related variables shows a significant effect for message mode.

The final hypothesis states that message style and mode will interact to induce the lowest level of safety for auditory command messages or text notification messages. Only perceived driving performance showed a significant effect related to this hypothesis. A three–way interaction between gender, style, and mode suggests that mode and style may interact, but that this interaction depends on gender, $F(1, 16) = 5.64$, $p<0.05$. Figure 5 shows this interaction, indicating that females perceived their driving performance to be better with notification messages compared to command messages, but only when they were presented through the auditory mode. Male drivers thought they drove more safely when they received notification messages compared to command messages, but only when the messages were presented as text.

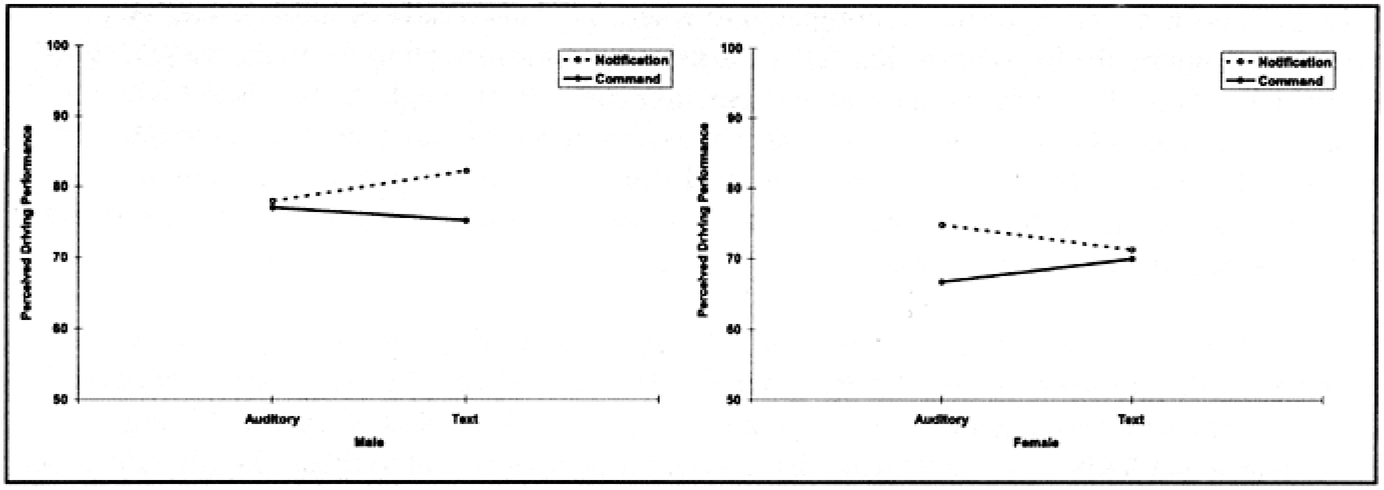


Figure 5. The effect of message style and modality on the perceived performance of male and female drivers.

This supports the hypothesis that ATIS messages might undermine safety by promoting overreliance rather than by overwhelming drivers with information. If the ATIS messages were to undermine safety by overloading drivers, then performance should be worse for the visual notification messages.

Beyond the specific hypotheses, all the measures of driving safety, except for perceived driving performance, showed a significant effect for age. Older drivers performed more poorly than younger drivers.

Table 10. The effect of age on the five measures of driving safety.

Measure	Younger	Older	Significance Test
Perceived Driving Performance	74.0	74.2	$F(1, 16) = 0.05$, $p>0.05$
Crashes per hour	4.4	10.1	$F(1, 16) = 8.14$, $p<0.05$
Lane Position (RMS)	0.40	0.54	$F(1, 15) = 18.18$, $p<0.001$
Velocity (RMS)	0.38	0.62	$F(1, 15) = 7.78$, $p<0.05$
Turn-Signal Use (percent)	95.1	75.3	$F(1, 16) = 5.86$, $p<0.05$

Table 11 summarizes the effects of the independent variables on the measures of driving safety.

Table 11. The effects of the independent variables on the five measures of driving safety.

Effects	Perceived Driving	Crashes per hour	Turn Signal Use	Lane Position (RMS)	Velocity (RMS)
Age (A)		*	*	***	*
Gender (G)	*				
AxG	*				
Style (S)	*				*
Info. Avail. (I)	**	****			***
IxAxG			*		
Mode (M)xS					**
MxSxG	*				
MxSxGx Location (L)			*		
MxSxAxGxL			*		
SxIxAxG					*

$p<0.05$, ** $p<0.01$, *** $p<0.005$, **** $p<0.001$, blank, unshaded cells = non-significant results.

TRUST IN THE ATIS AND SELF–CONFIDENCE

Past research has shown trust and self–confidence to be important intervening variables that moderate reliance on automation. In this experiment, understanding variations in trust and self–confidence could illuminate the process that governs compliance with ATIS messages. Two repeated measures analysis of variance were used to evaluate the factors influencing trust in the ATIS and self–confidence. These analyses included age, gender, information availability, message style, message mode, and message location as independent variables. This analysis identified several significant effects that will be considered in terms of specific hypotheses and then in terms of how they might influence compliance with warning messages. The specific hypotheses regarding trust and self–confidence include:

- Trust will be enhanced when ATIS information is available and self–confidence will be enhanced when roadway information is available.
- Trust in ATIS systems with the command message style will be fragile, leading to a greater decline when ATIS information is missing, compared to the notification message style.
- Self–confidence will be greatest with notification–style messages.
- Self–confidence will be more robust with the notification message style and it will drop less when roadway information is missing.

The first hypothesis states that information availability will affect subjective ratings of trust and self–confidence. Trust will decline when ATIS information is unavailable and self–confidence will decline when roadway information is not available. The analysis shows that trust and self–confidence are affected by information availability in an orderly manner that is consistent with this hypothesis, $F(2.6, 40.92) = 36.0$, $p<0.001$ for trust and $F(2.1, 32.8) = 6.6$, $p<0.005$ for self–confidence. Figure 6 shows trust dropping when ATIS information is not available and self–confidence dropping when roadway information is not available. Thus, trust in the ATIS and self–confidence respond to gross changes in the system as hypothesized.

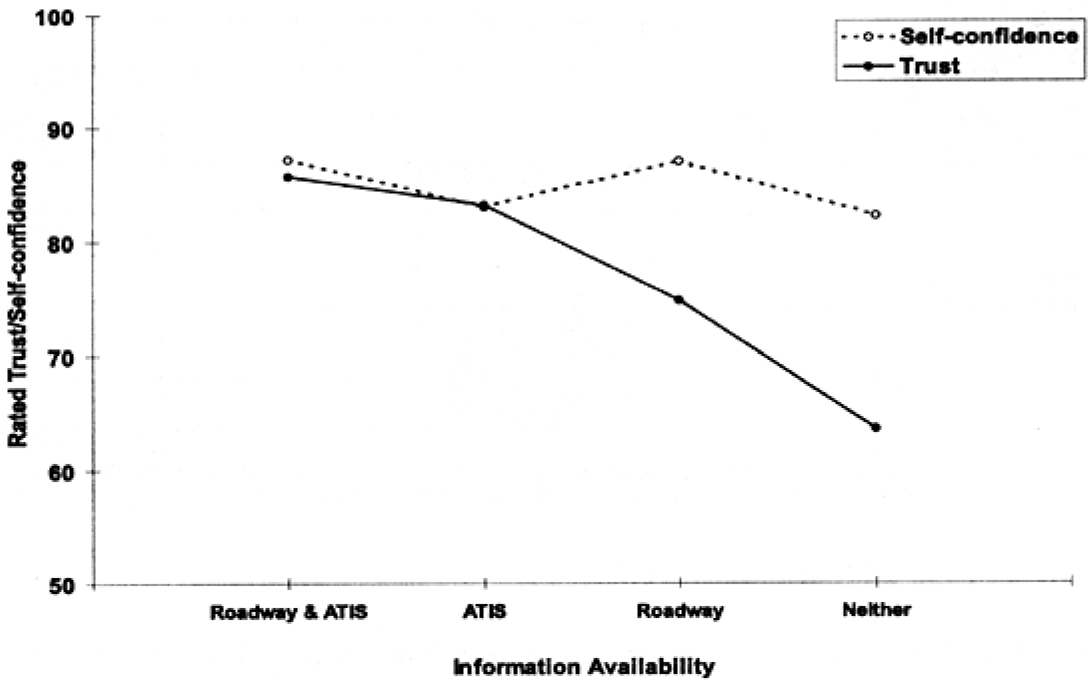


Figure 6. The function of trust and self-confidence for various levels of roadway and ATIS information.

The second hypothesis states that trust in the ATIS with a command message will be more fragile than with a notification message. A two–way interaction between information availability and message style partially supports this hypothesis, $F(1.97, 31.82) = 5.55$, $p<0.005$. The interaction, shown in figure 7, between message style and information availability suggests that the command message style does not instill a very high level of trust, compared to notification messages. This is particularly pronounced when drivers are forced to rely on the ATIS when no roadway information is available. However, trust in both message styles declines to approximately the same level when ATIS information is not available. Thus, when command messages are not paired with redundant roadway information, drivers tend to distrust the ATIS, compared to notification messages. This finding is consistent with the more general hypothesis that command messages will lead to a more fragile sense of trust in the ATIS.

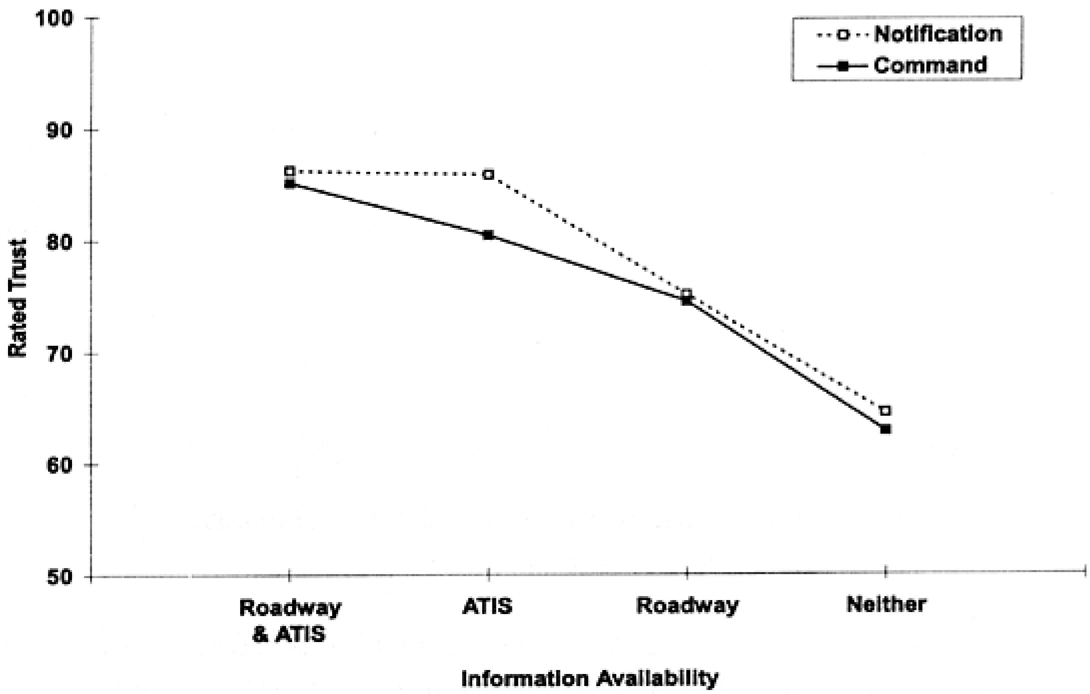


Figure 7. The effect of information availability and message style on trust in the ATIS.

The third hypothesis states that self–confidence will be greatest with notification–style messages. The main effect of message style does not support this hypothesis, $F(1, 16) = 1.17$, $p>0.05$. However, the interaction between style and information availability supports this hypothesis, $F(2.4, 39.0) = 3.42$, $p<0.05$. Figure 8 shows that command messages diminish self–confidence when drivers have only ATIS information to rely upon. This figure also addresses the fourth hypothesis that states that self–confidence will be more robust with notification–style messages. This partially supports the hypothesis because self–confidence does not decline for drivers receiving notification messages in the ATIS–only condition. However, self–confidence for both message styles was approximately equal when neither roadway nor ATIS information is available.

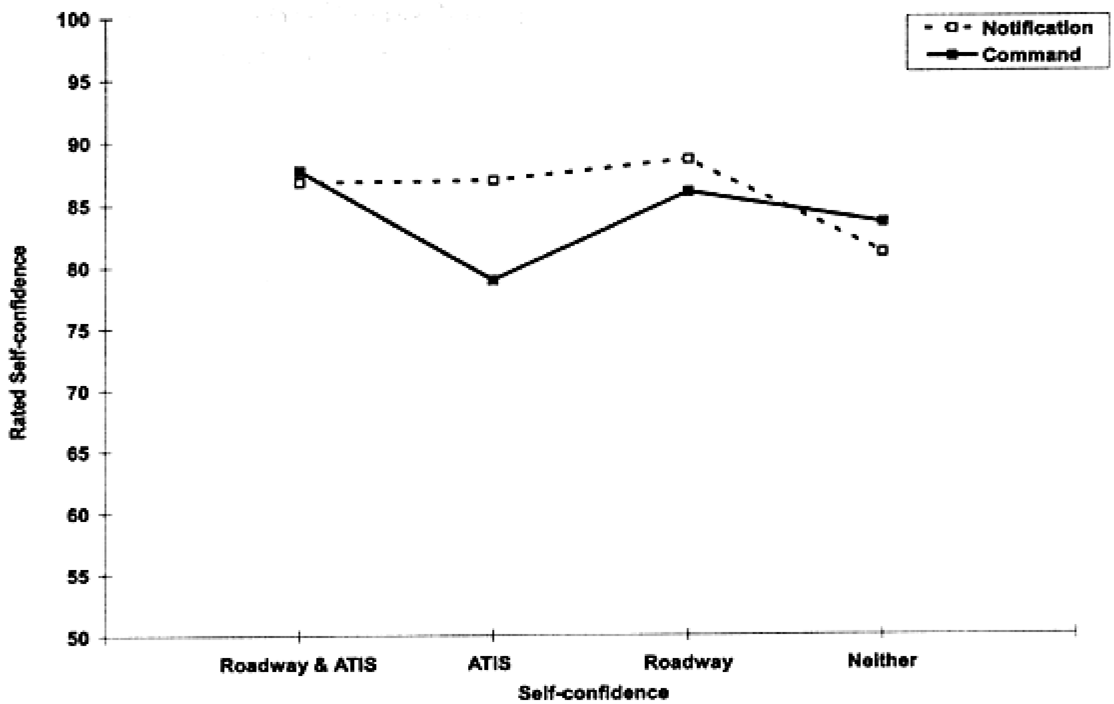


Figure 8. The effect of information availability and message style on drivers' self-confidence.

Like message style, message mode interacts with message availability to affect trust, $F(1.99, 31.82) = 5.55$, $p<0.01$. Figure 9 shows that drivers' trust is initially higher with auditory messages, but that it is also more brittle, declining more when ATIS messages do not appear on a regular basis.

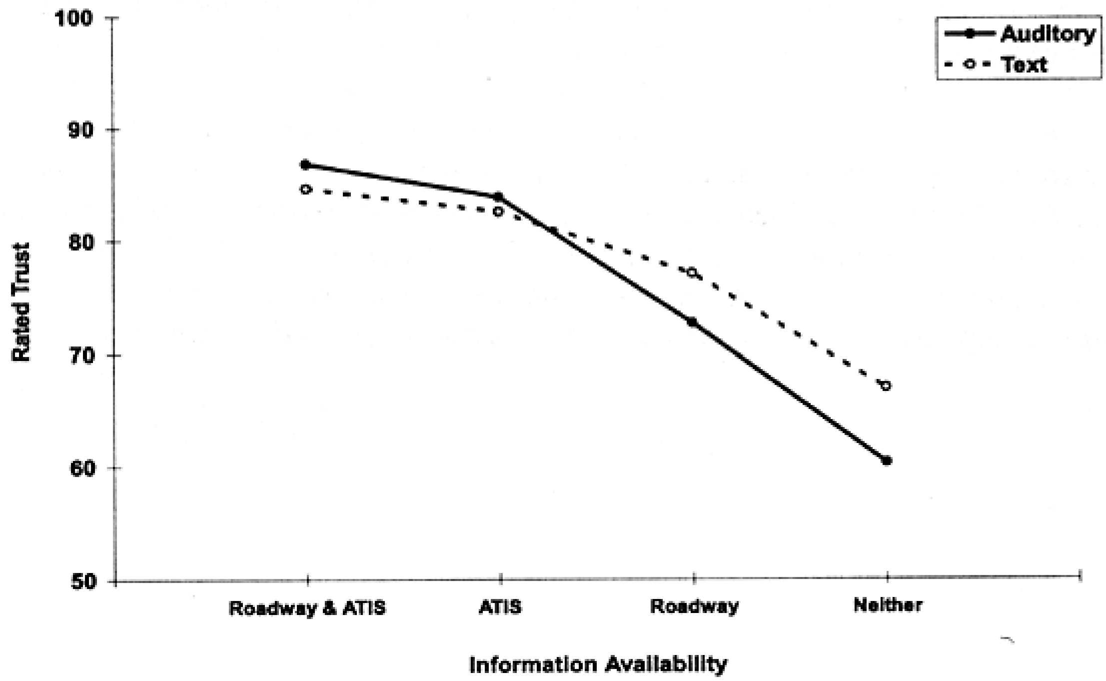


Figure 9. The effect of information availability and message mode on trust.

Beyond the specific hypotheses, trust also shows a main effect and interaction linked to age differences, $F(1, 16) = 7.71$, $p<0.05$, $F(2.56, 40.92) = 7.08$, $p<0.005$. Figure 10 shows that the older drivers' trust in the system is not as fragile as that of the younger drivers. The trust of younger drivers drops dramatically when ATIS information is not available, while the trust of older drivers declines only a moderate amount. This result suggests an apparent contrast with other studies of older drivers and their acceptance of technology. For example, Kantowitz, Hanowski, and Kantowitz (1997) and Kantowitz, et al. (1996) show that older drivers are less likely to increase their use of a traffic information device, compared to younger drivers. Older drivers' use of the device remains constant, while younger drivers increase their use. Figure 10 shows a possible underlying similarity in the behavior. With the onset of less redundant ATIS, the trust of older drivers remains relatively constant, while younger drivers' trust changes. The underlying cause may not be an inherent reluctance to use technology, but a greater inertia. The greater inertia of older drivers may be reflected in older drivers' continued higher level of trust in this experiment. This parallels the reluctance of older drivers to use the traffic information device in Kantowitz, et al. (1997), where this inertia was reflected in a reluctance to adopt the technology. These results suggest that older drivers' trust will have greater inertia and will be more constant than that of younger drivers; their trust will decline less and increase less than that of younger drivers.

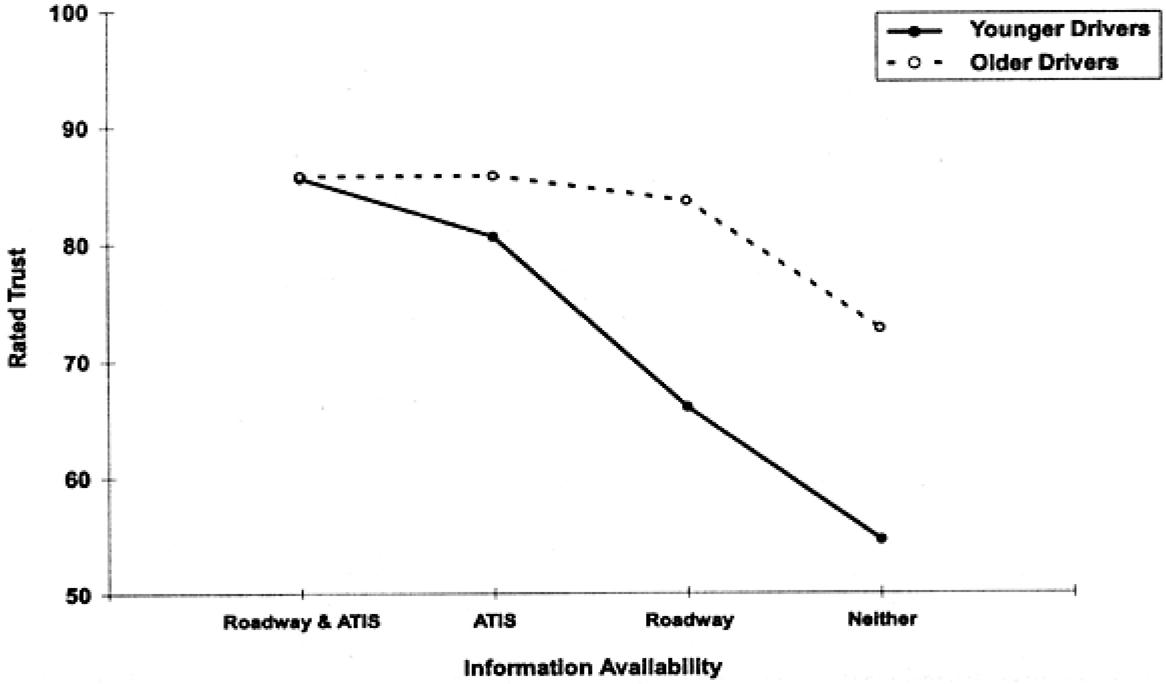


Figure 10. The effect of information availability and driver age on trust in the ATIS.

Trust also depends on an interaction between message style and mode, $F(1, 16) = 15.14$, $p<0.005$. This interaction shows that the combination of text notification messages engenders the greatest level of trust (80.8) compared to the rated trust for the text command (74.7), auditory notification (75.0), or auditory command (76.8). This interaction is complicated by a four–way interaction between message style, mode, age, and gender, $F(1, 16) = 13.3$, $p<0.01$. Figure 11 shows this interaction. This interaction shows that older females tend to distrust ATIS information when it is presented as an auditory notification. This pattern is similar for younger females, who trust auditory command messages more than auditory notification messages. While men trust the auditory command message more than the text command message, they tend to distrust command messages in general.

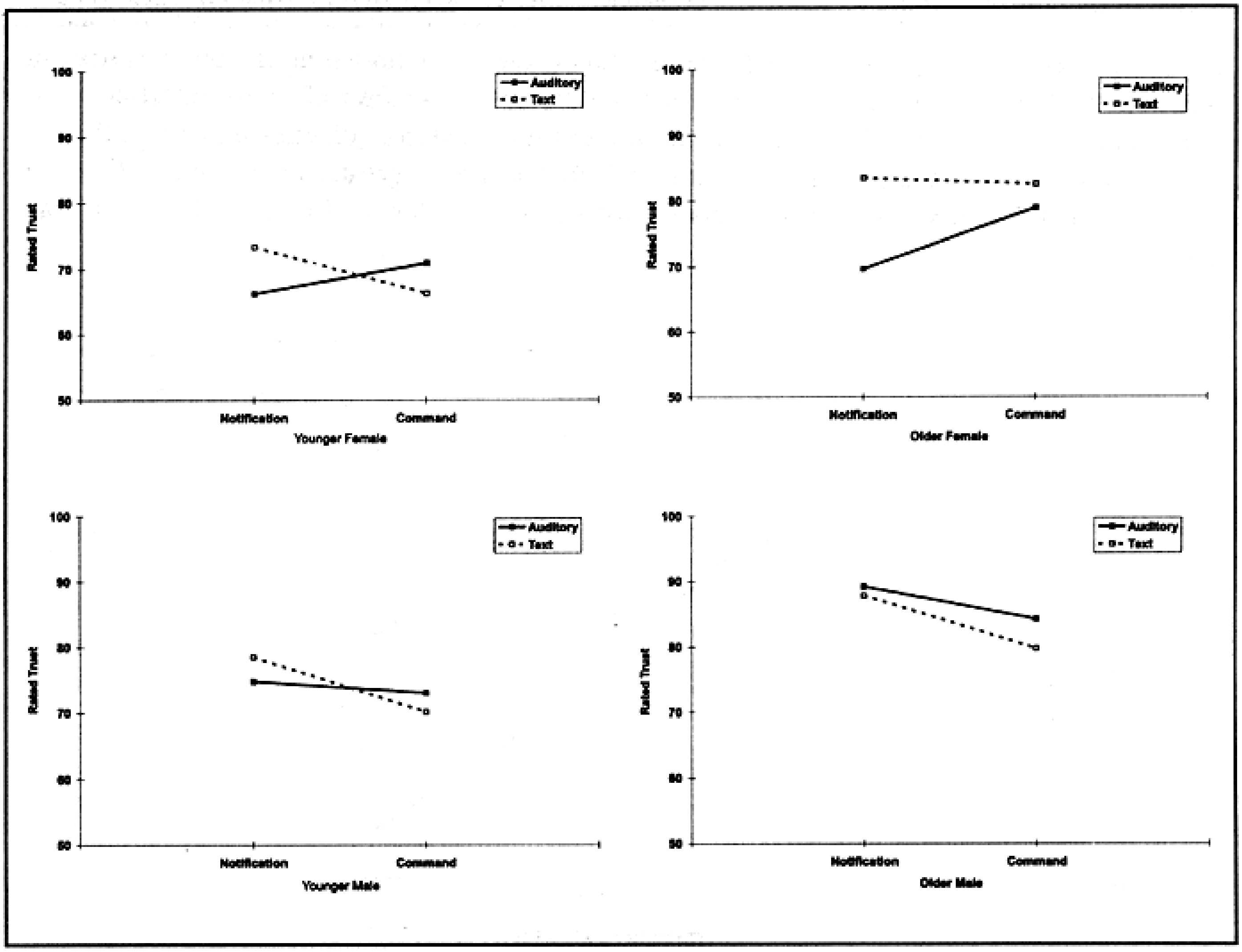


Figure 11. The effect of age, gender, style, and mode on trust.

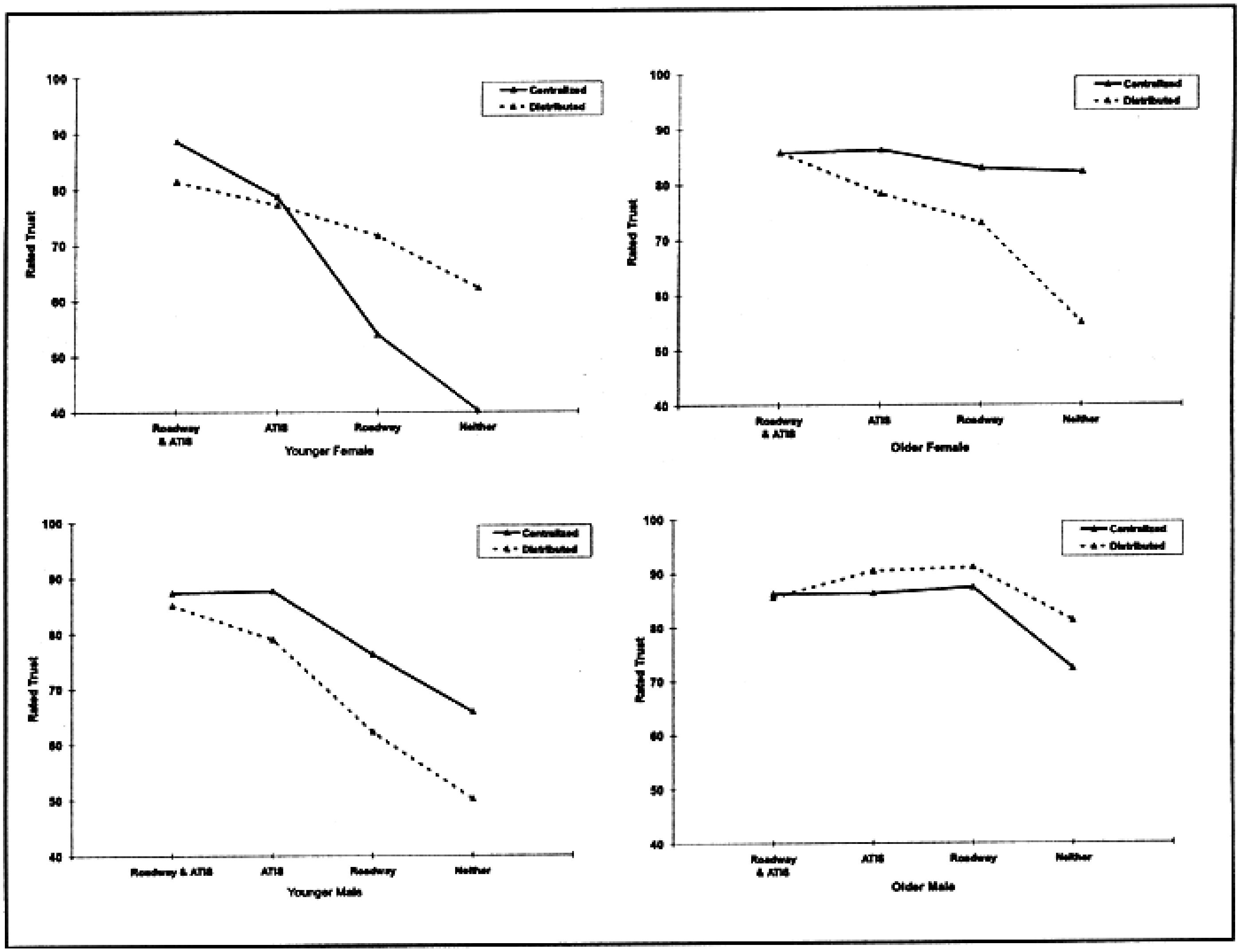


Figure 12. The effect of information availability, age, gender, and display location on trust.

The independent variables influence trust in several complicated ways. A three–way interaction between age, gender, and location is significant, $F(1, 16) = 4.89$, $p<0.05$. A related four–way interaction between age, gender, location, and information availability is also significant, $F(2.56, 40.92) = p<0.005$. Figure 12 shows that information availability differentially affects trust depending on age, gender, and the location of the display. Table 12 explains these differences.

Table 12. Comments explaining the effects shown in figure 12.

Gender	Younger	Older
Female	A crossover interaction indicates that the trust of younger females drops more with centralized displays.	The trust of older females drops more with distributed displays, remaining almost unaffected by the centralized displays.
Male	The trust of younger males drops more with the distributed displays.	The trust of older males remains relatively constant for both the centralized and distributed displays and only declines slightly when ATIS and roadway information are not present.

The strong interactions between the driver characteristics of age and gender with message characteristics suggest that drivers' attitudes do not depend only on the characteristics of the ATIS. These interactions suggest that individual differences play a complex, but important role in shaping drivers' attitudes. Table 13 summarizes all the effects for trust in the ATIS and self–confidence.

Table 13. Summary of all significant effects for trust and self–confidence.

Effects	Trust	Self–confidence
A	*	
AxGxL	*	
I	****	***
IxA	**	
IxAxGxL	**	
MxS	**	
MxSxL	*	
MxSxAxG	**	
MxSxAxL		*
MxI	**	
SxI	**	*
MxSxIxGxL	*	

* $p<0.05$, ** $p<0.01$, *** $p<0.005$, **** $p<0.001$.

ANALYSIS OF SITUATIONAL AWARENESS, WORKLOAD, AND MESSAGE ACKNOWLEDGMENT

Situational awareness, workload, and message acknowledgment are important intervening variables that may illuminate the influence of ATIS messages on driving safety. Six repeated measures analysis of variance examined the dependence of six measures on ATIS and driver characteristics. The analyses of situational awareness, workload, and message acknowledgment included age, gender, information availability, message style, message mode, and message location as independent variables. The analysis of message acknowledgment examined only those cases where drivers received both ATIS and roadway information and so information availability was replaced by acknowledgment type (acknowledgment of ATIS messages versus roadway information). The significant results will be considered in terms of the specific hypotheses and then in terms of how these intervening variables may illuminate the factors affecting driving safety. The specific hypotheses include:

- Situational awareness will decline as drivers' attention is drawn into the vehicle when they receive ATIS information without redundant road signs.
- The ATIS will overwhelm drivers with information.
- The text–based ATIS messages will increase workload.
- Redundant sign information will increase driver workload.
- Auditory messages will capture attention, resulting in shorter latencies for message acknowledgment.
- Centralized displays will facilitate information assimilation, as indicated by shorter latencies for message acknowledgment.

The first hypothesis suggests that situational awareness will decline as drivers' attention is drawn into the vehicle when they receive ATIS information without redundant road–sign information. Figure 13 shows the main effect of information availability that supports this hypothesis, $F(2.59, 41.50) = 27.41$, $p<0.0001$. In addition, this figure includes a two–way interaction between age and information availability that suggests that younger drivers are more prone to having their attention drawn into the vehicle when only ATIS information is available, $F(2.59, 41.5) = 4.64$, $p<0.01$. Figure 13 shows that the difference in situational awareness between older and younger drivers is smallest when older drivers have access to ATIS information. Situational awareness for older drivers is approximately the same as that for younger drivers when the ATIS information is present. When ATIS information is not available, younger drivers have greater situational awareness. These results do not support the second hypothesis that the ATIS will overwhelm drivers with information because the level of situational awareness is higher when the potential for information overload is greatest (when roadway and ATIS information are both present). These results show that ATIS messages might undermine driving safety by drawing drivers' attention into the vehicle, rather than by overloading them with information. These results are particularly striking because several situational questions could be answered based on the ATIS information. It seems that older drivers are able to use the ATIS more effectively than younger drivers and that information overload is not the cause of the decline in safety associated with ATIS messages.

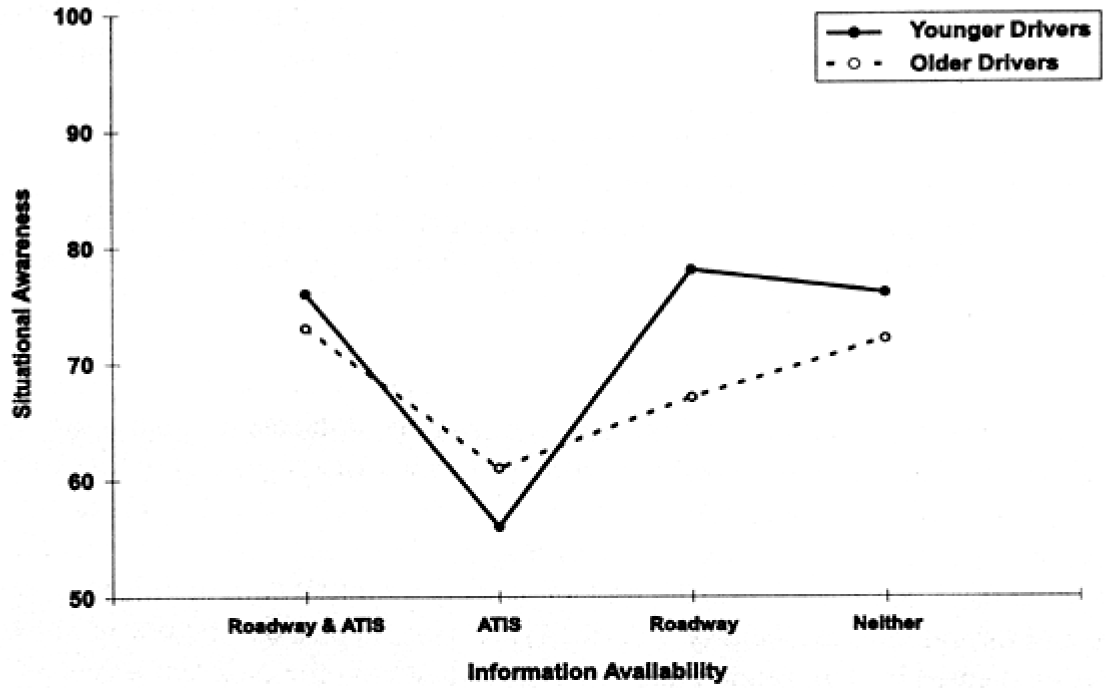


Figure 13. The effect of information availability and driver age on situational awareness.

The third hypothesis states that presenting drivers with text messages will result in higher mental effort because driving and reading ATIS messages draw upon the same visual resources. The results do not support this hypothesis. No main effects involve message modality. The fourth hypothesis states that redundant sign information may lead to a higher workload as drivers process both the roadway and ATIS information. Again, the results fail to support this hypothesis. Message mode and different levels of information availability show no effect on drivers' rated mental effort.

The fifth hypothesis suggests that auditory messages will capture driver attention, resulting in shorter latencies for ATIS message acknowledgment. The analysis showed that the latencies for the auditory ATIS messages do not differ from the latencies for the text messages or the roadway messages. The sixth hypothesis states that centralized displays will support more efficient information assimilation, resulting in shorter latencies. The analysis does not support this hypothesis. Whether information was presented in a centralized or distributed location does not have a significant effect on acknowledgment latencies. In fact, no ATIS design characteristics seem to affect response time to the ATIS messages as compared to the roadway messages.

The specific hypotheses help clarify the cognitive processes that interact with certain ATIS message characteristics to affect driving safety. Examining the specific hypotheses together suggests that the concept of information overload does not explain how the ATIS might undermine driving safety. Instead, it seems that overreliance on the ATIS compromises safety. The sensitivity of subjective ratings of mental effort and physical effort to the effect of age supports this argument. As expected, older drivers show a much higher level of mental effort. Younger drivers showed a mean subjective effort of 35.2 compared to a mean of 64.5 for older drivers, $F(1, 16) = 20.21$, $p<0.0005$. Like mental effort, physical effort also shows a strong effect due to age, $F(1, 16) = 41.68$, $p<0.0001$. Interestingly, the magnitude of the difference between older and younger drivers is approximately 30 percent greater for physical effort, compared to mental effort. If information overload compromises safety, the sensitivity of these measures should enable them to support the appropriate hypotheses. These findings suggest that an ATIS can undermine safety by drawing drivers' attention into the vehicle, causing them to give less consideration to the roadway. This interpretation is consistent with the effect of ATIS information on situational awareness. Situational awareness is lowest when ATIS information is presented without redundant roadway information.

A complex interaction affecting mental effort reveals how ATIS message characteristics influence drivers' safety and compliance. The main effect of age interacts with message style so that younger drivers experience lower workload with notification messages and older drivers experience lower workload with command messages, $F(1, 16) = 9.29$, $p<0.01$. This effect is further complicated by a three–way interaction involving age, information availability, and message style, $F(2.60, 41.66) = 4.87$, $p<0.01$, and a four–way interaction involving age, gender, message style, and information availability, $F(2.60, 41.66) = 5.10$, $p<0.01$. Figure 14 shows how mental effort is moderated by age, gender, and message style across the different levels of information availability. In general, older drivers experience more effort compared to younger drivers. Furthermore, younger females and older females experience a different level of effort in response to command and notification messages. Younger females experience a higher level of effort assimilating ATIS information presented as commands compared to notifications. In contrast, older females experience a lower level of effort with command messages compared to notification messages. As one might expect, this effect is most pronounced when the ATIS information is present. This effect is particularly difficult to interpret as an effect of information overload; however, a sociological perspective may clarify the issue. Accepting instructions may be consistent with the experience of older women, but collecting information and making autonomous decisions is more consistent with the expectations of younger women. Notification messages support this more autonomous decision–making style, while command messages are more compatible with the role of accepting pre–defined instructions.

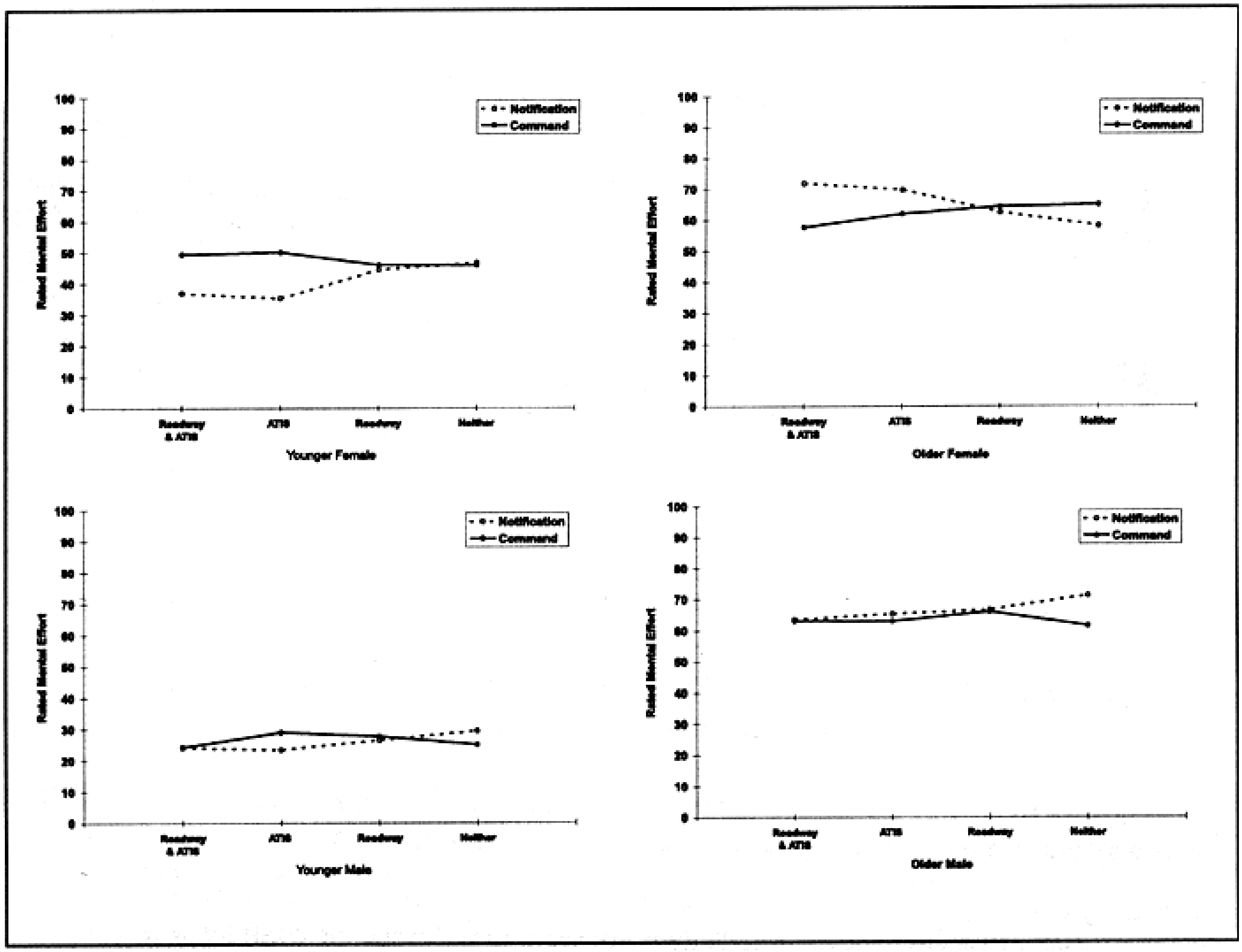


Figure 14. The effect of age, gender, message style, and information availability on mental effort.

For each situation awareness query, drivers rated their level of confidence in the accuracy of their response. Confidence might prove to be a more sensitive measure of situation awareness than the accuracy of their response because the graded scale provides more information than the binary coding associated with correct and incorrect responses. Surprisingly, drivers' confidence in their accuracy did not parallel their accuracy. SA confidence correlates with SA accuracy only slightly (r=0.16). Unlike SA accuracy, drivers' confidence in their accuracy was not affected by information availability. Confidence in the SA accuracy seems to be sensitive to factors other than those that affect SA accuracy. The divergence between the accuracy and drivers' confidence provides a measure of meta–SA. A poor correlation between accuracy and confidence indicates a situation where the driver does not recognize how much he or she does not know. This correlation was lower for older drivers (r=0.11) compared to younger drivers (r=0.21). Figure 15 shows the relationship between SA accuracy and perceived SA accuracy. Not only are older drivers' perceptions poorly correlated with their accuracy, they consistently overestimate their accuracy. Figure 15 shows that even though older drivers' SA is lower than that of younger drivers, their confidence is greater.

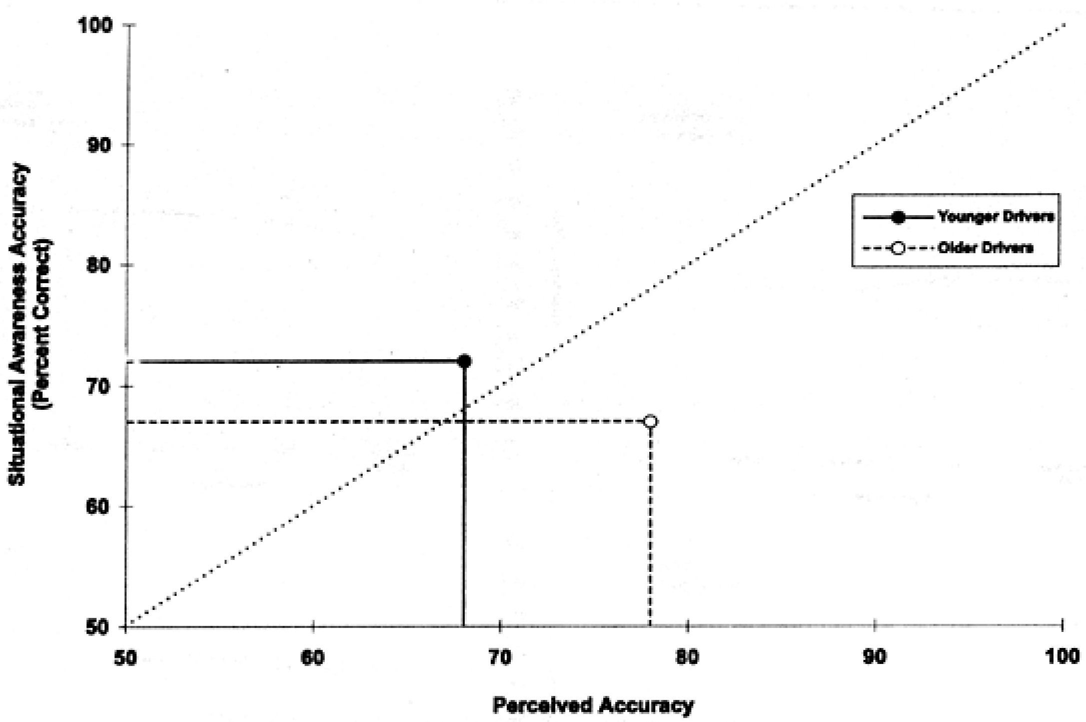


Figure 15. Situational awareness accuracy and perceived accuracy for younger and older drivers.

Figure 16 shows a three–way interaction between gender, age, and style, $F(1, 16) = 6.24$, $p<0.05$, and a two–way interaction between age and style, $F(1, 16) = 7.30$, $p<0.05$. These interactions show that older females are particularly confident in their SA query responses when they receive command–style messages, while younger females are more confident when they receive notification–style messages. Message style does not seem to influence the confidence of male drivers. This effect is similar to that for mental demand and trust. Younger females react more positively to notification–style messages compared to older females, who react more positively to command–style messages.

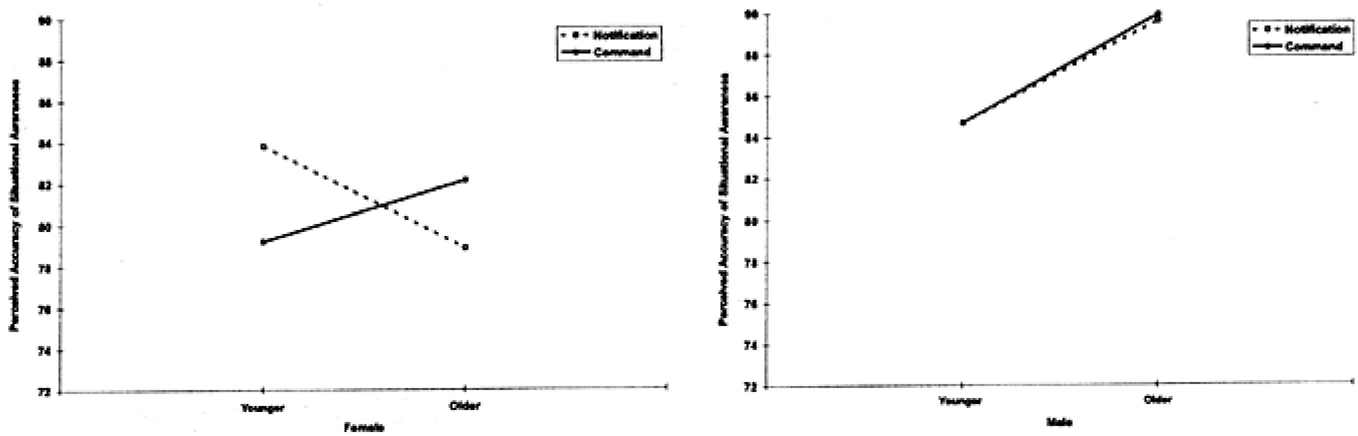


Figure 16. The effect of gender, age, and message style on the confidence in situational awareness accuracy.

The message acknowledgment latency shows no significant effects, but the percentage of correct responses reflect driver age, $F(1, 16) = 13.18$, $p<0.005$. Younger drivers respond more often than older drivers (95 percent compared to 81 percent). In addition, drivers acknowledge text messages (92 percent) more than auditory messages (85 percent), $F(1, 16) = 6.38$, $p<0.05$.

Information theory provides a useful framework to further analyze the attention devoted to road signs and ATIS messages. Signal–detection theory describes the ability to detect signals in terms of sensitivity (d') and the response criterion (). d' and should reflect differences in the relative salience of the ATIS compared to roadway messages. This analysis shows whether or not drivers are more sensitive to in–vehicle messages.

Tables 14 and 15 show the drivers' responses to ATIS messages and roadway signs. A', a non–parametric measure of d', has been calculated because it is less dependent on assumptions compared to d' (Wickens, 1984). Drivers appear slightly more sensitive to ATIS messages, but they respond in a more conservative manner compared to their responses to road signs. This probably reflects the greater diversity of cues from the roadway compared to the in–vehicle information sources, which may have prompted drivers to acknowledge in–vehicle messages as if they were roadway messages. As the similarity of the tables suggests, drivers detect and acknowledge ATIS and roadway messages in very similar ways. These similarities, together with the traditional analysis of variance, suggest that the acknowledgment of messages does not differ for ATIS or road signs.

Table 14. Responses to ATIS messages (A' = 0.94, = 0.97).

Response	Message	No Message
Acknowledgment (percent)	1123 (65.0)	44 (2.5)
No Acknowledgment (percent)	157 (9.1)	404 (23.4)

Table 15. Responses to road signs (A' = 0.91, = 1.10).

Response	Message	No Message
Acknowledgment (percent)	1120 (64.8)	77 (4.5)
No Acknowledgment (percent)	160 (9.3)	371 (21.5)

Tables 16 and 17 summarize the statistical analyses for situation awareness and workload, and message acknowledgment, respectively.

Table 16. Summary of significant effects for situation awareness and effort.

Effects	Situation awareness		Effort	
	Accuracy	Confidence	Mental	Physical
A			***	****
G		*		
MxAxG		*		
SxA		*	**	
SxAxG		*		
I	****			
IxA	**			
MxS				*
MxSxAxG			*	
MxSxAxL		*		
MxSxGxL		**		
SxIxA			**	
SxIxAxG			***	
MxSxIxG				*

* *p*<0.05, ** *p*<0.01, *** *p*<0.005, **** *p*<0.001.

Table 17. Summary of significant effects for message acknowledgment.

Effects	Percent Hits	Latency
Age (A)	**	
Mode (M)	*	
ATIS vs. Roadway xMxA	*	
ATIS vs. Roadway x M x Style (S)	*	

* *p*<0.05, ** *p*<0.01.

CHAPTER 4. CONCLUSIONS AND DESIGN IMPLICATIONS

Figure 17 summarizes the ATIS and driver characteristics that this experiment considered. The effects of these characteristics on driving safety and warning compliance were analyzed using a range of intervening variables and direct measures. The results of the analysis have both general and specific implications for the design and evaluation of ATIS.

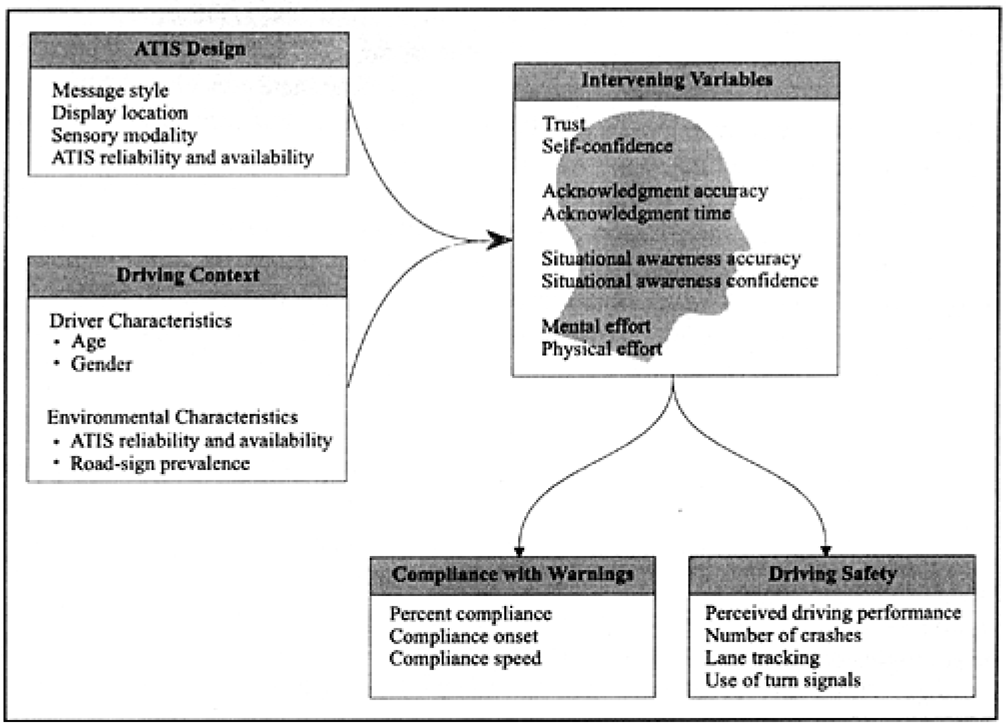


Figure 17. The variables examined in this study.

GENERAL CONCLUSIONS

A general issue facing ATIS designers is the concern that ATIS warning messages may go unheeded by drivers. A critical element of ATIS design concerns designing an ATIS device that makes information easily accessible and compelling so the drivers comply with the warnings. The results show converging evidence that ATIS warnings can generate a greater compliance compared to road signs; however, the effects on trust and self–confidence show that certain ATIS designs may undermine drivers' relationships with the ATIS device, leading to overreliance and reduced safety. The results also show that ATIS design characteristics can be manipulated to affect the level of driver compliance.

Another general issue that faces ATIS design is its potential to undermine driving safety. Based on the information processing and mental workload paradigm, many have suggested that an improperly designed ATIS device could jeopardize driving safety by overloading drivers. Multiple–resource theory predicts that this will be particularly critical for devices that force drivers to share their visual resource between reading ATIS warnings and the driving task. Measures of workload, driving performance, and situation awareness all suggest that multiple–resource theory and the mental workload paradigm does not explain safety decrements associated with the design characteristics of the ATIS.

This investigation hypothesized another safety concern. An improperly designed ATIS device might jeopardize safety by leading drivers to favor in–vehicle information sources and ignore critical roadway information. The results of this experiment show that ATIS devices can undermine driver performance by fostering an overreliance on ATIS information. The effects associated with workload, situation awareness, and driving safety measures all support this assertion. The results show little evidence that information overload undermines safety. Instead of workload–related safety problems, it seems that the ATIS may induce "complacency" as discussed in Singh, Molloy, and Parasuraman (1993). It seems that ATIS information may lead drivers to become complacent, focusing on in–vehicle information while disregarding important, out–of–vehicle information. More specifically, complacency may reflect inappropriate cue utilization (Hammond, 1966). The ATIS messages, particularly the command messages, may appear as a particularly salient cue that is weighted more heavily than more important roadway information. The results also show how particular ATIS design characteristics can exacerbate the overreliance and its negative effects on driving safety.

Not surprisingly, driver age emerged as an important variable that moderates the effectiveness of the ATIS. Although the overall driving performance of older drivers was worse than that for younger drivers, the negative effects on safety of the ATIS messages are less pronounced for older drivers compared to younger drivers. One explanation for this effect is the extensive driving experience of older drivers. The more extensive experience may provide older drivers with better strategies for sampling the environment and combining information from the ATIS and the roadway. Older drivers may use their experience to weight in–vehicle cues more appropriately than younger drivers. In addition, older drivers seem more likely to trust the capabilities of the ATIS, even when ATIS information is not consistently available. These results build upon those described by Kantowitz, et al. (1997). Their findings suggest that a different process governs the trust and self–confidence of older and younger drivers. They suggest that younger drivers use the ATIS based on their subjective feelings, while older drivers' use of the system alters their feelings. This suggests a greater inertia in older drivers' level of trust. Our data support this conjecture because the trust of older drivers was generally higher and did not drop when ATIS information was unreliable. This result is counter to previous research, but it is consistent with the process proposed by Kantowitz, et al. (1997). If drivers automatically receive information from an ATIS, older drivers learn to trust it more than younger drivers. If an ATIS device requires drivers to request information, then younger drivers' initial trust will lead them to use it more and older drivers may not learn to trust it.

Gender interacted with driver age and message style. Several converging effects suggest that younger women assimilate ATIS notification messages more effectively than command messages. The opposite is true for older women who assimilate command messages more effectively. In general, men assimilate notification messages more easily than command messages. These results show that complex sociological trends might complicate the design of ATIS devices.

DESIGN IMPLICATIONS

The implication for design guidelines is summarized briefly, followed by a more detailed description of the more important outcomes of this investigation.

Specific Design Guidelines and a Suggestion for Future Experiments

These results can be summarized with several recommendations:

- Where possible, ATIS information should be paired with redundant roadway information.
- Command–style messages without redundant roadway information should be used for only high–criticality information that requires the driver's immediate response.

- Command–style messages should be used for medium–criticality information only when they can be paired with redundant roadway information.
- Notification messages should be paired with redundant roadway information and used for low–criticality information.
- Complex interactions with age and gender suggest that systems may require options that can be tailored to the specific requirements of the driver.
- Younger drivers should receive additional training so that they do not become over reliant on ATIS information.
- Text–based messages should be used to preserve drivers' trust where ATIS information is not consistently available.
- Command messages should be used as infrequently as possible because they undermine drivers' trust in the system and self–confidence in their abilities to extract the information from roadway sources.
- Subjective estimates of situation awareness are not well–correlated with objective measures, suggesting that future studies should include objective measures of situation awareness when possible.

An important design implication concerns the implementation of ATIS devices relative to the infrastructure of standard and changeable–message road signs. Figure 18 shows the effects on safety and compliance for the different levels of ATIS and road–sign information. This figure shows that providing drivers with only ATIS information leads to a high level of compliance, but it can also compromise safety. The figure also shows that providing ATIS information with redundant road–sign information generates a high level of compliance without the associated decline in safety. When no ATIS information is available, compliance is relatively low.

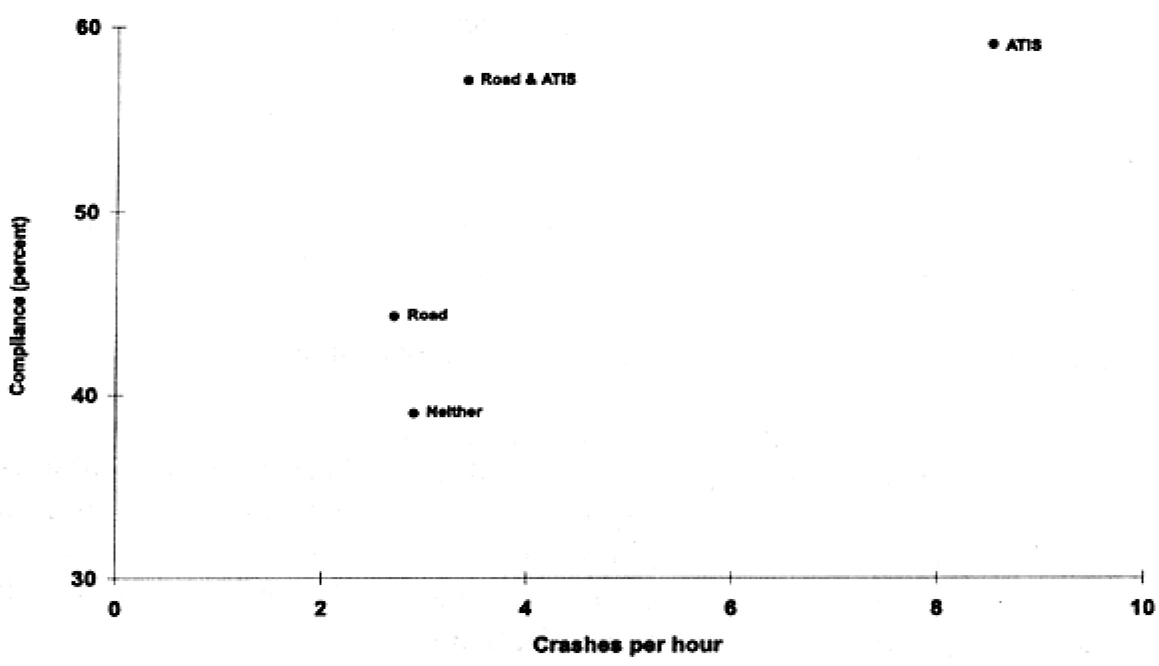


Figure 18. The design trade-off between driving safety and warning compliance for different levels of roadway redundancy.

Message style emerged as a critical ATIS design characteristic. This design characteristic has not been widely studied, but the results suggest that it has a more powerful effect on driver behavior than more commonly studied characteristics, such as display modality. Message style influences both compliance and safety. Figure 19 shows the design trade–offs for message style and the redundancy of roadway signs. Given the consequences for safety and compliance, command messages should be reserved for safety–critical situations. This is particularly true for situations where redundant roadway information is not provided. Specifically, the effect of message style in figure 19 suggests that the importance of the messages needs to be considered when choosing a message style. The four quadrants of figure 19 link the importance of the message to the style in which it should be presented. High–criticality messages should use a command style, while low–criticality messages should use a notification style with redundant roadway information.

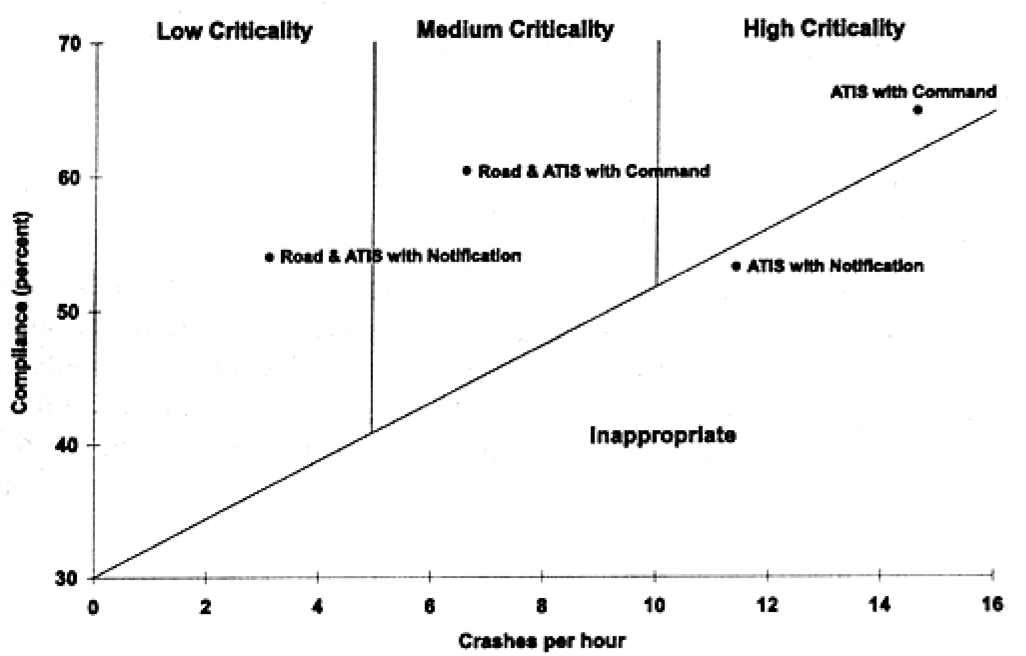


Figure 19. The design trade-off between driving safety and warning compliance for different message styles.

Command and notification message styles also had a great effect on drivers' trust in the ATIS and self–confidence. Figure 20 shows that the command message style undermines both trust and self–confidence. This situation will leave drivers in a double–bind situation, where they feel uncomfortable using the ATIS information, but have little alternative because they do not have confidence in their abilities.

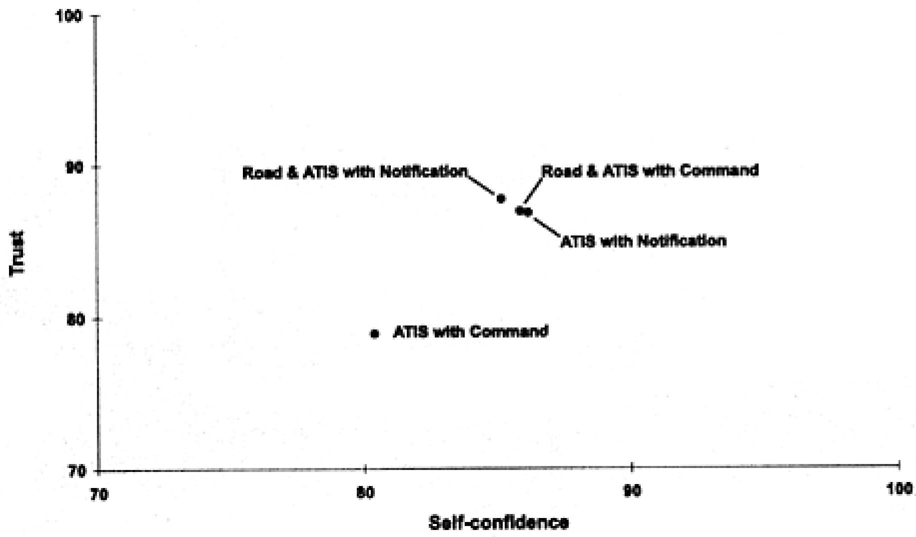


Figure 20. The design trade-off between trust and self-confidence for different message styles.

Message modality and location had little consistent effect on safety or compliance and so the results do not suggest any guidance beyond those that currently exist for these characteristics.

The design implication generated by this experiment addresses in–route IVSAWS and ISIS messages. These implications may also apply to route–guidance messages, but this should be validated. Furthermore, these conclusions are based on the results of a single experiment and further investigation is needed to confirm them and establish the limits of their application in ATIS guidelines. The Battelle automotive simulator is a relatively low–fidelity simulator, which can be considered as a "microworld" (Brehmer, 1990). As a microworld, the simulator presents the driver with many of the same demands and circumstances faced in actual driving scenarios; however, the limited field of view, low resolution of images, and the novelty of the ATIS messages limit generalizability of the results. Studies using more realistic driving simulators and on–road driving will help validate the findings of this study.

APPENDIX A: SUBJECT SELECTION PHONE QUESTIONNAIRE AND DRIVER DEMOGRAPHIC CHARACTERISTICS QUESTIONNAIRE

Subject Name ____________________________

Sub ID _______ Age _______ Gender ____ (1=M, 2=F)

Note to Experimenter: DO NOT read the following "Purpose" to subjects.

Purpose: Before a subject can be selected to participate in Task K/Experiment 4, he or she must have an active driver's license, drive at least twice per week, and not be prone to motion sickness.

Questions:

1. Do you have an active driver's license? Yes (1) No (2)
2. How many times per week do you drive in Seattle or the surrounding areas?
   < 1X (1) 1X (2) 2-3X (3) 4 + (4)
3. How often do you experience motion sickness when driving?
   Never (1) Sometimes (2)* Often (3)**

*Experimenter: if subject answers "sometimes" to experiencing motion sickness, ask them further questions to try and assess if this is likely to be a problem in the simulator. If so, go to **!

** Experimenter: if the subject answers "often" to experiencing motion sickness, inform them of the following:

One potential risk with any simulator study is the possibility of "simulator sickness." Simulator sickness is similar to the motion sickness that some experience when traveling in a vehicle. Because you often experience motion sickness, there might be a chance of you experiencing motion sickness from our simulator. We don't want this to happen, so unfortunately you won't be able to participate in this study. We do, however, greatly appreciate your time and interest, and if you like, we can put you on our list for other experiments. That way, if we have a need for subjects at any time in the future, we will contact you.

Scoring:

1. All subjects MUST have an active driver's license.
2. Subjects must drive at least two times/week.
3. Subjects must not experience motion sickness "often."

DRIVER DEMOGRAPHIC CHARACTERISTICS (ASKED BY PHONE)

Note to Experimenter: DO NOT read the following "Purpose" to subjects.

Purpose: In this section, the questions we ask will give us an idea of the subject's background and use of certain kinds of devices. For some questions you will need to fill in a number or word. For other questions, you can answer by placing an "X" in the box that applies to the subject.

1. Age: _____

2. Number of years as a licensed driver: _____

3. Number of years driving in Seattle: _____

4. Number of years lived in Seattle: _____

5. Community of residence: ________________________ Zip Code_____________
(i.e., Greenlake, First Hill, University district, etc.)

6. Gender: Male (1) Female (2)

7. Marital status: ______ [single (1), married (2), other (3)]

8. Number of family members in household (including yourself): _____

9. Do you own your own automobile? Yes (1) No (2)

For the vehicle you most frequently drive, what is its:

9a. Make

9b. Model

9c. Year

10. What is the average number of miles you drive annually?

- less than 5,000 (1)
- 5,000 – 9,999 (2)
- 10,000 – 19,999 (3)
- 20,000 – 39,999 (4)
- 40,000 – 69,999 (5)
- 70,000 – 99,999 (6)
- more than 100,000 (7)

11. For each of the following trip types, please estimate the number of trips per week you make by driving your automobile (round trip).

11a. _____ commute to work

11b. _____ shopping trips & errands

11c. _____ social visits

11d. _____ recreation

12. How many times per year do you drive your car in an unfamiliar town? _____

13. Which of the following features does the vehicle you most frequently use have?

13a. air bags Yes (1) No (2)

13b. anti-lock brakes (ABS) Yes (1) No (2)

13c. cassette player Yes (1) No (2)

13d. cellular phone/radio phone Yes (1) No (2)

13e. cruise control Yes (1) No (2)

13f. electronic dashboard displays Yes (1) No (2)

13g. garage door opener Yes (1) No (2)

13h. power brakes Yes (1) No (2)

13i. power steering Yes (1) No (2)

13j. power windows and door locks Yes (1) No (2)

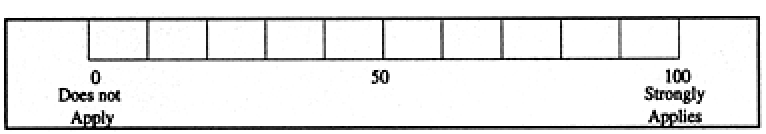
13k. radar detector Yes (1) No (2)

Experimenter: For each of the following devices, indicate if the subject owns the device by marking an "X" in the "OWN" column. Then indicate if they use the device by marking an "X" in the "USE" column. For the devices they use, indicate how frequently they use each device by entering a number in the "FREQUENCY OF USE" column (e.g., once a month, three times a week).

DEVICE	OWN	USE	FREQUENCY OF USE (per week)
Automatic teller machine (ATM) card	14)	15)	16)
Video cassette recorder (VCR)	17)	18)	19)
Hand-held calculator	20)	21)	22)
Cordless phone	23)	24)	25)
Microwave oven	26)	27)	28)
Personal computer			
DOS	29)	30)	31)
Windows	32)	33)	34)
Macintosh	35)	36)	37)
Computer bulletin boards / e-mail	N/A	38)	39)
Telephone answering machine / voice messaging	40)	41)	42)

43) For this question, I'm going to read a sentence and I would like you to decide how much it applies to you on a scale of 0 to 100, with 0 being "does not apply" and 100 being "strongly applies":

"I feel comfortable using new technology (for example, programming my VCR, using special functions on my telephone answering machine, or working with computers)."



APPENDIX B: PRE/POST–STUDY QUESTIONNAIRES

Subject ID _____

Pre–Study Questionnaire
How Comfortable Are You With Computers?

It is important for us to understand how comfortable you feel with computers. Please mark with an "X" to indicate how much each statement below applies to you. Marking toward the 100 indicates that a statement strongly applies. Marking toward the 0 indicates that it does not apply.

1. I am sure I could do work with computers.

0 Does not Apply					50				100 Strongly Applies

2. I would like working with computers.

0 Does not Apply					50				100 Strongly Applies

3. I would feel comfortable working with computers.

0 Does not Apply					50				100 Strongly Applies

4. Working with a computer would make me very nervous.

0 Does not Apply					50				100 Strongly Applies

5. I do as little work with computers as possible.

0 Does not Apply					50				100 Strongly Applies

6. I think using a computer would be very hard for me.

0 Does not Apply					50				100 Strongly Applies

Subject ID _____

Pre–Study Questionnaire
How Comfortable Are You With Computers?

It is important for us to understand how comfortable you feel with computers. Please mark with an "X" to indicate how much each statement below applies to you. Marking toward the 100 indicates that a statement strongly applies. Marking toward the 0 indicates that it does not apply.

1. I am sure I could do work with computers.

0 Does not Apply					50					100 Strongly Applies

2. I would like working with computers.

0 Does not Apply					50					100 Strongly Applies

3. I would feel comfortable working with computers.

0 Does not Apply					50					100 Strongly Applies

4. Working with a computer would make me very nervous.

0 Does not Apply					50					100 Strongly Applies

5. I do as little work with computers as possible.

0 Does not Apply					50					100 Strongly Applies

6. I think using a computer would be very hard for me.

0 Does not Apply					50					100 Strongly Applies

APPENDIX C: SUBJECTIVE MEASURES, SITUATION AWARENESS QUESTIONS, AND ATIS MESSAGES

Subjective Measures

TRUST

How well was the ATIS system able to notify you of roadway conditions and hazards?

0___________________________________100

SELF–CONFIDENCE

How well were you able to identify roadway conditions and hazards?

0___________________________________100

MENTAL DEMAND

How much thinking was required to operate this vehicle?

0___________________________________100

PHYSICAL DEMAND

How much physical activity was required to operate this vehicle?

0___________________________________100

DRIVING PERFORMANCE

How safely were you able to drive?

0___________________________________100

CONFIDENCE

How confident are you in your answer to the previous question?

0___________________________________100

<u>Questions for Situation Awareness Queries</u>

<u>Level 1</u>

Perception of relevant information

1. Did you receive a message from ATIS in the last 30 seconds?

a. yes b. no

2. What is your current speed?

a. > 40 mph b. < 40 mph

3. Which lane are you currently in?

a. right b. left

4. What color was the light through which you most recently passed?

a. green b. yellow

5. On what side of the road were the last pedestrians?

a. right b. left

6. At the last intersection, from which side was the cross traffic coming?

a. right b. left

7. How many pedestrians were at the last intersection?

a. one b. two

8. Is there currently a vehicle ahead of you in the right lane?

a. yes b. no

<u>Level 2</u>

Comprehension of the meaning of the information

9. Which action did the most recent ATIS message call for?

a. reduce speed b. change lanes

10. What is the speed of the car ahead relative to your speed?

a. slower b. faster

11. What did your last message from the ATIS warn you about?

a. icy road ahead b. curve in road ahead

12. What was the billboard that you most recently passed advertising?

a. food b. gas

13. What did your last message from the ATIS warn you about?

a. disabled vehicle b. construction

Level 3

Using the information to predict future events

14. Should you be driving less than 35 mph over the next 30 seconds?

a. yes b. no

15. Will you need to be in the left lane in the next 30 seconds?

a. yes b. no

Instance	Message	Appropriate Response
Group 1		
1. Icy road	a. Icy road ahead (A) b. Slow down (C)	Slow down
2. Curve in road	a. Curved road ahead (A) b. Slow down (C)	Slow down
3. Speed-limit change	a. 25-mph zone ahead (A) b. Slow down to 25-mph (C)	Slow down
4. Pedestrian crossing	a. Pedestrian crossing ahead (A) b. Slow down (C)	Slow down
Group 2		
5. Transit lane	a. Transit-only right lane (A) b. Merge left (C)	Merge left
6. Accident ahead	a. Accident ahead in right lane (A) b. Merge left (C)	Merge left
7. Disabled vehicle	a. Disabled vehicle ahead (A) b. Merge left (C)	Merge left
8. Construction ahead	a. Construction in right lane (A) b. Merge left (C)	Merge left

A=Advisory
C=Command

Group 1. Messages requiring responses involving vehicle speed.
Group 2. Messages requiring responses involving vehicle position

APPENDIX D: SCENARIO EVENT DOCUMENTATION

Events for Scenario 1.1

Distance (ft)	Roadway Event	ATIS Message	Roadway Information
400	speed limit 40 mph sign		
1900	billboard: "TACO BELL"		
3725		ATIS message: merge left	
3725			roadway disabled vehicle sign legible
4650	**disabled vehicle**		
5425		ATIS message: slow down to 25 mph	
5425			roadway speed zone ahead sign legible
5700	intersection (green light)		
5700	1 pedestrian (right)		
5900	SA query		
6150	**speed limit 25 mph**		
7000	intersection		
7000	cross traffic from left		
8700	intersection (red light)		
8925		ATIS message: merge left	
8925			roadway transit only sign legible
9100	**speed limit 40 mph**		
9500	**transit lane begins** (right lane closed)		
10900	**transit lane ends** (right lane open)		
11000	billboard: "MOTEL 6"		

12725		ATIS message: slow down	
12725			roadway icy road sign legible
13200	icy road sign		
13500	**ice begins**		
14900	**ice ends**		
16000	end simulation		

Situation Awareness Query:

3. Which lane are you currently in?

a. right b. left

7. How many pedestrians were at the last intersection?

a. one b. two

9. Which action did the most recent ATIS message call for?

a. reduce speed b. change lanes

14. Should you be driving less than 35 mph over the next 30 seconds?

a. yes b. no

Events for Scenario 1.2

Distance (ft)	**Roadway Event**	**ATIS Message**	**Roadway Information**
400	speed limit 40 mph sign		
1120	1 pedestrian (left)		
3125		ATIS message: slow down	
3600	**ice begins**		
4600	**ice ends**		
5500	billboard: "CHEVRON"		
6450		ATIS message: slow down	

6450			roadway Ped Xing sign legible
6475	2 pedestrians (right)		
6500	intersection (traffic from left)		
6925	SA query		
7000	**crosswalk**		
10250		ATIS message: merge left	
10300	billboard: "MOTEL 6"		
10300	**disabled vehicle**		
12425		ATIS message: merge left	
13400	**construction zone begins** (right lane closed)		
13650	1 pedestrian (right)		
13900	intersection (green light)		
13900	cross traffic (idle)		
14100	1 pedestrian (right)		
14350	1 pedestrian (right)		
14800	**construction zone ends** (right lane open)		
16600	end simulation		

Situation Awareness Query:

7. How many pedestrians were at the last intersection?

a. one **b. two**

1. Did you receive a message from ATIS in the last 30 seconds?

a. yes b. no

12. What was the billboard that you most recently passed advertising?

a. food **b. gas**

14. Should you be driving less than 35 mph over the next 30 seconds?

a. yes b. no

Scenario 1.3

Distance (ft)	Roadway Event	ATIS Message	Roadway Information
400	speed limit 40 mph sign		
600	intersection (green light)		
800	car approaching		
1425			roadway transit only sign legible
2000	**transit lane begins** (right lane closed)		
3000	**transit lane ends** (right lane open)		
3850			roadway curve ahead sign legible
3850		ATIS message: slow down	
4200	**curve begins**		
4700	**curve ends**		
5400	1 pedestrian (right)		
6000	intersection (yellow light)		
6300	billboard: "TACO BELL"		
6420			roadway road work ahead sign legible
6895	SA query		
7000	**construction zone begins** (right lane closed)		
7350	1 pedestrian (right)		
8050	1 pedestrian (right)		
8400	**construction zone ends** (right lane open)		
12000	billboard: "ARCO"		
12000			roadway speed zone ahead sign legible
12650	**speed limit 25 mph**		

14050	**speed limit 40 mph**		
14250	2 pedestrians (left)		
16000	end simulation		

Situation Awareness Query:

4. What color was the light through which you most recently passed?

a. green **b. yellow**

8. Is there currently a vehicle ahead of you in the right lane?

a. yes **b. no**

12. What was the billboard that you most recently passed advertising?

a. food b. gas

14. Should you be driving less than 35 mph over the next 30 seconds?

a. yes b. no

Scenario 1.4

Distance (ft)	**Roadway Event**	**ATIS Message**	**Roadway Information**
400	speed limit 40 mph sign		
1600	intersection (green light)		
2000	**construction zone begins** (right lane closed)		
3400	**construction zone ends** (right lane open)		
3900	intersection – cross traffic (left)		
6600	**curve left begins**		
7100	**curve left ends**		
8700	billboard: "WENDY'S"		
9500	2 pedestrians (left)		
10150	SA query		

10400	**accident zone begins** (right lane closed)		
11800	billboard: "EXXON"		
12100	**accident**		
13500	**accident zone ends** (right lane open)		
16275			roadway Ped Xing sign legible
16275		ATIS message: slow down	
16700	billboard: "ARBY'S" visible		
16750	**crosswalk**		
16750	1 pedestrian (right)		
17000	billboard: "ARBY'S"		
17500	end simulation		

Situation Awareness Query:

5. On what side of the road were the last pedestrians?

a. right **b. left**

3. Which lane are you currently in?

a. right b. left

10. What is the speed of the car ahead relative to your speed?

a. slower **b. faster**

15. Will you need to be in the left lane in the next 30 seconds?

a. yes **b. no**

Scenario 2.1

Distance (ft)	Roadway Event	ATIS Message	Roadway Information
400	speed limit 40 mph sign		
1225			roadway road work ahead sign legible
1225		ATIS message: construction in right lane	
1900	**road work begins** (right lane closed)		
4800	**road work ends** (right lane open)		
4800	billboard: "ARCO"		
5100	2 pedestrians (left)		
6550			roadway curve ahead sign legible
6550		ATIS message: curved road ahead	
7500	**curve begins**		
8000	**curve ends**		
11000	intersection (green light) – cross traffic left		
11300	pedestrian (right)		
11425			roadway disabled vehicle sign legible
11425		ATIS message: disabled vehicle ahead	
12000	SA query		
12450	**disabled vehicle**		
12925			roadway speed zone ahead sign legible
12925		ATIS message: speed zone ahead	
13100	intersection (yellow light)		

13600	**speed limit 25 mph**		
15000	**speed limit 40 mph**		
16800	billboard: "WENDY'S" legible		
17000	billboard: "WENDY'S"		
17100	end simulation		

<u>Situation Awareness Query:</u>

6. At the last intersection, from which side was the cross traffic coming?

a. right **b. left**

2. What is your current speed?

a. > 40 mph **b. < 40 mph**

13. What did your last message from the ATIS warn you about?

a. disabled vehicle b. construction

15. Will you need to be in the left lane in the next 30 seconds?

a. yes b. no

<u>Scenario 2.2</u>

<u>Distance (ft)</u>	**<u>Roadway Event</u>**	**<u>ATIS Message</u>**	**<u>Roadway Information</u>**
400	speed limit 40 mph		
1400	2 pedestrians (right)		
2575		ATIS message: accident ahead right lane	
3100	**accident zone begins** (right lane closed)		
4400	traffic ahead		
5100	**accident**		
5700	**accident zone ends** (right lane open)		
7100	billboard: "MARRIOTT"		

7625			roadway Ped Xing sign legible
7625		ATIS message: pedestrian crosswalk ahead	
8150	**crosswalk**		
10825		ATIS message: icy road ahead	
11300	**ice begins**		
12700	**ice ends**		
13000	billboard: "CHEVRON"		
13150		ATIS message: disabled vehicle ahead	
13400	intersection (yellow light)		
14025	SA query		
14150	**disabled vehicle**		
16985	1 pedestrian (left)		
17000	end simulation		

Situation Awareness Query:

1. Did you receive a message from ATIS in the last 30 seconds?

a. yes b. no

4. What color was the light through which you most recently passed?

a. green **b. yellow**

12. What was the billboard that you most recently passed advertising?

a. food **b. gas**

14. Should you be driving less than 35 mph over the next 30 seconds?

a. yes b. no

Scenario 2.3

Distance (ft)	Roadway Event	ATIS Message	Roadway Information
400	speed limit 40 mph		
1800	intersection (green light)		
1800	2 pedestrians (right)		
2250			roadway transit only sign legible
2400	**transit lane begins** (right lane closed)		
2725	SA query		
3525	**transit lane ends** (right lane closed)		
4700	intersection		
5425			roadway curve ahead sign legible
6000	**curve left begins**		
6500	**curve left ends**		
6700	billboard: "ARBY'S"		
7500	intersection		
8225			roadway road work ahead sign legible
8225		ATIS message: road work ahead	
8900	**road work begins** (right lane closed)		
10200	billboard: "EXXON"		
11600	**road work ends** (right lane open)		
13300	2 pedestrians (right)		
14500			roadway Ped Xing sign legible
15850	**crosswalk**		
16100	end simulation		

Situation Awareness Query:

8. Is there currently a vehicle ahead of you in the right lane?

a. yes **b. no**

7. How many pedestrians were at the last intersection?

a. one **b. two**

10. What is the speed of the car ahead relative to your speed?

a. slower **b. faster**

15. Will you need to be in the left lane in the next 30 seconds?

a. yes b. no

Scenario 2.4

Distance (ft)	Roadway Event	ATIS Message	Roadway Information
400	speed limit 40 mph		
1230	intersection (yellow light)		
1800	SA query		
2300	**accident zone begins** (right lane closed)		
4100	**accident**		
4100	**accident zone cleared** (right lane open)		
4150		ATIS message: speed zone ahead	
4325			roadway speed zone sign legible
4850	**speed limit 25 mph**		
6250	**speed limit 40 mph**		
8000	billboard: "HILTON"		
10100	2 pedestrians (left)		
11800	**ice begins**		

13250	**ice ends**		
13600	billboard: "CHEVRON"		
14950	**transit lane begins**		
15850	**transit lane ends**		
16230	intersection (green light)		
16700	billboard: "TACO BELL"		
17000	end simulation		

Situation Awareness Query:

3. Which lane are you currently in?

a. right b. left

4. What color was the light through which you most recently passed?

a. green **b. yellow**

10. What is the speed of the car ahead relative to your speed?

a. slower **b. faster**

15. Will you need to be in the left lane in the next 30 seconds?

a. yes b. no

Scenario 3.1

Distance (ft)	**Roadway Event**	**ATIS Message**	**Roadway Information**
400	speed limit 40 mph sign		
1400	billboard: "TACO BELL"		
1575			roadway disabled vehicle sign legible
1575		ATIS message: disabled vehicle ahead	
1600	intersection (green light)		
1600	cross traffic (right)		

2150	SA query		
2500	**disabled vehicle**		
2950			roadway transit lane only sign legible
2950		ATIS message: transit only right lane	
3500	**transit lane begins**		
3725	**transit lane ends**		
5200	intersection with cross traffic right		
8800	2 pedestrians (right)		
9725			roadway icy road sign legible
9725		ATIS message: icy road ahead	
10325	1 pedestrian (right)		
10500	**ice begins**		
10500	billboard: "CHEVRON"		
11900	**ice ends**		
12925		ATIS message: curved road ahead	
12925			roadway curve ahead sign legible
13800	**curve left begins**		
14300	**curve left ends**		
16000	end simulation		

<u>Situation Awareness Query:</u>

1. Did you receive a message from ATIS in the last 30 seconds?

a. yes b. no

6. At the last intersection, from which side was the cross traffic coming?

a. right b. left

12. What was the billboard that you most recently passed advertising?

a. food b. gas

15. Will you need to be in the left lane in the next 30 seconds?

a. yes b. no

Scenario 3.2

Distance (ft)	Roadway Event	ATIS Message	Roadway Information
400	speed limit 40 mph		
1600	intersection (green light)		
2225			roadway icy road sign legible
2225		ATIS message: icy road ahead	
2900	**ice begins**		
4300	**ice ends**		
4500	billboard: "ARCO"		
5050		ATIS message: accident ahead in right lane	
5525	SA query		
6000	**accident zone begins** (right lane closed)		
7250	1 pedestrian (left)		
7700	**accident**		
8100	**accident zone ends** (right lane open)		
9325		ATIS message: construction in right lane	
11510	2 pedestrians (right)		
13500	intersection with cross traffic right		
13850		ATIS message: 25 mph zone ahead	
14700	**speed limit 25 mph**		
16100	**speed limit 40 mph**		
18500	end simulation		

Situation Awareness Query:

2. What is your current speed?

a. > 40 mph b. < 40 mph

8. Is there currently a vehicle ahead of you in the right lane?

a. yes **b. no**

11. What did your last message from the ATIS warn you about?

a. accident b. icy road

14. Should you be driving less than 35 mph over the next 30 seconds?

a. yes b. no

Scenario 3.3

Distance (ft)	Roadway Event	ATIS Message	Roadway Information
400	speed limit 40 mph		
1200		ATIS message: construction zone	
1200			roadway road work ahead sign legible
1200	billboard: "WENDY'S"		
1700	**construction zone begins** (right lane closed)		
3900	**construction zone ends** (right lane open)		
4050	1 pedestrian		
4150			roadway Ped Xing sign legible
4920	intersection (green light)		
4950	**crosswalk**		
4955	2 pedestrians (left)		
5150			roadway curve ahead sign legible

5525	SA Query		
6100	**curve left begins**		
6600	**curve left ends**		
8750	intersection (red light)		
9025			roadway transit only sign legible
9500	**transit lane begins** (right lane closed)		
10750	**transit lane ends** (right lane open)		
11000	billboard: "MOTEL 6"		
16000	end simulation		

Situation Awareness Query:

3. Which lane are you currently in?

a. right b. left

5. On what side of the road were the last pedestrians?

a. right **b. left**

10. What is the speed of the car ahead relative to your speed?

a. slower b. faster

14. Should you be driving less than 35 mph over the next 30 seconds?

a. yes b. no

Scenario 3.4

Distance (ft)	Roadway Event	ATIS Message	Roadway Information
400	speed limit 40 mph		
3400	disabled vehicle (lane closed)		
3800	**disabled vehicle**		
4300	intersection (green light)		

5875			oadway speed zone ahead sign legible
6600	**speed limit 25 mph**		
8000	**speed limit 40 mph**		
8200	billboard: "EXXON"		
9400	billboard: "MARRIOTT"		
9800	intersection (no light)		
9800	cross traffic (left)		
9900	1 pedestrian (right)		
9950		ATIS message: accident ahead in right lane	
10300	SA query		
10500	**accident zone begins** (right lane closed)		
12000	**accident**		
13300	**accident zone ends** (right lane open)		
15550	**crosswalk**		
16500	end simulation		

Situation Awareness Query:

6. At the last intersection, from which side was the cross traffic coming?

a. right **b. left**

5. On what side of the road were the last pedestrians?

a. right b. left

10. What is the speed of the car ahead relative to your speed?

a. slower **b. faster**

15. Will you need to be in the left lane in the next 30 seconds?

a. yes b. no

Scenario 4.1

Distance (ft)	Roadway Event	ATIS Message	Roadway Information
400	speed limit 40 mph		
1625		ATIS message: slow down	
1625			roadway icy road sign legible
2400	**ice begins**		
3800	**ice ends**		
4425		ATIS message: slow down	
4425			roadway speed zone ahead sign
6300	**speed limit 25 mph**		
6600	billboard: "EXXON"		
7500	**speed limit 40 mph**		
7700	1 pedestrian (right)		
8125		ATIS message: merge left	
8125			roadway disabled vehicle sign legible
8175	intersection (yellow light)		
8600	SA query		
8950	**disabled vehicle**		
11000	billboard: "ARBY'S"		
12600	2 pedestrians (left)		
13325		ATIS message: merge left	
13325			roadway road work ahead sign legible
13800			roadway construction sign
14100	**construction zone begins** (right lane closed)		

15200	green light (intersection)		
16300	**construction zone ends** (right lane open)		
16700	end simulation		

Situation Awareness Query:

5. On what side of the road were the last pedestrians?

a. right b. left

4. What color was the light through which you most recently passed?

a. green **b. yellow**

13. What did your last message from the ATIS warn you about?

a. disabled vehicle **b. construction**

14. Should you be driving less than 35 mph over the next 30 seconds?

a. yes b. no

Scenario 4.2

Distance (ft)	Roadway Event	ATIS Message	Roadway Information
400	speed limit 40 mph		
1200	intersection		
1350	2 pedestrians (right)		
1375		ATIS message: slow down	
1850	SA query		
1900	**crosswalk**		
1900	2 pedestrians (right)		
1980	intersection		
3100	billboard: "CHEVRON"		
3825			roadway curve ahead sign legible

3825		ATIS message: slow down	
4700	**curve begins**		
5400	**curve ends**		
5700	2 pedestrians (left)		
8125		ATIS message: merge left	
8600	**construction zone begins** (right lane closed)		
9800	green light (intersection)		
10900	**construction zone ends** (right lane open)		
13000	billboard: "HILTON"		
15025		ATIS message: merge left	
15400	**transit lane begins** (right lane closed)		
16525	**transit lane ends** (right lane open)		
16600	1 pedestrian (left)		
17000	end simulation		

Situation Awareness Query:

2. What is your current speed?

a. > 40 mph b. < 40 mph

7. How many pedestrians were at the last intersection?

a. one **b. two**

10. What is the speed of the car ahead relative to your speed?

a. slower **b. faster**

14. Should you be driving less than 35 mph over the next 30 seconds?

a. yes b. no

Scenario 4.3

Distance (ft)	Roadway Event	ATIS Message	Roadway Information
400	speed limit 40 mph		
700	intersection (green light)		
925			roadway curve ahead sign
1800	**curve begins**		
2500	1 pedestrian (right)		
2500	**curve ends**		
5105			roadway accident ahead sign legible
6000	**accident zone begins** (right lane closed)		
6600	**accident**		
7900	**accident zone ends** (right lane open)		
8625		ATIS message: merge left	
9000			roadway transit only sign legible
9400	**transit lane begins** (right lane closed)		
10500	**transit lane ends** (right lane open)		
11500	billboard: "TACO BELL"		
11950	intersection		
11950	cross traffic (right)		
12450	SA query		
12600	2 pedestrians (right)		
12925			roadway icy road sign legible
13600	**ice begins**		

14600	**ice ends**		
15700	intersection (green light)		
16500	end simulation		

Situation Awareness Query:

6. At the last intersection, from which side was the cross traffic coming?

a. right b. left

1. Did you receive a message from ATIS in the last 30 seconds?

a. yes **b. no**

12. What was the billboard that you most recently passed advertising?

a. food b. gas

15. Will you need to be in the left lane in the next 30 seconds?

a. yes **b. no**

Scenario 4.4

Distance (ft)	**Roadway Event**	**ATIS Message**	**Roadway Information**
400	speed limit 40 mph		
3150	**disabled vehicle**		
5275		ATIS message: slow down	
5750	**crosswalk**		
6300	car approaching from ahead		
7425	billboard: "WENDY'S"		
7530	intersection (green light)		
7530	cross traffic		
8100	SA query		
8500	**speed limit 25 mph**		
9900	**speed limit 40 mph**		

10030	intersection (green light)		
14000	2 pedestrians (left)		
15300			roadway accident ahead sign legible
15800	**accident zone begins** (right lane closed)		
17500	**accident zone ends** (right lane open)		
17700	billboard: "CHEVRON"		
18000	end simulation		

Situation Awareness Query:

2. What is your current speed?

a. > 40 mph b. < 40 mph

8. Is there currently a vehicle ahead of you in the right lane?

a. yes **b. no**

12. What was the billboard that you most recently passed advertising?

a. food b. gas

15. Will you need to be in the left lane in the next 30 seconds?

a. yes **b. no**

REFERENCES

Becker, S., and Baloff, N. (1969). Organization structure and complex problem solving. *Administrative Science Quarterly*, *14*, 260–271.

Blyth, D. (1987). *Leader and subordinate expertise as moderators of the relationship between directive leader behavior and performance*. Doctoral Dissertation. Seattle, Washington: University of Washington.

Brehmer, B. (1990). Towards a taxonomy of microworlds. In J. Rasmussen, B. Brehmer, M. de Montmollin, and J. Leplat (Eds.), *Taxonomy for analysis of work domains*. Proceedings of the first Mohawc workshop. Roskilde: Risö National Laboratory.

Brollier, C. (1984). Managerial leadership in hospital–based occupational therapy. *Dissertation Abstracts International*, *45*, 1433.

Cammalleri, J., Hendrick, H., Pittman, W., Blout, H., and Prather, D. (1973). Effects of different leadership styles on group accuracy. *Journal of Applied Psychology*, *57*, 32–37.

Crockenberg, S., and Litman, C. (1990). Autonomy as competence in 1–year–olds: Maternal correlates of child defiance, compliance, and self–assertion. *Developmental Psychology*, *26*, 961–971.

Deatherage, B.H. (1972). Auditory and other sensory forms of information presentation. In H.P. Van Cott and R.G. Kincade (Eds.), *Human engineering guide to equipment design*. Washington, DC: U.S. Government Printing Office.

Endsley, M.R. (1995a). Toward a theory of situation awareness in dynamic systems. *Human Factors*, *37*(1), 32–64.

Endsley, M.R. (1995b). Measurement of situation awareness in dynamic systems. *Human Factors*, *37*(1), 65–84.

Erlichman, J. (1992). A pilot study of the in–vehicle safety advisory and warning system (IVSAWS) driver–alert warning system design. *Proceedings of the Human Factors and Ergonomics Society 36th Annual Meeting*, 480–484. Santa Monica, CA: Human Factors and Ergonomics Society.

Fiedler, F., and Garcia, J. (1987). *New approaches to effective leadership: Cognitive resources and organizational performance*. New York: Wiley.

Hammond, K.R. (1966). Probabilistic functionalism: Egon Brunswik's integration of the history, theory, and method of psychology. In K.R. Hammond (Ed.), *The psychology of Egon Brunswik,* 15–80. New York: Holt, Rinehart & Winston.

Hellier, E.J., Edworthy, J., and Dennis, I. (1993). Improving auditory warning design: Quantifying and predicting the effects of different warning parameters on perceived urgency. *Human Factors*, *35*(4), 693–706.

Hendrix, W., and McNichols, C. (1982). Organizational effectiveness as a function of managerial style, situational environment, and effectiveness criterion. *Journal of Experimental Education*, *52*, 145–151.

Kantowitz, B. H., Hanowski, R. J., and Kantowitz, S. C. (1997). Driver reliability requirements for traffic advisory information. In I. Noy (Ed.), *Ergonomics of intelligent vehicle highway systems*,1–22. Hillsdale, NJ: Lawrence Erlbaum Associates.

Kantowitz, B.H., Lee, J.D., Becker, C.A., Bittner, A.C., Jr., Kantowitz, S.C., Hanowski, R.J., Kinghorn, R.A., McCauley, M.E., Sharkey, T.J., McCallum, M.C., and Barlow, S.T. (1996). *Development of human factors guidelines for Advanced Traveler Information Systems (ATIS) and Commercial Vehicle Operations (CVO) components of the Intelligent Vehicle–Highway System (IVHS); Task H draft report: Identify and explore driver acceptance of in–vehicle IVHS* (Report No. FHWA–RD–96–143). McLean, VA: Federal Highway Administration.

King, R.A., and Corso, G.M. (1993). Auditory displays: If they are so useful, why are they turned off? *Proceedings of the Human Factors and Ergonomics Society 37th Annual Meeting*, 549–553. Santa Monica, CA: Human Factors and Ergonomics Society.

Konrad, C.M., Kramer, A.F., and Watson, S.E. (1994). A comparison of sequential and spatial displays in a complex monitoring task. *Proceedings of the Human Factors and Ergonomics Society 38th Annual Meeting*, 1331–1335. Santa Monica, CA: Human Factors and Ergonomics Society.

Landry, S., and Chapieski, M. (1989). Joint attention and infant toy exploration: Effects of Down's syndrome and prematurity. *Child Development*, *60*, 103–118.

Landry, S., Garner, P., Pirie, D., and Swank, P. (1994). Effects of social context and mother's requesting strategies on Down's syndrome children's social responsiveness. *Developmental Psychology*, *30*, 293–302.

Lee, J.D., and Moray, N. (1994). Trust, self–confidence, and operators' adaptation to automation. *International Journal of Human–Computer Studies*, *40*, 153–184.

Lee, J.D., and Moray, N. (1992). Trust and the allocation of function in the control of automatic systems. *Ergonomics*, *35*, 1243–1270.

Lippitt, R. (1940). An experimental study of the effect of democratic and authoritarian group atmospheres. *University of Iowa Studies in Child Welfare*, *16*, 43–95.

Lytton, H. (1977). Correlates of compliance and the rudiments of consciences in two–year–old boys. *Canadian Journal of Behavioral Sciences*, *9*, 243–251.

Maurer, H., and Sherrod, K. (1987). Context of directives given to young children with Down's syndrome and non–retarded children: Development over two years. *American Journal of Mental Deficiency*, *91*, 579–590.

McCallum, M.C., Lee, J.D., Sanquist, T.F., and Wheeler, W.A. (1995). *Development of human factors guidelines for Advanced Traveler Information Systems (ATIS) and Commercial Vehicle Operations (CVO) components of the Intelligent Vehicle–Highway System (IVHS); Task B final report: ATIS and CVO development objectives and performance requirements* (Report No. FHWA–RD–95–109). McLean, VA: Federal Highway Administration.

McCormick, E.J., and Sanders, M.S. (1982). *Human factors in engineering and design*. New York: McGraw–Hill.

Miller, K., and Monge, P. (1986). Participation, satisfaction, and productivity: A meta–analytic review. *Academy of Management Journal*, *29*, 727–753.

Misumi, J., and Peterson, M. (1985). The performance–maintenance theory of leadership: Review of a Japanese research program. *Administrative Science Quarterly*, *30*, 198–223.

Moray, N. (1981). The role of attention in the detection of errors and the diagnosis of errors in man–machine systems. In J. Rasmussen and W.B. Rouse (Eds.), *Human detection and diagnosis of system failures*. New York: Plenum Press.

Rocissano, L., Slade, A., and Lynch, V. (1987). Dyadic synchrony and toddler compliance. *Developmental Psychology*, *16*, 54–61.

Rudin, S. (1964). Leadership as a psychophysiological activation of group members: A case experimental study. *Psychological Reports*, *15*, 577–578.

Schneider, W., and Shiffrin, R. (1977). Controlled and automatic human information processing. *Psychological Review, 84*, 1–66.

Shackleton, V., Bass, B., and Allison, S. (1975). *PAXIT*. Scottsville, NY: Transnational Programs.

Shaw, M.L. (1984). Division of attention among spatial locations: A fundamental difference between detection of letters and detection of luminance increments. In H. Bouma (Ed.), *Attention and performance*, 109–121. Hillsdale, NJ: Erlbaum.

Sheridan, T.B. (1982). *Supervisory control: Problems, theory, and experiment for application to human–computer interaction in undersea remote systems* (Technical Report). Cambridge, MA: MIT.

Singh, I.L., Molloy, R., and Parasuraman, R. (1993). Automation–induced "complacency": Development of the complacency–potential rating scale. *The International Journal of Aviation Psychology*, *3*(2), 111–122.

Sorkin, R.D. (1987). Design of auditory and tactile displays. In G. Salvendy (Ed.), *Handbook of human factors*. New York: Wiley.

Wickens, C.D. (1984). *Engineering psychology and human performance*. Glenview, IL: Scott, Foresman, and Company.

1. All analyses were performed with the Bio–Medical Data Processing (BMDP) Version 7.0 software package. Where appropriate, the results were interpreted using the Greenhouse–Geisser adjustment to the degrees of freedom to compensate for violations to the sphericity assumption in the repeated measures analysis of variance.