
Development of Human Factors Guidelines for Advanced Traveler Information Systems and Commercial Vehicle Operations: Investigation of ATIS Function Transition and the Effects of an In-Vehicle ATIS on Driver Performance

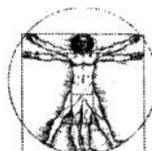
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FOREWORD

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

These studies are part of the empirical phase of the on-going human factors design guidelines project. The first examines the cognitive demands imposed on the driver by the need to transition from one pre-drive in-vehicle information function to another while in pre-drive mode. The second study evaluates driving performance with a moving map implementation of an ATIS device.

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Director, Office of Safety
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16. Abstract: The objective of the first experiment reported below was to measure the cognitive demands associated with transitioning across Advanced Traveler Information System (ATIS) functions. This required the development of both objective and subjective indices of driver behavior and cognition. To accomplish this, a small number of pre-drive trip scenarios that invoke appropriate transitions across ATIS functions were developed. Driving performance under more representative conditions was investigated in experiment 2 using a driving simulator. This study investigated several issues on the influence of an ATIS on driving behavior. The questions asked were: ! How does a moving map display of the current vehicle location influence driving performance? ! How do ATIS control inputs influence driving performance? Should they be allocated to pre-drive? Is it too much to expect the driver to do while in transit? ! Do ATIS messages affect drivers' reactions to roadway events? ! Does message potency affect drivers' reactions to roadway events? Overall, the two experiments reported here suggest that in-vehicle ATIS devices can be learned, understood, and successfully used by drivers for both pre-drive trip planning tasks and on-road driving conditions. ATIS devices have the potential to improve driver compliance to regulatory information, as compared with standard roadside signs. While concurrent visual and auditory ATIS alert messages may be beneficial, the visual ATIS messages alone are significantly better than roadside signage alone. While cognitive demands associated with ATIS transitions and ATIS complexity should continue to be a concern, these demands can be addressed by selecting ATIS functions with clear benefits to the driving task.					
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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol	Symbol	When You Know	Multiply By	To Find	Symbol
LENGTH					LENGTH				
in	inches	25.4	millimeters	mm	mm	millimeters	0.039	inches	in
ft	feet	0.305	meters	m	m	meters	3.28	feet	ft
yd	yards	0.914	meters	m	m	meters	1.09	yards	yd
mi	miles	1.61	kilometers	km	km	kilometers	0.621	miles	mi
AREA					AREA				
in ²	square inches	645.2	square millimeters	mm ²	mm ²	square millimeters	0.0016	square inches	in ²
ft ²	square feet	0.093	square meters	m ²	m ²	square meters	10.764	square feet	ft ²
yd ²	square yards	0.836	square meters	m ²	m ²	square meters	1.195	square yards	yd ²
ac	acres	0.405	hectares	ha	ha	hectares	2.47	acres	ac
mi ²	square miles	2.59	square kilometers	km ²	km ²	square kilometers	0.386	square miles	mi ²
VOLUME					VOLUME				
fl oz	fluid ounces	29.57	milliliters	mL	mL	milliliters	0.034	fluid ounces	fl oz
gal	gallons	3.785	liters	L	L	liters	0.264	gallons	gal
ft ³	cubic feet	0.028	cubic meters	m ³	m ³	cubic meters	35.71	cubic feet	ft ³
yd ³	cubic yards	0.765	cubic meters	m ³	m ³	cubic meters	1.307	cubic yards	yd ³
NOTE: Volumes greater than 1000 l shall be shown in m ³									
MASS					MASS				
oz	ounces	28.35	grams	g	g	grams	0.035	ounces	oz
lb	pounds	0.454	kilograms	kg	kg	kilograms	2.202	pounds	lb
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")	Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
TEMPERATURE (exact)					TEMPERATURE (exact)				
°F	Fahrenheit temperature	5(F-32)/9 or (F-32)/1.8	Celcius temperature	°C	°C	Celcius temperature	1.8C + 32	Fahrenheit temperature	°F
ILLUMINATION					ILLUMINATION				
fc	foot-candles	10.76	lux	lx	lx	lux	0.0929	foot-candles	fc
fl	foot-Lamberts	3.426	candela/m ²	cd/m ²	cd/m ²	candela/m ²	0.2919	foot-Lamberts	fl
FORCE and PRESSURE or STRESS					FORCE and PRESSURE or STRESS				
lbf	poundforce	4.45	newtons	N	N	newtons	0.225	poundforce	lbf
lbf/in ²	poundforce per square inch	6.89	kilopascals	kPa	kPa	kilopascals	0.145	poundforce per square inch	lbf/in ²

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

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LIST OF ABBREVIATIONS

ANOVA	Analysis of Variance
ATIS	Advanced Traveler Information System
BMDP	Bio-Medical Data Processing
CTA	Cognitive Task Analysis
CVO	Commercial Vehicle Operations
FHWA	Federal Highway Administration
GPS	Global Positioning System
HFTC	Human Factors Transportation Center
HVAC	heating/ventilation/air conditioning
IMSIS	In-Vehicle Motorist Services Information Systems
IRANS	In-Vehicle Routing and Navigation Systems
ISIS	In-Vehicle Signing Information Systems
ITS	Intelligent Transportation Systems
IVSAWS	In-Vehicle Safety Advisory and Warning Systems
km/h	kilometers per hour
LCD	liquid crystal display
mi/h	miles per hour
NASA	National Aeronautics and Space Administration
PC	Personal Computer
SCA	Subject Comfort Assessment
TLX	Task Load Index

EXECUTIVE SUMMARY

OBJECTIVES OF THE EXPERIMENTS

The objective of the first experiment reported below was to measure the cognitive demands associated with transitioning across Advanced Traveler Information System (ATIS) functions. This required the development of both objective and subjective indices of driver behavior and cognition. To accomplish this, a small number of trip scenarios that invoke appropriate transitions across ATIS functions were developed. The starting point for these scenarios was the Intelligent Transportation Systems (ITS) scenario originally developed in McCallum, Lee, Sanquist, and Wheeler (1996) and then refined and expanded in Lee, Morgan, Wheeler, Hulse, and Dingus (1997). Importantly, experiment 1 only investigated pre-drive performance.

Driving performance under more representative conditions was investigated in experiment 2 using a driving simulator. This study investigated several issues on the influence of an ATIS on driving behavior. The questions asked were:

- ! How does a moving map display of the current vehicle location influence driving performance?
- ! How do ATIS control inputs influence driving performance? Should they be allocated to pre-drive? Is it too much to expect the driver to do while in transit?
- ! Do ATIS messages affect drivers' reactions to roadway events?
- ! Does message potency affect drivers' reactions to roadway events?

EXPERIMENT 1: METHODS

To examine the cognitive demands placed on the driver by the need to transition across ATIS functions, two prototype ATIS were developed and tested using the Battelle ATIS Simulator. One of the ATIS prototypes had subsystem functions that were *integrated* in that each function had a similar user-interface and screen format ("look and feel"). The second ATIS prototype had subsystem functions that were *non-integrated* in that each function had a different user-interface and screen format. ATIS pre-drive functions were investigated using this approach. In a follow-on study, ATIS drive functions will be further investigated using the Battelle High-Fidelity Driving Simulator. The Barfield et al. (1993) working paper noted that, while current guidelines can be used for pre-drive mode, there is a serious gap in guideline information for drive mode.

In this experiment, a cognitive task analysis (CTA) has been used to measure driver cognition. Typical CTA methods include verbal protocol analysis (Ericsson and Simon, 1984; Triggs, Kantowitz, Terrill, Bittner, and Fleming, 1990), concept mapping (Wolf, Klein, Thordsen, and Klinger, 1991) and psychological scaling (Redding, 1990). CTA is still a new technology and we do not know which techniques will be best for this application. Thus, some pilot testing using several CTA methods preceded the final data collection.

The ATIS prototypes of the integrated and non-integrated systems were created using the ToolBook software application developed by Asymetrix Corporation. Both types of systems were well-designed from a human factors perspective in terms of general layout, legibility, ease of use, and system logic. Both systems, and all functions within the non-integrated system, were modeled or had design features consistent with that of well known or widely available software applications. The integrated system was developed based on the TravTek system, with each subsystem function having an identical format. For example, all buttons used to operate each function were located in the same location within a function and across functions. On the other hand, each subsystem functions of the non-integrated system did not share the same format.

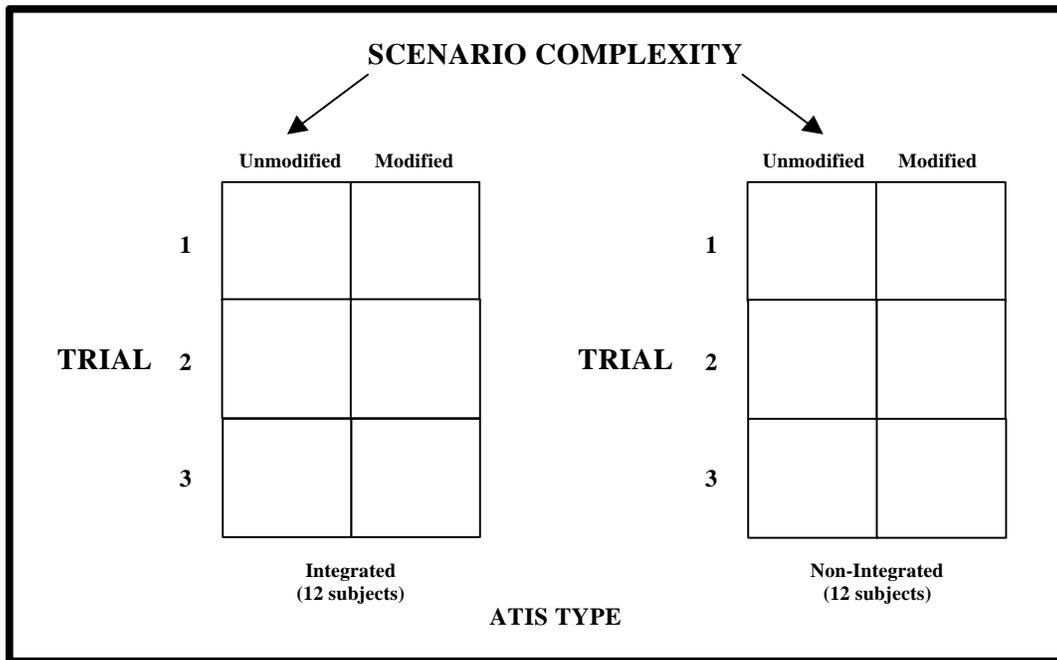


Figure 1. Experimental design for experiment 1.

To examine driver performance with an in-vehicle ATIS, a simulated ATIS was developed and incorporated into a high-fidelity driving simulator. Eighteen subjects participated in the study, which consisted of driving through a virtual representation of the city of Seattle, while making control inputs to the ATIS and responding to traffic conditions and driving events. ATIS information, including the current vehicle position within the database of Seattle, was presented on a 4" color monitor, located on top of the vehicle's dashboard. Subjects made inputs to the system and navigated through menus within the system, using a dedicated keypad. To make valid estimates of the driving performance implications associated with making these control inputs, subjects were also asked to make inputs to standard in-vehicle devices, such as the radio and heating/ventilation/air conditioning (HVAC) system. Key driving events that were used to assess performance included lane changes, sudden stops, and pulling off to the shoulder of the road. Key independent variables included the status of the ATIS (e.g., on, off), the type of control inputs (e.g., ATIS or standard), and the type of message advising subjects of the need to make a brake or steering correction (e.g., auditory only, ATIS visual only, ATIS visual plus auditory tone, or roadside sign).

EXPERIMENT 1: RESULTS AND CONCLUSIONS

The following conclusions may be drawn from experiment 1:

- ! Overall, the cognitive demands associated with ATIS function transitions during pre-drive trip planning were low and associated with acceptable levels of ATIS task performance.
- ! For pre-drive trip planning and, perhaps, for kiosk, hotel, and other non-vehicle-based applications of ATIS, there may be no performance-related advantages or disadvantages associated with an integrated versus a non-integrated screen design approach.
- ! Both the performance data and the CTA results in experiment 1 suggest that even a relatively complex ATIS with multiple functions can be learned, understood, and successfully used by drivers in a relatively short period of time.
- ! The CTA results suggest that transitions between different ATIS functions may be associated with increased cognitive demands; this further suggests that the number of ATIS functions should be minimized and that unwanted ATIS functions should be eliminated.
- ! The multiple choice CTA findings also suggest that drivers may recognize non-integrated ATIS screens faster and more accurately than integrated ATIS screens; that is, there may be certain advantages to designing each ATIS function with a unique “look and feel,” as in the non-integrated condition.
- ! Since many of the functions associated with ATIS (e.g., navigation, in-vehicle warnings) are associated with actual driving, cognitive demands should be investigated further in a high workload situation that requires subjects to drive while operating an ATIS.
- ! The hypermedia-based ATIS simulation developed for this study proved to be a powerful research tool that can be used to investigate a range of ATIS design issues.
- ! The CTA methodologies developed for this study provided insight into the experimental conditions investigated and can be used in the future to assess the cognitive demands of inexperienced users of advanced and novel automotive technologies.

EXPERIMENT 2: METHODS

To examine driver performance with an in-vehicle ATIS, a simulated ATIS was developed and incorporated into a high-fidelity driving simulator. Eighteen subjects participated in the study, which consisted of driving through a virtual representation of the city of Seattle, while making control inputs to the ATIS and responding to traffic conditions and driving events. ATIS information, including the current vehicle position within the database of Seattle, was presented on a 4" color monitor, located on top of the vehicle's dashboard. Subjects made inputs to the system and navigated through menus within the system, using a dedicated keypad. To make valid estimates of the driving performance implications associated with making these control inputs, subjects were also asked to make inputs to standard in-vehicle devices, such as the radio and

HVAC system. Key driving events that were used to assess performance included lane changes, sudden stops, and pulling off to the shoulder of the road. Key independent variables included the status of the ATIS (e.g., on, off), the type of control inputs (e.g., ATIS or standard), and the type of message advising subjects of the need to make a brake or steering correction (e.g., auditory only, ATIS visual only, ATIS visual plus auditory tone, or roadside sign). Driving behavior was investigated using the Battelle high-fidelity driving simulator, a simulated ATIS, and seven driving scenarios. Each of these is described below.

The simulated ATIS had the ability to present current vehicle location information, warnings about upcoming traffic conditions, and navigation information. ATIS information was presented on a Sharp 4" diagonal color display located on the dashboard, 82.3 centimeters to the right of the steering wheel.

The current vehicle location information was presented using the Retki Global Positioning System (GPS) Navigational Interface. During the simulation, the coordinate data provided by the simulator were fed into the ATIS computer, replacing the real-time GPS data it would receive during usual on-the-road operating conditions. Therefore, as the subject drove through the simulated route, the vehicle's location could be continuously tracked and updated on the moving map display. While stationary, the position of the vehicle appeared on the map as a star. Once the vehicle began to move, a black arrowhead showed the vehicle position and direction of travel.

A database of the Seattle area was used in this experiment. Thus, roadways and roadside elements were familiar to the subjects. A representation of the navigation portion of the ATIS display can be seen in figure 2.

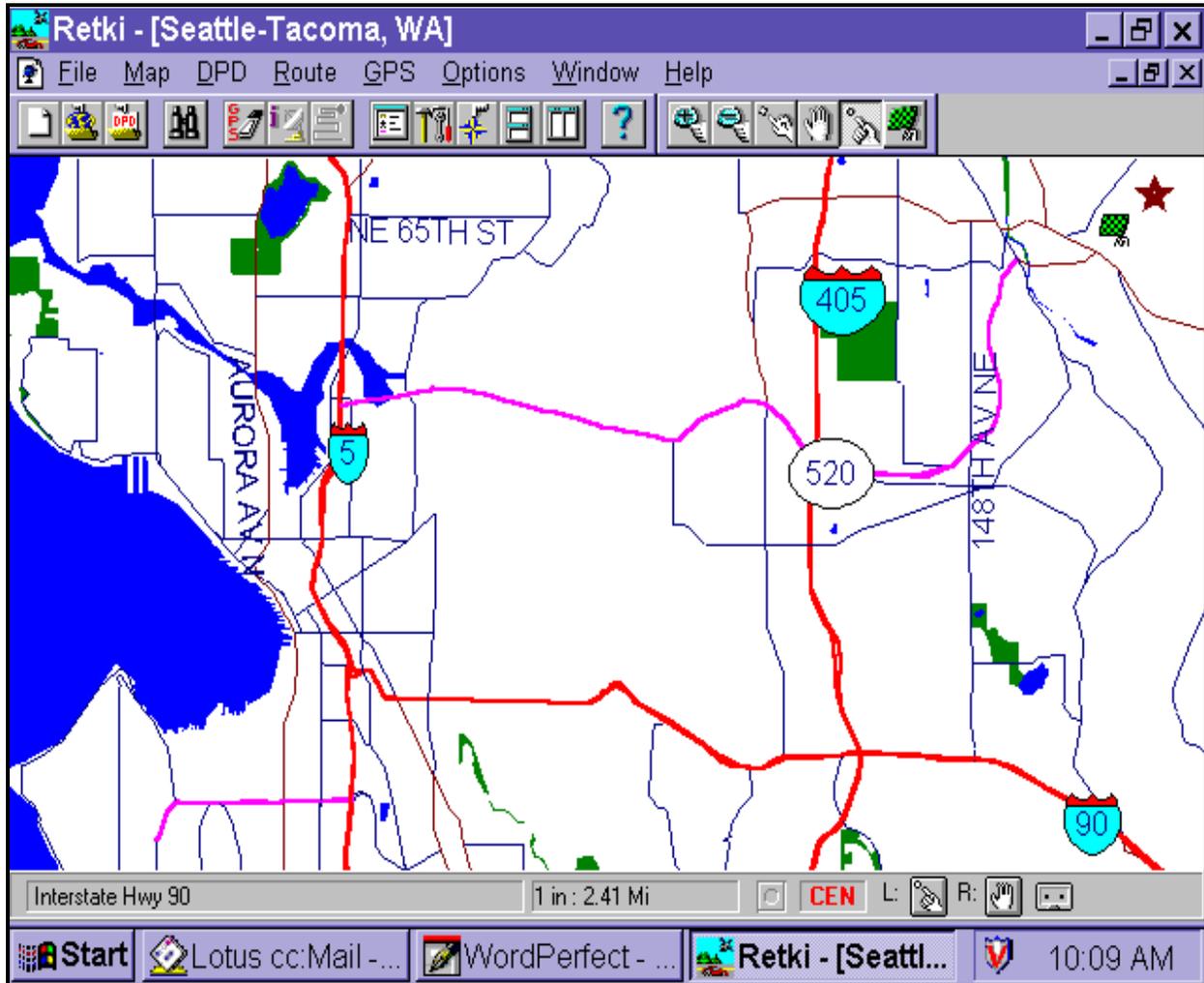


Figure 2. The moving map display of the current vehicle location.

Warnings about upcoming traffic conditions were presented as the subjects were approaching several roadway events placed within the driving scenarios. Warnings were presented in one of the following forms:

- ! A visual text message, which simply stated the upcoming traffic condition (Visual/Notification-no alert).
- ! A visual text message, which simply stated the upcoming traffic condition, preceded by an auditory tone (Visual/Notification-auditory alert).
- ! An auditory message, which informed the subject of the upcoming traffic condition and suggested the appropriate action to take (Auditory/Command).

Dependent variables for experiment 2 are shown in table 1 below.

Table 1. Dependent variables.

Type	Dependent Variable
Driving Performance	Standard deviation of speed Mean speed, m/s Rate of large steering reversals, count/second
Roadway Events	Speed events Compliance, binary Compliance before the road sign, binary Percent compliance, % Distance to the road sign at compliance, feet Time to compliance, seconds Lane events Compliance, binary Time to lane crossing, seconds Distance to the event at lane crossing, feet

EXPERIMENT 2: RESULTS AND CONCLUSIONS

The following conclusions may be drawn from experiment 2:

- ! Driving performance was not negatively affected by the presence of a moving map ATIS device. Thus, the results suggested that an ATIS device will not represent an undue distraction for drivers.
- ! Making control inputs to the ATIS also had no greater effect on driving performance than did using standard secondary vehicle controls. These results suggest that drivers are able to self-regulate their use of the ATIS, and that time-sharing between the ATIS and the driving task can be accomplished.
- ! Improved compliance to regulatory messages in the ATIS conditions suggests a benefit to the in-vehicle presentation of such information.
- ! Although concurrent auditory and visual alerts may be beneficial, the results of this study suggest that visual messages alone are much better than no message at all and will lead to high levels of driver compliance to regulatory messages.

SUMMARY OF EXPERIMENTS 1 & 2

Overall, the two experiments reported here suggest that in-vehicle ATIS devices can be learned, understood, and successfully used by drivers for both pre-drive trip planning tasks and on-road driving conditions. ATIS devices have the potential to improve driver compliance to regulatory information, as compared with standard roadside signs. While concurrent visual and auditory ATIS alert messages may be beneficial, the visual ATIS messages alone are significantly better

than roadside signage alone. While cognitive demands associated with ATIS transitions and ATIS complexity should continue to be a concern, these demands can be addressed by selecting ATIS functions with clear relationships and benefits to the driving task.

INTRODUCTION

BACKGROUND

Recent advances in electronics and microcomputing have led to the feasibility of functionally-powerful, computer-based Advanced Traveler Information Systems (ATIS) as part of the automotive environment. Although these systems range in functionality, they all have the goal of acquiring, analyzing, communicating, and presenting information to assist travelers in moving from a starting location to a desired destination. While systems under development or in production promise to improve travel safety, efficiency, and comfort, they represent a new frontier in ground transportation. If not carefully developed, such systems could result in misapplied and unusable technology. In particular, there is a growing information gap between the advanced and diverse status of ATIS devices, and the availability of human factors design criteria that can be used during the ATIS design process.

Battelle's Human Factors Transportation Center (HFTC) is carrying out a study for the U.S. Federal Highway Administration (FHWA) to develop human factors design guidelines for the ATIS and Commercial Vehicle Operations (CVO) components of the Intelligent Transportation Systems (ITS). These systems are intended to provide a wealth of real-time information to the driver, including route guidance to avoid congestion and minimize travel time, safety and warning notices, and identification of desired motorist services, such as how to get to the nearest service station. While ATIS and CVO systems offer great potential benefits, their effectiveness depends on driver acceptance of the new technology, the ability of the system to integrate with other driving tasks, and the extent to which the systems conform to driver physical and cognitive limitations and capabilities. The guidelines that result from this effort will help designers produce ATIS and CVO systems that conform to human limitations and capabilities, thereby improving driver efficiency, enhancing driver acceptance, and promoting highway safety.

There are three technical phases associated with this project: (1) an analytical phase, (2) an empirical phase, and (3) an integrative phase. In this report, we summarize the rationale, methods, and results from a study from the empirical phase of this effort.

RATIONALE FOR THE EXPERIMENTS

In a previous project study conducted by Kantowitz, Lee, and Kantowitz (1997), 91 research issues were rated by eight human factors experts along 14 separate criteria. The highest-rated issue resulting from this effort was issue A1: *Examine the cognitive demands placed on the driver by the need to transition from one ATIS function to another*; it is also one of the most difficult issues to study. The goal of the experiments reported here is to examine the cognitive demands placed on the driver by the need to transition across ATIS functions and to examine driver performance with an ATIS device.

Two experiments are reported here. In the first, cognitive demands associated with an ATIS device were evaluated during pre-drive trip planning activities. In the second, driving performance with an in-vehicle ATIS device was examined using a high-fidelity driving simulator.

Table 2 lists 27 ATIS functions identified in Lee, Morgan, Wheeler, Hulse, and Dingus (1997). As this study explained, functions interact and can sometimes inhibit and sometimes facilitate one another. Furthermore, as explained in the task analyses contained in Wheeler et al. (1996), some

sets of cognitive activities are closely linked while others are not. Therefore, cognitive demands placed on the driver will depend both upon these linkages discovered in the Wheeler et al. (1996) task analysis and also upon the functional analyses derived in Lee et al. (1997).

Table 2. Functional characteristics for commercial and private drivers.

Subsystem	Subsystem Functional Characteristics
IRANS	Trip planning
	Multi-mode travel coordination and planning
	Pre-drive route and destination selection
	Dynamic route selection
	Route guidance
	Route navigation
	Automated toll collection
	CVO-specific (Route scheduling)
IMISIS	Broadcast services/attractions
	Services/Attractions directory
	Destination coordination
	Message transfer
ISIS	Roadway guidance sign information
	Roadway notification sign information
	Roadway regulatory sign information
	CVO-specific (Road restriction information)
IVSAWS	Immediate hazard warning
	Road condition information
	Automatic aid request
	Manual aid request
	Vehicle condition monitoring
	CVO-specific (Cargo and vehicle monitoring)
CVO-specific	Fleet resource management
	Dispatch
	Regulatory administration
	Regulatory enforcement

The framework for the first experiment reported here had two major components. First, ATIS functions shown in table 2 (In-Vehicle Routing and Navigation Systems [IRANS], In-Vehicle Motorist Services Information Systems [IMSIS], In-Vehicle Signing Information Systems [ISIS], In-Vehicle Safety Advisory and Warning Systems [IVSAWS], and CVO) create cognitive demands on the driver. Second, linkages across cognitive demands determine how well a driver can meet transitions across ATIS functions. For example, the ATIS function of Route Navigation may impose cognitive demands upon memory. If another ATIS function, say Roadway Notification Sign Information, also imposes a cognitive demand upon memory, transition across these ATIS functions may be impaired. Furthermore, the driver must keep track of the cognitive status of all these ATIS functions as well as those cognitive demands associated with safe driving. Memory demands within a particular ATIS function should be easier to organize and coordinate than memory demands across ATIS functions.

Implications of Stimulus-Response Compatibility on ATIS Design

Stimulus-response compatibility is a key concept in human factors (Kantowitz, Triggs, and Barnes, 1990) and will affect the cognitive demands associated with ATIS function transitions. Stimulus-response compatibility refers to the relationship, both geometric and conceptual, between a stimulus such as a display, and a response, such as a control action. In the flight-deck domain, for example, the debate about the relative merits of outside-in (moving airplane) versus inside-out (moving horizon) artificial horizon indicators is an argument about stimulus-response compatibility. (Actually, a better display has both moving; see Kantowitz and Sorkin, 1983, p. 221.)

Figure 3 shows a recent model of stimulus-response compatibility (Kantowitz et al., 1990) based upon a nested hierarchy of frames, rules, and response tendencies. Without going into great detail, it is sufficient for present purposes merely to note that a frame is a well-developed knowledge structure based upon driver experience and training. Plans and actions that run counter to established frames, i.e., low stimulus-response compatibility, are potential problems in ATIS design.

For example, a navigation aid on an ATIS might inform the driver of a need to turn right at the next intersection by presenting a right arrow on the right-side of the display. An accurate response to such ATIS information will reflect the compatibility between display stimuli and driver responses. For example, if the arrow indicating a right turn was placed on the left-side of the display, it might create confusion and lead drivers to turn left instead of right. In this situation, it is not the perception of the information or the response capability alone that governs the accuracy and timing of the response, but the relationship between the stimulus and the response. Thus, ATIS functions and screens that exhibit low stimulus-response compatibility can confuse the driver, increasing cognitive demands unnecessarily. They also create extra workload and lower trust in the ATIS.

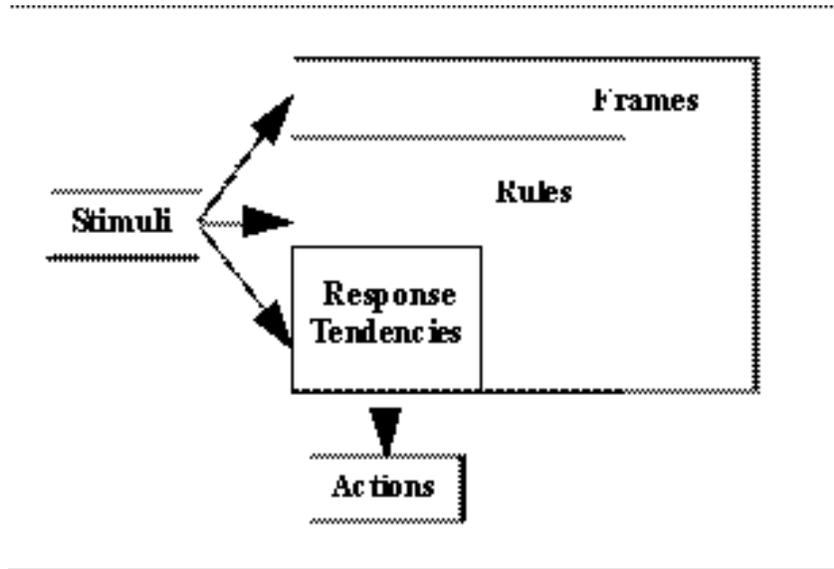


Figure 3. Nested hierarchical relations among frames, rules, and response tendencies as sources of stimulus-response compatibilities.

The degree of stimulus-response compatibility within an ATIS will be affected by three related concepts: innate stimulus-response tendencies, population stereotypes, and design consistency (see Barfield et al., 1993, for a more detailed discussion of these concepts). Each of these three concepts represent the interaction of cognitive characteristics that affect the rate of learning, response speed, and response accuracy. Of particular relevance to the question of cognitive demands during ATIS function transitions is the concept of design consistency. Design consistency influences learned relationships among stimuli and responses that, over time, become expectancies on the part of the users. In general, a consistent interface design leads to automatic and performance-enhancing responses, while an inconsistent interface design can lead to increased errors and response times. Consistency associated with design standards facilitates understanding of new systems based on experience with other systems and promotes efficient performance through well practiced, consistent stimulus-response mappings. Schneider and Shiffrin (1977) showed that, after extended practice with consistent stimulus-response pairings, subjects developed automaticity in their responses and were able to respond with little conscious effort. Inconsistent mappings did not promote automaticity as reflected by less accurate performance.

On the basis of these and other findings, design consistency is frequently cited as a standard requirement associated with the design of the user-interface, for both general system design (e.g., Gardiner and Christie, 1987), as well as the design of driver information systems (e.g., Green, Levison, Paelke, and Serafin, 1995). Thus, the “look and feel” associated with different system functions are recommended to be matched with respect to screen design, control location, labels, and functions. However, the very nature of certain types of human-machine systems often precludes a consistent interface design across system functions. The best example of such a situation occurs with the standard home- or office-based computer. Most computers contain a number of independent software applications, often from different software development companies, and with different (to varying degrees) formats for the screen and various control functions. Thus, we start out with a “basic” computer, and add functions (word processing, graphics, statistics, spreadsheets) based on our needs. Importantly, the user-interface across these

different functions is not always consistent. ATIS devices of the future may be similar to our computers of today in this respect; i.e., users may add “modules” such as trip planning, navigation, communications, user services, etc., to a basic ATIS. Importantly, each addition may come from a different software development company and have a slightly different “look and feel” to the user-interface. As described in more detail below, we will address this issue in the first experiment reported below by investigating cognitive demands using both consistent and inconsistent versions of a simulated ATIS device.

MESSAGE POTENCY

The second experiment reported here examined the issue of message potency. Message potency is defined as a combination of message style and presentation modality. Lee et al. (1996) define message style on a dimension of directiveness. At one extreme, messages simply advise drivers of a particular roadway condition (e.g., “Icy Road Ahead”). At the other extreme, messages command drivers to take specific actions in response to the condition (e.g., “Slow Down”). The two endpoints of this dimension of message design are referred to as notification and command styles. Presentation modality offers other options in message design, as ATIS information can be presented through either the visual or the auditory channels.

In Lee et al.’s low-fidelity simulator study, subjects received command or notification style, ISIS and IVSAWS messages in either the visual and auditory modality. The results of the study showed that, while the presentation modality was not important, message style had a powerful effect on compliance to ATIS messages. Specifically, command style messages promoted greater compliance than notification style messages.

Kantowitz, Hooey, and Simsek (1998, in process) performed an on-road study in an attempt to replicate the findings of Lee et al. in a real-world setting. They presented high potency (command style message presented in the auditory modality) and low potency (notification style message presented in the visual modality) messages. The results showed that compliance to high potency messages were higher than to low potency messages. Questions associated with message potency were investigated in the second experiment reported below by varying message characteristics with an in-vehicle ATIS device implemented in a driving simulator.

OBJECTIVE OF THE EXPERIMENTS

The objective of the first experiment reported below was to measure the cognitive demands associated with transitioning across ATIS functions. This required the development of both objective and subjective indices of driver behavior and cognition. To accomplish this, a small number of trip scenarios that invoke appropriate transitions across ATIS functions were developed. The starting point for these scenarios was the ITS scenario originally developed in McCallum et al. (1996) and then refined and expanded in Lee et al. (1997). Importantly, experiment 1 only investigated pre-drive performance.

Driving performance under more representative conditions was investigated in experiment 2 using a driving simulator. This study investigated several issues on the influence of an ATIS on driving behavior. The questions asked were:

- ! How does a moving map display of the current vehicle location influence driving performance?
- ! How do ATIS control inputs influence driving performance? Should they be allocated to pre-drive? Is it too much to expect the driver to do while in transit?
- ! Do ATIS messages affect drivers' reactions to roadway events?
- ! Does message potency affect drivers' reactions to roadway events?

In general, ATIS messages are expected to encourage faster and more effective responses to roadway events. However, an ATIS might also degrade driving safety by drawing the driver's attention away from the roadway. Presence of a moving map display and engaging the driver in control inputs while the vehicle is in motion are design characteristics that might further increase the distracting properties of an ATIS. These considerations are reflected in the following hypotheses for experiment 2 that guided our analysis:

- ! Driving performance will be negatively impacted by the presence of a moving map display.
- ! Driving performance will be better during baseline driving than while making a control input.
- ! Driving performance will be better while making a control input to the standard systems found in a car (i.e., radio and temperature controls) than while making a control input to the ATIS.
- ! Subjects who receive messages will react sooner than those who do not receive messages.
- ! Subjects receiving high potency (command/auditory) messages will react sooner than those receiving other types of messages.
- ! Subjects receiving low potency (notification/text) messages will react sooner than those receiving no messages.
- ! Subjects receiving low potency (notification/text) messages preceded by an auditory alert will react sooner than those receiving low potency messages with no alert.

METHOD

EXPERIMENT 1

GENERAL APPROACH

To examine the cognitive demands placed on the driver by the need to transition across ATIS functions, two prototype ATIS were developed and tested using the Battelle ATIS Simulator. One of the ATIS prototypes had subsystem functions that were *integrated* in that each function had a similar user-interface and screen format (“look and feel”). The second ATIS prototype had subsystem functions that were *non-integrated* in that each function had a different user-interface and screen format. ATIS pre-drive functions were investigated using this approach.

In this experiment, a CTA has been used to measure driver cognition. Typical CTA methods include verbal protocol analysis (Ericsson & Simon, 1984; Triggs et al., 1990), concept mapping (Wolf et al., 1991) and psychological scaling (Redding, 1990). CTA is still a new technology and we do not know which techniques will be best for this application. Thus, some pilot testing using several CTA methods preceded the final data collection.

SUBJECTS

Twelve male and twelve female subjects participated in this experiment. The subjects ranged in age from 19 to 28 years. All subjects had a valid driver’s license and drove at least twice per week. Subjects were recruited from the University of Washington and were paid \$5 per hour for approximately 3 hours of research time.

APPARATUS

Cognitive demands associated with ATIS, and the resulting operation performance, were investigated using an experimental setup that included: (1) the Battelle ATIS simulator, (2) trip planning scenarios, and (3) three separate CTA methods. Each of these is described below.

Battelle ATIS Simulator

The ATIS prototypes operated on an Intel 486 computer that was connected to a monitor with a MicroTouch Systems touch screen. Subjects used the touch screen to operate between and within the various ATIS subsystem functions.

Both the integrated and non-integrated ATIS prototypes had identical functionality that included six distinct subsystem functions:

- ! Main Menu: The first screen and starting point to access system features.
- ! Trip Planning: Function that allowed users to enter the name of a destination.

- ! Travel Modes: Function that allowed users to select available mode options (e.g., car, train, bus, or ferry), travel routes, and schedules.
- ! Services Directory: Function that allowed users to select available accommodations, restaurants, activities, and learn about his/her destination and other available services.
- ! Travel Coordination: Function that allowed users to make reservations for the travel mode selected, accommodations, and restaurant.
- ! Communications: Function that allowed users to communicate with outside parties by sending, reading, and replying to messages.

These functions were selected by examining the descriptions of the functions in table 2, as originally described in the Lee et al. (1997) study, to identify plausible pre-drive functions for a near-term ATIS. Each function that was incorporated into the study comprised several “screens” arranged hierarchically within the system. A screen was the interface that the user interacted with and included a combination of text, boxes, and buttons. The text provided function-related information. For example, text in the “Help” screen would provide the user with instructions on how to operate within that particular function. Also, text was used to label buttons and selection options. The boxes house the text and input information. The boxes can also be thought of as “fields” that contain text and input information. The buttons allow users to move a cursor within a screen, select options presented on the screen, and/or move to other screens. In essence, the buttons were the means by which the user interacted with the system. In addition, each screen within a subsystem function had an accompanying on-line help feature that provided the user with assistance specific to the current screen.

The ATIS prototypes of the integrated and non-integrated systems were created using the ToolBook software application developed by Asymetrix Corporation. Both types of systems were well-designed from a human factors perspective in terms of general layout, legibility, ease of use, and system logic. Both systems, and all functions within the non-integrated system, were modeled or had design features consistent with that of well known or widely available software applications. The integrated system was developed based on the TravTek system, with each subsystem function having an identical format. For example, all buttons used to operate each function were located in the same location within a function and across functions. On the other hand, each subsystem functions of the non-integrated system did not share the same format.

Table 3 outlines the software applications that were used for designing each system, and each function within the non-integrated system. Figures of both the integrated and non-integrated screens are shown in appendix A¹.

¹ These images are presented in black and white in appendix A. In the experiment, color screen images were used.

Table 3. Outline of software applications used in the design of the ATIS prototypes for this study.

Subsystem Function	Integrated System	Non-Integrated System
Trip Planning	TravTek	TravTek ¹ & Telephone Keypad ²
Travel Modes	TravTek	Travelogix [®] Online
Services Directory	TravTek	Great American Vacation Guide [®]
Travel Coordination	TravTek	Quicken [®]
Communications	TravTek	Lotus cc:Mail [®] V.2.1

¹First entry of destination. ²Subsequent destination entries when changing a destination required. Note also that the Telephone Keypad format was also used in the Communications function when composing a new message.

As noted, though a standard screen format was used for each of the five functions for the integrated system, functions of the non-integrated system had different formats. And, as outlined in table 3, ideas for the non-integrated functions came from readily available software applications that shared common characteristics with the five functions. Details on the design of each non-integrated function are delineated below.

Trip Planning

For initial selection of a destination, the keypad format for entering in destinations used in the integrated system was also used for the non-integrated system. However, subsequent entries of destinations, for functions other than Trip Planning, used a different format. The format used for these instances was modeled after a keypad on a telephone, where numbers and letters share keys.

Travel Modes

Travelogix[®] Online is a program accessible on Internet (<http://www.travelogix.com>) that allows users to plan trips and perform many of the activities typical of a travel agent. With this program, users input their origin and destination and the time they would like to travel. A list of flights is given, along with departure and arrival times, number of stops, and price. From this list, users can select a flight and, using a credit card, make and confirm reservations. Several characteristics of Travelogix[®] Online are similar to those of the Travel Modes function. For example, in the Travel Modes function, a user selects and confirms a route. Many of the interface features of Travelogix[®] Online, such as button design and placement, screen title format, input and selection format, text boxes, text format, and method of information display, were used in designing the Travel Modes function of the non-integrated system.

Select Services

In designing the non-integrated Select Services function, the characteristics and interface layout found in the “Cities” function of the Great American Vacation Guide[®], developed by Essential Software, was used. Design ideas found in the Great American Vacation Guide[®] that were mimicked in the non-integrated Select Services function included: button design, button placement, button icons, scrolling menus, selection highlighting features, text boxes, text formatting, and map usage.

Travel Coordination

The primary purpose of the Travel Coordination function is to review previously selected destination, mode, and services selections and make or cancel reservations, as needed. A program that had similar characteristics to this was the Travelogix® Online software used for the Travel Modes function. Modeling two non-integrated functions after the same software application was unacceptable since it could be argued that the two functions would not be truly non-integrated. As such, another software program that was functionally similar to that of Travel Coordination was used. Quicken®, a very well known and available finance organization software package, includes a function whereby the user can transmit information to an outside source (e.g., a bank). One use of this function is to pay bills electronically. Data are transmitted to an external device and acknowledgment that the data has been received is returned to the originating device. Similarly, with the Travel Modes function a user is required to transmit information electronically to an outside source and then to receive some form of acknowledgment. An example of a Travel Coordination task would be confirming a reservation at a hotel or a train ticket on Amtrak. Given this similarity, Quicken® was used as a model for the non-integrated system Travel Coordination function. Buttons, icons, labels, and formats used in Quicken® were used in designing the interface for the Travel Coordination function.

Communications

The Communications function allows users to read, review, create, send and receive messages. Lotus cc:Mail® V.2.1, the well known and widely available electronic communications software application, was used as a model for developing the Communications function of the non-integrated system. Interface design characteristics similar to Lotus cc:Mail® V.2.1 included button placement, button icons, button labels, and text boxes.

Trip Planning Scenarios

Eight scenarios were developed that provided users with a structure from which to make travel arrangements and a vehicle with which to transition between functions. Each scenario was a brief story that described a context in which the subject could plan a trip. Each scenario included an intended destination, as well as various constraints that served to guide the subject's use of the simulator. Such constraints included time limits (e.g., reach the destination by a certain time), spending limits and preferences on hotels (e.g., 2-star versus 3-star), preferences for food (e.g., Chinese versus Italian), and requirements to check in with work or home for e-mail messages. The complete scenarios are included in appendix B. In the first two scenarios, the experimenter demonstrated optimal system operation to the subject. In this way, the subject could watch the experimenter complete the travel arrangements and be introduced to all of the functions. The next six scenarios were completed by the subject during the course of the experiment.

Cognitive Task Analysis

Each of the three CTA approaches (perceived demand questionnaire, multiple choice task, and the similarity rating task) used a different set of materials and equipment.

The perceived demand questionnaire uses a slightly modified version of the National Aeronautics and Space Administration (NASA) Task Load Index (TLX) workload instrument. This questionnaire measured the perceived visual, mental, and physical demands associated with the trip planning task. Subjects were videotaped performing their trip planning sessions. This videotape was replayed to the subjects, who rated their perceived level of demand on a 100-point scale using a written questionnaire. The perceived demand questionnaire is shown in appendix C.

The multiple choice task was designed to assess subjects' ability to navigate within and between functions of the ATIS. Six target screens (actual ATIS screens) were presented one at a time on posterboard and subjects were asked to decide from four options which screen was most likely to have preceded and followed the target screen. The choices presented to subjects reflected the experimental condition associated with individual subjects (i.e., integrated versus non-integrated version of the ATIS).

The similarity rating task was designed to assess the subjects' overall understanding of the structure of the ATIS. Using a personal computer (PC)-based spreadsheet, subjects were presented with a list of 14 ATIS features to be compared with a highlighted comparison feature. As with the multiple choice task, the choices presented to subjects reflected the experimental condition associated with individual subjects (i.e., integrated versus non-integrated version of the ATIS). Figures 4 and 5 present examples of the forms used to collect the rating task data for the integrated and non-integrated systems.

	DRIVE
Drive	
Send new message	
Things to do	
Train	
City facts	
Where to stay	
Make reservation now	
Reply to a message	
Other services	
Cancel reservation now	
Where to eat	
Bus	
Enter destination	
Drive/Ferry	
Read new message	
TOTAL	

CONTINUE

Total must sum to 1000

Figure 4. Form used to collect rating task data for the integrated system.

	DRIVE
Drive	
 Send	
Fun	
Train	
Information	
Accomodations	
Make reservation now	
 Reply	
Other services	
Cancel reservation now	
Food	
Bus	
Enter destination	
Drive/Ferry	
 Inbox	
TOTAL	

CONTINUE

Total must sum to 1000

Figure 5. Form used to collect rating data for the non-integrated system.

EXPERIMENTAL DESIGN

Independent Variables

This study employed a repeated measures design with two within-subjects variables (scenario complexity and trial) and one between-subjects variable (ATIS type). There were two levels of scenario complexity: (1) Unmodified, where trip planning did not require deviation from the original scenario notes, and (2) Modified, where a subject did have to change his/her plans based on newly learned information that was not outlined in the original scenario notes. There were a total of six scenarios, three of each scenario complexity. For example, subjects might be told to select a certain hotel and make a reservation. Then, they might learn from a message sent to them via the Communications function that the hotel they selected was full and that they have to cancel their reservation, select a different hotel, and make a new reservation. Of the six scenarios that subjects completed, three were unmodified and three were modified.

Each administration of the unmodified and modified scenarios was called a trial. For example, the first administration of an unmodified scenario was trial 1, the second administration of an unmodified scenario was trial 2, and the third administration of an unmodified scenario was trial 3. Similarly, there were three trials of the modified scenario. Note that each of the six scenarios was unique and required different travel plans.

As described above, the ATIS type variable consisted of an integrated and a non-integrated system. Both the scenario complexity and the trial variable were included primarily because of their possible interactions with the ATIS type variable. Figure 6 depicts the experimental design for experiment 1.

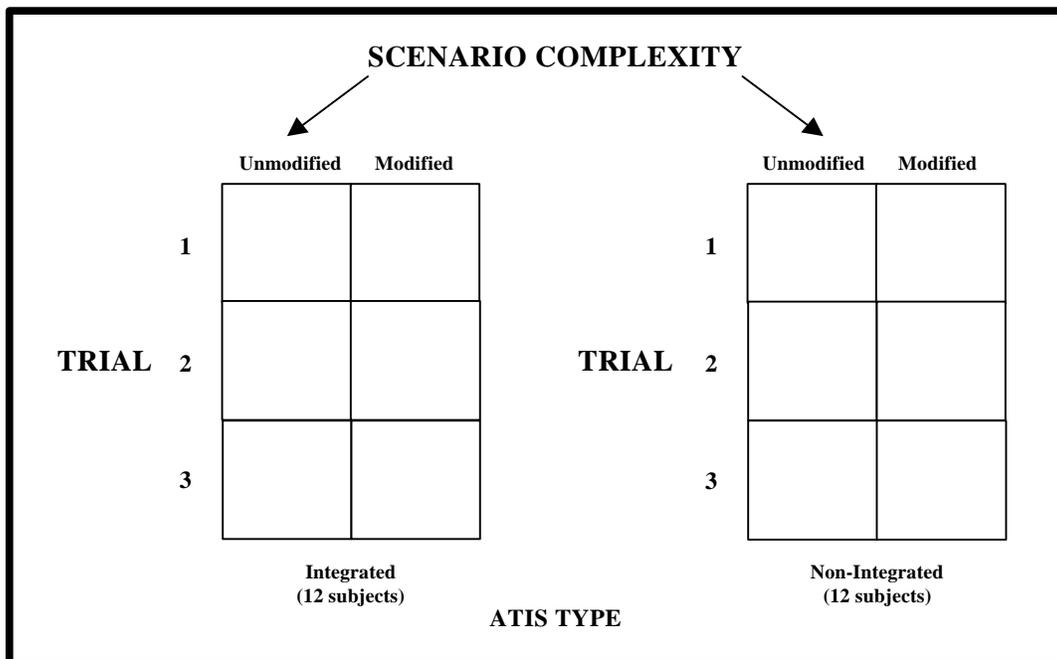


Figure 6. Experimental design for experiment 1.

Dependent Variables

As outlined in table 4, data were collected during three primary phases of the experiment: (1) Subject Recruitment Phase, (2) Testing Phase, (3) CTA Phase. The dependent variables collected in each of the three phases are listed below.

Table 4. Dependent variables associated with the three phases of data collection.

Subject Recruitment Phase	Testing Phase	CTA Phase (3 Separate CTA's)
Subject suitability	Trip latency	Cognitive workload ratings
Demographic information	Function latency	Ratings of ATIS function relationships
Driving experience	Button frequency	Response time and accuracy to multiple choice questions
Technology use experience	Help frequency	
	Main Menu frequency	
	Page Back frequency	
	Error frequency	

Subject Recruitment Phase

There were two objectives of the Subject Recruitment Phase. The first was to determine a subject's suitability for this experiment. This was assessed via the *Subject Selection Phone Questionnaire* (appendix D). To be suitable for this study, subjects were required to have an active driver's license and drive at least twice per week.

After it had been determined that a subject qualified to participate, they were administered the *Driver Demographic Characteristics Phone Questionnaire* (appendix E). This questionnaire elicited responses pertaining to a wide range of demographic characteristics (e.g., age, marital status), driving experience (e.g., number of miles driven annually), and experience with technology (e.g., own/use a computer).

Testing Phase

The Testing Phase consisted of subjects' use of the ATIS and the completion of the six travel planning scenarios. In addition to recording all operations and button selections while working through the scenarios, data were also recorded on the following:

- ! Trip Latency: Measured in milliseconds, the time to plan an entire trip.
- ! Function Latency: Measured in milliseconds, the time to complete a function, e.g., coordinate travel plans.

- ! Button Frequency: Number of button selections per button.
- ! Help Frequency: Number of instances on-line Help button was selected.
- ! Main Menu Frequency: Number of instances that Main Menu button was selected.
- ! Page Back Frequency: Number of instances that Page Back button was selected.
- ! Error Frequency: Number of instances that an on-line error message was activated.

Cognitive Task Analysis Phase

Each version of the CTA Phase was associated with a number of dependent variables. The perceived demand task included workload ratings (using a 0-100 Likert scale) for visual, perceptual, and psychomotor demand. These ratings were provided by the subjects for each ATIS function within a scenario.

The rating task included similarity ratings between 15 ATIS concepts or operations. Since these concepts or operations were not given ratings with themselves, each rating set consisted of 14 ratings. The total of these ratings on individual items could range from 0 to 1000.

The dependent variables associated with the multiple choice task consisted of accuracy scores (correct, incorrect) and response times to the multiple choice questions.

PROCEDURE

The initial screening of participant suitability was done by telephone. The *Subject Selection Phone Questionnaire* and the *Driver Demographic Characteristics Phone Questionnaire* were administered at this time. The purpose of the screening procedure was to ensure a homogeneous population in terms of age, driving knowledge, and experience. Potential subjects who were either over 30 years of age, did not have an active driver's license, or drove less than twice per week were eliminated from the subject pool. Only younger drivers were included as participants in the study because the study was not expected to yield any age effects; that is, no differences were expected between younger and older subjects for the independent variables included in the study. Those who met the criteria outlined were asked a series of demographic characteristics questions and scheduled for a laboratory testing time. The demographic questionnaire was given during the telephone interview to reduce the time required for the testing session.

Upon arrival at the testing site, subjects filled out a written consent form, *FHWA Research Participation Consent Form* (appendix F). Subjects began the experiment by listening to instructions about the purpose of the study, information about ATIS, and about their task (appendix G). Specifically, subjects were told that the data from their participation would allow researchers to better understand how people use an ATIS. They were provided with a brief overview of ATIS that included ATIS objectives, concepts, and technologies. Several possible implementations of an ATIS for this system were described, including ATIS located in a vehicle, in a hotel room, at a kiosk, in a hotel or airport lobby, or from a PC at the home or office. In addition, more specific information was introduced regarding the ATIS used in this study.

After the overview and general instructions were read to the subjects, the experimenter successively demonstrated using the ATIS simulator for both an unmodified and modified scenario. Both of these practice scenarios were designed so that the experimenter was required to use all subsystem functions. This allowed the experimenter to demonstrate successful scenario completion and to introduce all ATIS functions to the subjects. During the two practice sessions, subjects were allowed to ask the experimenter questions about the ATIS and system operation. However, after the practice sessions were completed, the only help that the subject was allowed was via the on-line help system programmed into the ATIS simulator.

Once the experimenter had concluded the unmodified and modified practice scenarios, the subject began the first of his/her six scenarios. These scenarios are presented in appendix B, and describe the trip that the subjects were instructed to plan using the ATIS simulator, including any time or preference constraints. Subjects were instructed to complete each scenario as quickly and accurately as possible. A Latin-Square design was used to order the sequence that the scenarios were administered to each subject. Table 5 shows the subjects' orders of scenario presentation and whether the subjects received the modified TLX, or the new version of the CTA called the "rating task" plus the multiple choice task. For the purpose of the follow-up CTA (the perceived demand CTA method), subjects were videotaped while they completed the scenarios. A Sony camcorder was positioned such that the ATIS screen and the subject's hand interacting with the system could be seen. Each scenario took approximately 5 minutes to complete.

For the eight subjects completing the perceived demand CTA method, the videotape was replayed to the subject after completing each scenario and then they were asked questions about the visual, mental, and physical demands associated with each step (corresponding to each ATIS function) that they had just completed. The instructions and scales for this task are shown in appendix C. This task took subjects 10-15 minutes to complete.

Each subject was also given a short multiple choice quiz two times during data collection. A picture of an actual ATIS screen (the target screen) was presented and the subject was asked to decide which of four screens presented on the left of the target was most likely to have come before the target screen. This was also completed for those coming after the target. These four pictures were presented on the right of the target. The screens appeared exactly as they would on the computer. Subjects were given 20 seconds to examine the target. Subjects were timed on their responses when asked which picture came before or after the target. This process was counterbalanced for each presentation of the pictures and took subjects approximately 5 minutes to complete. The multiple choice quiz was administered two times to each subject: (1) after the practice scenarios, and (2) after the sixth test scenario was completed.

The CTA "rating task" required subjects to rate their perception of various ATIS items. For this task, subjects were given a set number of points to allocate to a number of different items. All items were related, some more than others, and the subjects' task was to assign different values to them accordingly. Subjects had a total of 1000 points to allocate on each of 15 worksheets. This task took anywhere between 35-45 minutes to complete per worksheet. The rating task was administered five times to each subject: (1) after the introduction to ATIS, (2) after the practice scenarios demonstrated by the experimenter, (3) after the second test scenario was completed, (4) after the fourth test scenario was completed, and (5) after the sixth test scenario was completed. Within each subject, the order in which the multiple choice quiz and the rating task was presented was counterbalanced across the two administrations.

In total, the entire study lasted anywhere between 4-5 hours per subject. At the conclusion of the experiment, each subject was asked whether they had any final questions/comments regarding the study. These comments, if any, were noted. The payment form was then completed, the subject was paid and thanked for their participation, and then escorted out of the building.

Table 5. Scenario order and CTA methods for each subject.

Sub	Gen	Modified	Unmodified	Unmodified	Modified	Modified	Unmodified	CTA
1	Male	2	1	3	4	6	5	TLX
2	Male	4	3	5	6	2	1	TLX
3	Male	6	5	1	2	4	3	TLX
4	Male	4	5	1	6	2	3	TLX
5	Male	6	1	3	2	4	5	TLX
6	Male	2	3	5	4	6	1	Rating/MC
7	Male	6	3	5	2	4	1	Rating/MC
8	Male	2	5	1	4	6	3	Rating/MC
9	Male	4	1	3	6	2	5	Rating/MC
10	Female	2	1	3	4	6	5	TLX
11	Female	4	3	5	6	2	1	TLX
12	Female	6	5	1	2	4	3	TLX
13	Female	4	5	1	6	2	3	TLX
14	Female	6	1	3	2	4	5	TLX
15	Female	2	3	5	4	6	1	Rating/MC
16	Female	6	3	5	2	4	1	Rating/MC
17	Female	2	5	1	4	6	3	Rating/MC
18	Female	4	1	3	6	2	5	Rating/MC
19	Male	2	1	3	4	6	5	Rating/MC
20	Male	4	3	5	6	2	1	Rating/MC
21	Male	6	5	1	2	4	3	Rating/MC
22	Female	4	5	1	6	2	3	Rating/MC
23	Female	6	1	3	2	4	5	Rating/MC
24	Female	2	3	5	4	6	1	Rating/MC

Note: All subjects were given two practice trials, one unmodified and one modified, prior to beginning their experimental scenarios.

EXPERIMENT 2

GENERAL APPROACH

To examine driver performance with an in-vehicle ATIS, a simulated ATIS was developed and incorporated into a high-fidelity driving simulator. Eighteen subjects participated in the study, which consisted of driving through a virtual representation of the city of Seattle, while making control inputs to the ATIS and responding to traffic conditions and driving events. ATIS information, including the current vehicle position within the database of Seattle, was presented on a 4" color monitor, located on top of the vehicle's dashboard. Subjects made inputs to the system and navigated through menus within the system, using a dedicated keypad. To make valid estimates of the driving performance implications associated with making these control inputs, subjects were also asked to make inputs to standard in-vehicle devices, such as the radio and HVAC system. Key driving events that were used to assess performance included lane changes, sudden stops, and pulling off to the shoulder of the road. Key independent variables included the status of the ATIS (e.g., on, off), the type of control inputs (e.g., ATIS or standard), and the type of message advising subjects of the need to make a brake or steering correction (e.g., auditory only, ATIS visual only, ATIS visual plus auditory tone, or roadside sign).

SUBJECTS

Eighteen subjects, nine male and nine female, ranging in age from 18 to 30 years old ($M = 23.4$, $SD = 3.62$), participated in the study. Each subject had a valid driver's license, drove at least twice per week in the Seattle area, and reported no health problems that might cause difficulty while driving in the simulator. Subjects were recruited from the University of Washington and by posting flyers at local stores near the Battelle campus, and were paid \$10 per hour for their participation.

APPARATUS

Driving behavior was investigated using the Battelle high-fidelity driving simulator, a simulated ATIS, and seven driving scenarios. Each of these is described below.

Battelle High-Fidelity Simulator

The Battelle high-fidelity driving simulator is housed within a mobile trailer and incorporates a Saturn sedan mounted on a "road feel" motion platform. The 180° horizontal by 45° vertical forward scene and the 60° by 45° rear scene are generated by a Silicon Graphics Onyx Rack System with Reality Engine II graphics. A spatial sound system provides realistic engine, road, wind, and other vehicle noises with appropriate direction cues, intensity levels, and Doppler shift. The entire simulator is controlled from a single operator workstation. The Battelle high-fidelity driving simulator provides the capability to immerse subjects in a realistic environment in which they can be safely exposed to a wide range of driving and traffic conditions.

The visual database provides the subject with a high-fidelity representation of the real world. The outside visual scene presents multi-lane highways, two-lane rural roads, residential roads, and downtown core roads with representative roadway features and changes in elevation and terrain. Also, homes and commercial buildings, functional traffic control devices, pedestrians, and a range of other vehicles are presented to the subject. All scenarios present the subject with a rich driving experience. The simulator also provides full control over ambient conditions, such as time of day and weather conditions.

The simulator vehicle is a 1994 Saturn sedan, modified to meet a number of strict experimental requirements, and linked to the host computer. The five-channel directional sound system provides engine, road, and tire noise for both the simulator vehicle and other vehicles in the driving scenarios. All sounds are consistent with vehicle states, changes in road surfaces, and the location and distance of external sound sources. The “road feel” motion platform imparts high-frequency movements that are correlated with all visual and auditory cues. The reconfigurable display suite includes a programmable, full-color liquid crystal display (LCD) to present either navigation information or roadway relevant information. The vehicle dynamics, including engine displacement, gear ratios, shift points, and vehicle constants, can be found in appendix H.

The performance measurement subsystem measures, records, analyzes, and manipulates all simulation data, at a rate of 30 Hz. All subject inputs to the steering wheel, accelerator, brake, and vehicle secondary controls (e.g., gear shift, headlights) are recorded. Acceleration rates are measured with a linear potentiometer, and braking behaviors are measured by a strain gauge. Inputs into these devices are translated into percentage of throttle and brake pressure. Driving performance measures such as lane position and steering variability are logged by a host computer. The locations and states of the autonomous objects within the visual database are also recorded.

The Advanced Traveler Information System

The simulated ATIS had the ability to present the subject current vehicle location information, warnings about upcoming traffic conditions, and navigation information. ATIS information was presented on a Sharp 4" diagonal color display located on the dashboard, 82.3 centimeters to the right of the steering wheel.

The current vehicle location information was presented using the Retki Global Positioning System (GPS) Navigational Interface. During the simulation, the coordinate data provided by the simulator were fed into the ATIS computer, replacing the real-time GPS data it would receive during usual on-the-road operating conditions. Therefore, as the subject drove through the simulated route, the vehicle’s location could be continuously tracked and updated on the moving map display. While stationary, the position of the vehicle appeared on the map as a star. Once the vehicle began to move, a black arrowhead showed the vehicle position and direction of travel.

A database of the Seattle area was used in this experiment. Thus, roadways and roadside elements were familiar to the subjects. A representation of the navigation portion of the ATIS display can be seen in figure 7.

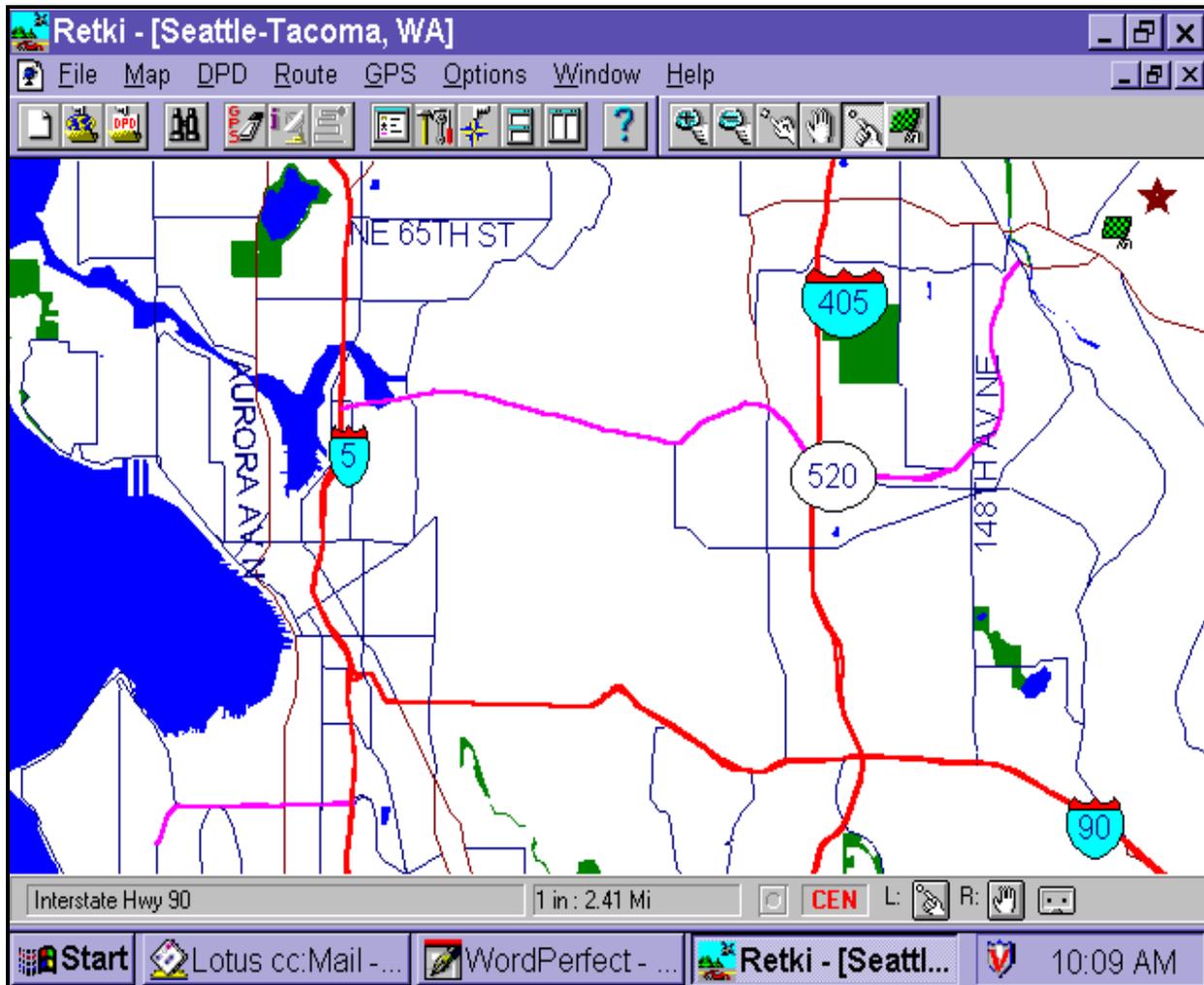


Figure 7. The moving map display of the current vehicle location.

Warnings about upcoming traffic conditions were presented as the subjects were approaching several roadway events placed within the driving scenarios. Warnings were presented in one of the following forms:

- ! A visual text message, which simply stated the upcoming traffic condition (Visual/Notification-no alert).
- ! A visual text message, which simply stated the upcoming traffic condition, preceded by an auditory tone (Visual/Notification-auditory alert).
- ! An auditory message, which informed the subject of the upcoming traffic condition and suggested the appropriate action to take (Auditory/Command).

Auditory messages were played only once while text messages remained on the screen until the vehicle reached the event. When the messages were presented visually, the moving-map display of the current vehicle location would be temporarily interrupted. Once the subject passed the event, the current vehicle location was updated on the moving map display.

Warning messages were always given 7.1 seconds prior to a point 21 meters before the roadway event. This timing algorithm was determined by using an equation derived by Ross, Vaughan, and Nicolle (1997). Ross et al. plotted regression lines based on the subjective ratings of the timeliness of navigation instructions, and derived preferred minimum distance, ideal distance, and preferred maximum distance equations for presentation of navigation information. The timing algorithm of this study used their ideal distance equation.

Navigation messages informed subjects of upcoming exits and turns on their route. These messages were always presented using the auditory channel. After reviewing the timing algorithms and conducting in-house pilot testing, it was determined that an additional 3 seconds should be added to the equation for presenting navigation instructions. This made it easier for the subjects to comply with the navigation instructions, as making turns requires slightly more effort in the simulator than it would in the real world. Therefore, all of the navigation messages were presented 10.1 seconds prior to a point 21 meters before the upcoming exit or turn.

A Scorpius 22-key keypad could be used to make control inputs to the ATIS. By using this keypad, the subjects could rotate the map, zoom in/out on the map, turn the compass on/off and obtain attraction information. The keypad was mounted to an adjustable arm and placed approximately 5 centimeters above and 3 centimeters to the right of the gear shift located on the center console. Several of the keys were removed from the keypad and the remaining space was covered so that only the keys necessary for manipulating the system could be seen by the subject. These keys included right, left, up and down arrow keys, a MENU key, an ENTER key, and a BACK key (see the diagram shown in figure 8).

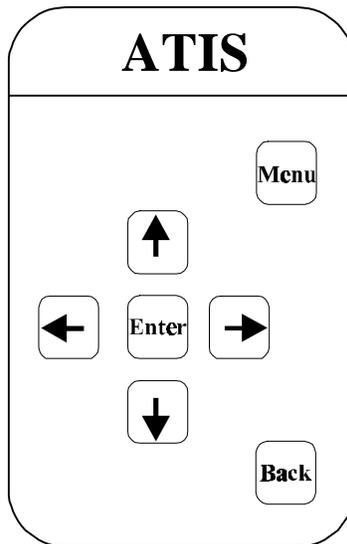


Figure 8. Keypad for making control inputs to the ATIS.

Pressing the MENU key on the keypad activated the menu structure by bringing up a list of the four possible control actions: compass, rotate map, zoom, and attraction information. Using the arrow keys, the subjects could then negotiate their way through the menu. Once a menu command was highlighted, the ENTER key could be used to execute the command. The BACK key was added as a means for correcting errors; pressing it allowed the subjects to return to the previous screen.

The menu structure was two levels deep. If, for example, “compass” was selected from the main menu, a second screen would require the subject to choose between the options “compass on” and “compass off.” The main menu and their associated second-level menus are presented in table 6.

Table 6. ATIS display: First- and second-level menus.

Main Menu Control Option	Associated Second-Level Menu Control Options
Compass	Compass On Compass Off
Rotate Map	Heading Up North Up
Zoom	Zoom In Zoom Out
Attraction Information	The Kingdome Lake Union Space Needle Bellevue Community College

Driving Scenarios

The subjects completed a total of seven driving scenarios. Three of these were 5-minute practice scenarios; the remaining four were experimental scenarios that took 8 to 10 minutes to complete at the posted speed limits. All driving was done in daytime, foggy weather conditions.

Each of the practice scenarios consisted of 6,600 meters of rural roads, with a limited number of other vehicles or objects encountered along the route. The visual database included both straight and curved roadway elements, surrounded by trees, hills, and grass. The practice scenarios helped the subjects to become familiar with the feel of the steering, accelerator, and brake characteristics of the simulator, get accustomed to the simulated environment, and drive according to the posted speed limits.

During the experimental scenarios, subjects traveled through a visual database that represented certain parts of the State of Washington. The database comprised multi-lane highways, residential roads, and downtown core roads, all with the identical changes in elevation and terrain as would be found in the real world. The database also contained actual local landmarks (i.e., the Kingdome, the Mercer Island Tunnel, etc.) in order to increase the realism of the simulation. During all experimental scenarios, the subjects were presented navigation information to help ensure that they would not miss the necessary exits and turns.

Experimental scenario 1 was 12,407 meters long, requiring approximately 10 minutes to complete at the posted speed limit of 60 mi/h (97 km/h). This road portion represented the I-90 Eastbound segment of the local Seattle road network. In this scenario, three events required the subjects to make some change in either their speed or lane position. Subjects had to change lanes once to avoid a construction zone, had to reduce their speed as they were traveling through a construction zone, and make a speed change when exiting I-90 on a slow curve.

Experimental scenario 2a was 3,890 meters long, requiring approximately 8 minutes to complete at the posted speed limit of 35 mi/h (56 km/h). This road portion represented driving in the city of Bellevue, Washington. During this scenario, the subjects were required to change lanes to avoid a parked car in the lane ahead, reduce their speed in a school zone, and stop for a pedestrian crossing.

Experimental scenario 2b was 4,190 meters long, requiring approximately 8 minutes to complete at the posted speed limit of 35 mi/h (56 km/h). This scenario took place in the streets linking Bellevue, Washington, with the Highway 520 bridge. The subjects were required to change lanes to avoid an object in the roadway, pull to the side of the road for an approaching emergency vehicle, and change lanes to avoid an accident in the lane ahead.

Experimental scenario 3 was 11,970 meters long, and required approximately 10 minutes to drive at the posted speed limit of 50 mi/h (81 km/h). This scenario took place between Bellevue, Washington, and I-5. Three incidents required the subjects to make a lane change; these were an overturned truck, a disabled vehicle, and a slow moving vehicle.

Control Inputs

During one or two of the driving scenarios, the subjects were asked to perform several tasks as they drove. These tasks required them to make control inputs either to the standard systems found in a car (i.e., radio, temperature controls) or to the ATIS. A list of the tasks that the subjects might have been asked to perform can be found below:

Standard

- ! Set clock 1 hour ahead.

- ! Turn on the radio and set to preset channel number 3.

- ! Tune radio to 106.9 FM using the seek button.

- ! Turn the fan to defrost and turn it on high.

- ! Turn the fan to bi-level and turn it on low.

- ! Tune radio manually to 107.7 FM and set it to become preset channel 7.

Advanced

- ! Turn on the compass.

- ! Rotate map, heading up.

- ! Zoom in on the map.

- ! Obtain information about the Space Needle.

- ! Rotate map, north up.

- ! Zoom out on the map.

In a training session completed before the experiment, subjects were shown how to perform each of these control inputs. Training was continued until the subjects were able to perform the control inputs without error.

Subjects were asked to complete each of the control inputs during a part of the drive where there were no other events. The instructions to perform control inputs were presented visually on the ATIS display. Through the use of cameras mounted in the car, the experimenter was able to determine when the subject completed the standard control inputs. When the input was complete, the experimenter pressed a button, marking the data with the completion time of the control input. Time stamping was done automatically by the computer for the advanced control inputs.

EXPERIMENTAL DESIGN

Independent Variables

Within-subject variables examined in this study were: ATIS Status, Control Input Type, Message Type, Event Type, Route, Window, Baseline, and Route Ordinal Position; between-subject variables were Order of Route and Order of ATIS Status. The independent variables are summarized in table 7; additional details are provided below.

There were three levels of the variable ATIS Status: On, On with Control Inputs, and Off. In the On condition, the ATIS was fully functional. That is, the ATIS constantly tracked the vehicle location on the moving map display, presented advance warnings of upcoming roadway conditions, and provided navigation information. In the On with Control Inputs condition, in addition to the ATIS being fully functional, the subject was required to perform certain tasks (i.e., control inputs) using the ATIS controls and the standard controls found in a car (i.e., radio, temperature controls, etc.). In the Off condition, the ATIS was fully functional only when the vehicle speed was below 5 mi/h. When the vehicle speed was above 5 mi/h, the subjects were not able to track their location on the moving map, nor were they able to receive advanced warnings of approaching traffic conditions. They did, however, continue to receive navigation information.

There were two levels of the variable Control Input Type: Advanced and Standard. The advanced inputs required the subjects to manipulate the ATIS system, either by engaging a compass, rotating the heading of the map, zooming in or out, or obtaining information about some attraction along their route. The standard control inputs required the subjects to change the radio station, set the clock, or use the temperature controls.

The binary variable ATIS message type indicated whether the subjects received an in-vehicle message as they were approaching a roadway event. There were three message types used to present information to the subject: Auditory/Command, Visual/Notification-no alert, and Visual/Notification-auditory alert. Auditory/Command messages warned the subject aurally of upcoming traffic situations and suggested the appropriate action to take (i.e., Truck overturned ahead—merge left). Visual/Notification-no alert messages were text messages presented on the ATIS display. This type of message would simply warn the subject without suggesting any particular action (i.e., Accident in lane ahead). Visual/Notification-auditory alert messages presented an auditory tone that alerted the subjects to a text message being presented on the ATIS display. The text message simply informed the subject of an upcoming traffic situation without suggesting any particular action (i.e., Slow moving vehicle ahead).

The variable Event referred to the 12 roadway events placed in the driving scenarios. The subjects encountered three events during each scenario. If they were driving the scenario in the ATIS On or ATIS On with Control Inputs conditions, the subjects received ATIS warning messages regarding these roadway events. In the ATIS Off condition, the subjects still encountered the roadway event, but did not receive any in-vehicle warnings. For any specific roadway event, the same ATIS message was presented to all subjects who did receive a warning. Table 8 presents a description of the roadway events and the associated ATIS messages.

The variable Route indicated the driving environment. The roadway used in the experimental scenarios could roughly be divided into three sections. The first part mainly consisted of a part of I-90 in the State of Washington, the second part, of the city of Bellevue and surroundings, and the

third part, of a portion of Washington State Highway 520. The first and the third sections were each driven in one scenario. The second part was too long for one scenario; therefore, it was split into two scenarios roughly equal in length.

Window refers to the three data collection windows before, during, and after a control input is made by the subject. Pre-input window spanned the 6 seconds immediately preceding the input request. During-input window started with the message onset requesting a control input, and ended when the input was complete. Post-input window followed the during-input window, and was 6 seconds long.

Baseline refers to the three data collection windows placed in the beginning, the middle, and toward the end of all driving scenarios. These were 100-meter-long, straight sections of road. No roadway events or control input requests occurred during the baseline segments, nor were any navigation messages presented.

Table 7. Independent variables.

Variable Name	Levels	Description
ATIS Status (within-subject)	1) On 2) On with Control Inputs 3) Off	ATIS fully functional at all times; no control inputs required from the subject. ATIS fully functional at all times; control inputs required from the subject. ATIS presents only navigation information when the vehicle speed is above 5 mi/h; no control inputs required from the subject.
Control Input Type (within-subject)	1) Advanced 2) Standard	ATIS controls (e.g., Zoom in on the moving map display). Radio or temperature controls (e.g., Tune the radio to 107.7 FM using the seek button).
Message Type (within-subject)	1) Auditory/Command 2) Visual/Notification-no alert 3) Visual/Notification-auditory alert	Auditory message that advises subjects of a particular roadway condition and suggests the appropriate action to take (e.g., Truck overturned ahead—merge left). Text message that simply advises subjects of a particular roadway condition (e.g., Accident in lane ahead). Text message that simply advises subjects of a particular roadway condition (e.g., Disabled vehicle ahead), preceded by an auditory alert.
Event (within-subject)	1-12	See table 8 for event descriptions.
Event type (within-subject)	1) Speed event 2) Lane event	Requires the subject to make a speed change. Requires the subject to make a lane change.
ATIS Message (within-subject)	1) Present 2) Not present	In-vehicle ATIS message presented. No in-vehicle messages presented.

Route (within-subject)	1) I-90 2) Bellevue 3) Highway 520	Driving scenario 1. Driving scenarios 2a and 2b. Driving scenario 3.
Window (within-subject)	1) Pre-input 2) During-input 3) Post-input	Data collected for 6 seconds immediately preceding the control input request. Data collected from the control input request until the control input is completed. Data collected for 6 seconds following the completion of the control input.
Baseline (within-subject)	1) First 2) Second 3) Third	First baseline in a scenario (in the beginning). Second baseline in a scenario (in the middle). Third baseline in a scenario (in the end).
Route Ordinal Position (within-subject)	1) First 2) Second 3) Third	Driven first. Driven second. Driven third.
Order of Route (between-subject)	1) I-90, Bellevue, Highway 520 2) Bellevue, Highway 520, I-90 3) Highway 520, I-90, Bellevue	
Order of ATIS Status (between-subject)	1) On, On with Control Inputs, Off 2) On, Off, On with Control Inputs 3) On with Control Inputs, On, Off 4) On with Control Inputs, Off, On 5) Off, On, On with Control Inputs 6) Off, On with Control Inputs, On	

The subjects drove through each of the three routes during a different ATIS Status. A Greco-Latin square design was used to determine the order of Route and the order of ATIS Status. The design is presented in appendix I.

Three control inputs were associated with each driving scenario. The subjects were asked to complete these inputs only when they were driving a scenario in the ATIS On with Control Inputs condition. Subjects completed three or six control inputs, depending on how many scenarios they drove in this condition. Each subject completed both standard and advanced inputs.

Table 8. Roadway events and associated ATIS messages.

Event No.	Scenario	Event Type	Event Description	Associated ATIS Message	Message Type
1	1	Lane event	Lane closed for construction	“Right Lane Closed Ahead for Construction—Merge Left”	Auditory/Command
2	1	Speed event	Reduced speed limit in construction zone	“Speed Limit 35 mi/h in Construction Zone”	Visual/Notification
3	1	Speed event	Reduced speed limit on exit ramp	“Speed Limit 35 mi/h on Exit Ramp”	Visual/Notification-Auditory Alert
4	2a	Lane event	Parked car in lane	“Parked Car in Lane Ahead”	Visual/Notification
5	2a	Speed event	Reduced speed limit in school zone	“Speed Limit 20 mi/h in School Zone”	Visual/Notification-Auditory Alert
6	2a	Speed event	Pedestrian crossing	“Stop for Pedestrian Crossing”	Auditory/Command
7	2b	Lane event	Object in lane	“Object in Road Ahead”	Visual/Notification-Auditory Alert
8	2b	Lane event	Fire truck approaches from behind	“Fire Truck Approaching from Behind—Pull to Side of Road”	Auditory/Command
9	2b	Lane event	Accident in lane	“Accident in Lane Ahead”	Visual/Notification
10	3	Lane event	Overtaken truck in lane	“Truck Overtaken Ahead—Merge Left”	Auditory/Command
11	3	Lane event	Disabled vehicle in lane	“Disabled Vehicle Ahead”	Visual/Notification-Auditory Alert
12	3	Lane event	Slow moving vehicle in lane	“Slow Moving Vehicle Ahead”	Visual/Notification

Dependent Variables

Two types of dependent measures were collected: driving performance data and roadway event data. The dependent variables are summarized in table 9.

Table 9. Dependent variables.

Type	Dependent Variable
Driving Performance	Standard deviation of speed Mean speed, m/s Rate of large steering reversals, count/second
Roadway Events	Speed events Compliance, binary Compliance before the road sign, binary Percent compliance, % Distance to the road sign at compliance, feet Time to compliance, seconds Lane events Compliance, binary Time to lane crossing, seconds Distance to the event at lane crossing, feet

Driving Performance Data

Driver performance data of particular interest were measures of steering wheel movements and speed deviations. Research has shown that changes in driving steering behavior occur when driver attention changes (Wierwille and Gutman, 1978). In driving situations that place low attentional demands on drivers, drivers typically make continuous, smaller steering corrections to make up for roadway variance and driving conditions. These corrections are generally within the range of 2 to 6 degrees. As attention or workload demands increase, the frequency of steering corrections tends to decrease. Since the small centering corrections decrease, the vehicle tends to drift farther from the lane center, and a larger steering input is required to correct the position. These larger steering inputs generally exceed 6 degrees and are referred to as large steering reversals. An increase in the number of large steering reversals, therefore, indicates high attention or workload requirements and a reduction in driving performance.

Vehicle speed, like lane position, can be considered a vehicle state that, at some level, has to be held constant in most circumstances. Therefore, for the same reasons described above for steering reversals, variations in velocity are used to evaluate driving performance. Drivers are required to make continuous adjustments in pedal displacement to maintain the correct speed. When driver attention is drawn away from the driving task, there is a tendency to maintain the foot in the same position. When drivers realize that they are going (generally) too slow, the accelerator is pressed to a greater degree than is normal for a continuous adjustment. Research has found the standard deviation of speed to be a sensitive measure of change in the amount of attention demands by secondary driving tasks (Monty, 1984).

Roadway Event Data

Different measures were collected for two different types of roadway events; these are listed above in table 8.

Among the measures investigated for speed events were compliance, compliance before the road sign, and percent compliance. Compliance was a binary variable that indicated whether the

subject slowed down to the required speed (either before the road sign or after passing the road sign). Compliance before the road sign, another binary variable, indicated whether the subject complied before passing the road sign. Percent compliance took into account how much the subjects needed to slow down, and how much they actually did; this variable was equal to $100 \times (\text{observed speed reduction}/\text{required speed reduction})$. For those subjects who did slow down to the required speed, distance to the road sign at compliance and time to compliance were also calculated.

For lane events, compliance, a binary variable, indicated whether the subjects successfully changed lanes before reaching the roadway event. For those subjects who complied (i.e., were able to change lanes), distance to the roadway event at lane crossing and time (from message onset) to lane crossing were calculated.

PROCEDURE

Recruiting Subjects

The Subject Selection Phone Questionnaire (appendix J) and the Driver Demographic Characteristics Phone Questionnaire (appendix K) were administered by telephone as the initial screening for participant suitability. Individuals who experienced motion sickness, frequent migraines, serious heart condition, were pregnant, suffered any medical condition, or took any medications that predisposed them to nausea, blurred vision, or drowsiness were omitted from the study. The purpose of the screening procedure was to minimize the possibility of simulator sickness. Only potential subjects who were over 18 years of age, held an active driver's license, and drove in Seattle at least twice per week were scheduled to participate in the study.

Pre-Experiment

Upon arrival at the simulator, subjects were asked to read the Research Participation Information Summary (appendix L) and to sign the associated Consent Form (appendix M). The purpose of the study and a brief introduction of the simulator were provided at this time as well (see appendix N for the Experimental Protocol). This was followed by an explanation of the symptoms and possibility of simulator sickness. A Subject Comfort Assessment (SCA) questionnaire (appendix O) was administered to record the subject's state of well-being before the experiment. It was used both as a pre-screening tool and to compare the subject's state of well-being after each scenario and following the experiment. Subjects were not permitted to enter the simulation room if their score on the comfort assessment did not meet pre-determined criteria. A Postural Disequilibrium Test (appendix P) was also administered at this time. Subjects were asked to balance on one foot with their eyes closed and their arms folded across their chest. The experimenter recorded the length of time, up to 30 seconds, the subjects could keep their position without opening their eyes. This was performed three times, and the mean score was computed. The mean score was kept and compared with post-test results.

Experiment

Subjects were escorted to the simulator vehicle and were encouraged to adjust the seat and mirrors to a comfortable position. The vehicle's controls and displays, including the navigation aid, were shown to the subject. The location of a microphone was noted so that the subjects could speak to the experimenter if necessary. Subjects were instructed that their primary task throughout the experiment was to operate the vehicle as if they were driving their own vehicle in the real world. The importance of obeying all traffic rules, including speed limits, was emphasized.

Each subject completed the three practice trials, which consisted of rural driving with very few vehicles on the roadway or objects in the visual scene. The purpose of the practice session was to allow the subject to become used to the feel of the simulator, as steering and braking require some acclimation. Upon completion of the practice drives, the advanced vehicle system was activated and the subject was trained on all of its functions as well as on the standard features of the vehicle. The training continued until the subject was able to perform, without any errors, all of the tasks associated with the study.

Each subject drove the four experimental trials in a pre-determined order, which varied between subjects. Conditions experienced by each of the subjects were also counterbalanced. (The Greco-Latin square design used for this study can be seen in appendix I.)

The four experimental scenarios consisted of two highway portions (I-90 bridge to Bellevue Way NE and Highway 520 to downtown Seattle), and two city street portions (Bellevue Way to Bellevue Mall and Bellevue Mall to the Highway 520 bridge). The two city street portions always followed one another and were assigned the same ATIS condition so that they could be combined for subsequent data analysis.

Each scenario began with instructions from the experimenter to drive to a specific location with the help of the navigation system (see appendix Q for experimenter instructions). The experimenter monitored the subjects' speed and verbally reminded subjects to slow down or speed up if they deviated too far from the posted speed limits. It was important that subjects maintained the speed limit so that all subjects experienced the planned incidents in the same way. When subjects reached their destination, they were instructed to stop the vehicle and place the gear shift lever in park to end the scenario.

At the conclusion of each scenario, subjects were asked to complete the Driver Comfort Assessment Questionnaire and the Postural Disequilibrium Test to make sure that they were not experiencing any adverse effects of the simulation. If the subjects were experiencing negative effects, the experiment was not completed.

Post-Experiment

After all four experimental scenarios were driven, the Driver Comfort Assessment Questionnaire and the Postural Disequilibrium Test were administered one final time. These tests were administered to ensure subjects were not negatively affected by their simulator experience and to determine if it was safe for them to drive home. If the difference between the pre-test and post-test scores was substantial according to a pre-determined criteria, it was recommended that the subject not leave the experiment site. Rather, they were encouraged to remain and rest for 30

minutes. After 30 minutes, the tests were re-administered. If subjects met the criteria, they were permitted to drive home, otherwise subjects were sent home in a taxi. All subjects were paid and a record of payment form was completed and signed before leaving.

RESULTS

EXPERIMENT 1

The results for experiment 1 will be described in four sections: (1) ATIS performance, (2) perceived demand, (3) multiple choice, and (4) similarity rating task data. All analyses were conducted using the Bio-Medical Data Processing (BMDP), version 7.0 software package. Following data entry and verification of basic data integrity, the data were subjected to a number of analyses that screened for missing data and outliers. Further, where appropriate, the data were analyzed to verify that the assumptions associated with the repeated measures of analysis of variance (ANOVA) were met. The assumption of normality was assessed by examining the skewness and kurtosis of each variable. Where appropriate, results are interpreted using the Greenhouse-Geisser adjustment to avoid violations of the sphericity assumption.

ATIS PERFORMANCE DATA

A series of repeated measures ANOVA was used to examine the relationship between system type, complexity, and trial. The variable for type consisted of two levels: integrated and non-integrated. The variable complexity consisted of two levels: unmodified (where trip planning did not require deviation from the original scenario notes) and modified (where a subject did have to change his/her plans based on newly learned information that was not outlined in the original scenario notes) scenarios. In all modified scenarios, the subject was forced to cancel a previously reserved selection, and then make a new selection and reservation. The variable trial had three levels and refers to the order in which each subject completed the three unmodified and three modified scenarios. Four measures of ATIS performance were examined with the ANOVA: trip latency, help requests, error messages, and pause frequency. Only trip latency provided insights into the performance of ATIS users, with modified scenarios taking longer to complete than unmodified scenarios.

The repeated measures ANOVA revealed no significant difference in the time required to plan a trip between the integrated (293 seconds) and non-integrated systems (287 seconds), $F(1,22) = 0.04$, $p > 0.05$.

A number of analyses were conducted on the performance data. A summary of the analyses can be seen below in table 10. Many of these analyses were exploratory in nature. As the analyses did not provide insight into the experimental hypotheses, they are not discussed further. Appendix R, however, presents complete ANOVA tables for trip latency (table 12) and each function latency (tables 13-18). Also, appendix R provides frequency tables and exploratory ANOVA tables for help requests (tables 19 and 20), error messages (tables 21 and 22), and pause frequency (tables 23 and 24). Table 11 provides means for all dependent measures as a function of the complexity variable. These are aggregate means, collapsed across all 24 subjects and 3 trials per subject (72 trials).

Table 10. Summary of ATIS performance analyses.

Effect	Dependent Variables			
	Total Latency	Help Requests	Error Messages	Pause Frequency
Type	F(1,22) = 0.04	F(1,22) = 1.54	F(1,22) = 0.11	F(1,22) = 0.54
Present Complexity Means for all DV	F(1,22) = 52.59***	F(1,22) = 4.30*	F(1,22) = 0.00	F(1,22) = 9.02*
Trial	F(1.44,31.66) [†] = 64.57***	F(1.21, 26.69) [†] = 4.92*	F(2,44) = 1.45	F(2,44) = 2.80
Type × Complexity	F(1,22) = 0.02	F(1,22) = 0.48	F(1,22) = 0.00	F(1,22) = 0.36
Type × Trial	F(2,44) = 0.97	F(2,44) = 0.30	F(2,44) = 1.02	F(2, 44) = 0.09
Complexity × Trial	F(1.91, 42.10) [†] = 10.24**	F(1.23, 27.13) [†] = 7.0**	F(2,44) = 0.24	F(2, 44) = 1.37
Type × Complexity × Trial	F(2,44) = 0.44	F(2,44) = 1.00	F(1.88, 41.29) [†] = 3.18	F(2, 44) = 2.55

* $p < 0.05$ ** $p < 0.01$ *** $p < 0.001$

[†]Degrees of freedom were adjusted using the Greenhouse-Geisser correction where appropriate.

Table 11. Means for all dependent variables on the variable “Complexity.”

Variable	Unmodified	Modified
Latency (seconds)	253.00	326.00
Number of Help Requests	0.01	0.14
Number of Errors	0.13	0.13
Number of Pauses	0.08	0.35

PERCEIVED DEMAND QUESTIONNAIRE

Perceived visual, mental, and physical demands were rated on a scale of 0 to 100 for each of the 7 steps in the unmodified scenarios, and 10 steps in the modified trials. A composite score was obtained by averaging across all steps in a scenario. Visual demands (22.4) were perceived higher than mental demands (17.9), which were perceived as being higher than physical demands (10.7), $F(2,8) = 26.13, p < 0.001$. However, the perceived demands across all dimensions were generally low due to low workload conditions, as subjects were not required to drive a vehicle while operating the ATIS. The ANOVA table can be found in appendix R (table 25).

MULTIPLE CHOICE TASK

Subjects' ability to navigate within the ATIS system was assessed by navigation accuracy and the time required to examine a target screen and identify the preceding and following screens. In the analysis, a distinction was made between trials in which the correct response was in the same function as the target screen (e.g., trip planning, trial modes, communications) versus trials in which the correct response was in a different function. A repeated measures ANOVA performed on the percent correct (accuracy) data revealed that a significant effect of transition was observed, $F(1,14) = 23.33, p < 0.001$, with accuracy being higher when the correct response was in the same function as the target screen (78.3 percent) than when it was in a different function (51.6 percent). Further, figure 9 illustrates that accuracy was not significantly different for the integrated and non-integrated condition when the correct answer was in the same function as the target screen. However, accuracy dropped significantly, $F(1,14) = 6.35, p < 0.05$, for the integrated condition when the correct answer was in a different function (38.9 percent) than the target screen than when it was in the same function (77.9 percent). The ANOVA table can be found in appendix R (table 26).

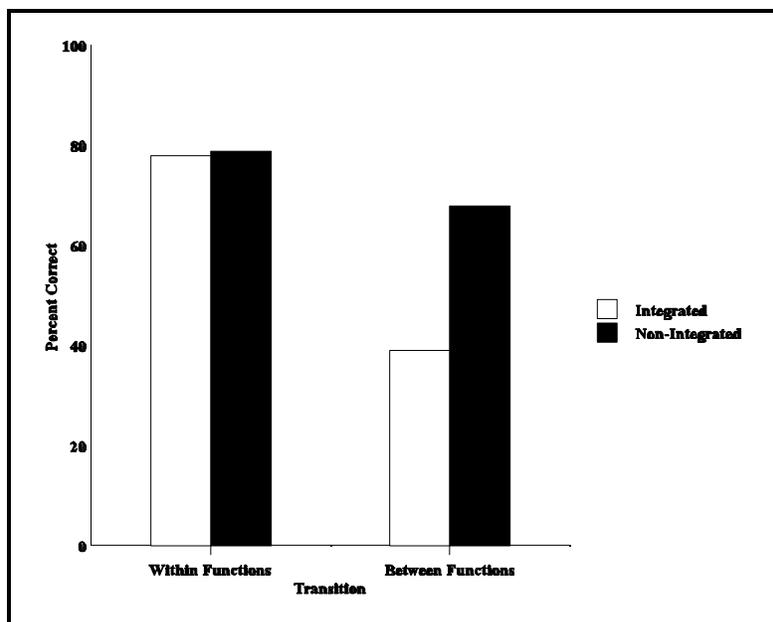


Figure 9. Percent correct as a function of ATIS type and transition.

Figure 10 shows that the time to respond to the multiple choice questions decreased only slightly from pre-test to post-test trials in the integrated condition (1.9 seconds), whereas there was a large decrease from pre-test to post-test trials in the non-integrated condition (9.2 seconds), $F(1,12) = 4.93, p < 0.05$. Presumably, this occurred because on the post-test, subjects in the non-integrated condition were able to navigate within the system using the different colors and formats of each function as cues. Also, when the correct answer was within the same function as the target, latencies (8.2 seconds) were shorter than when the correct answer was in a different function (17.6 seconds), $F(1,12) = 24.33, p < 0.001$. The ANOVA table is found in appendix R (table 27).

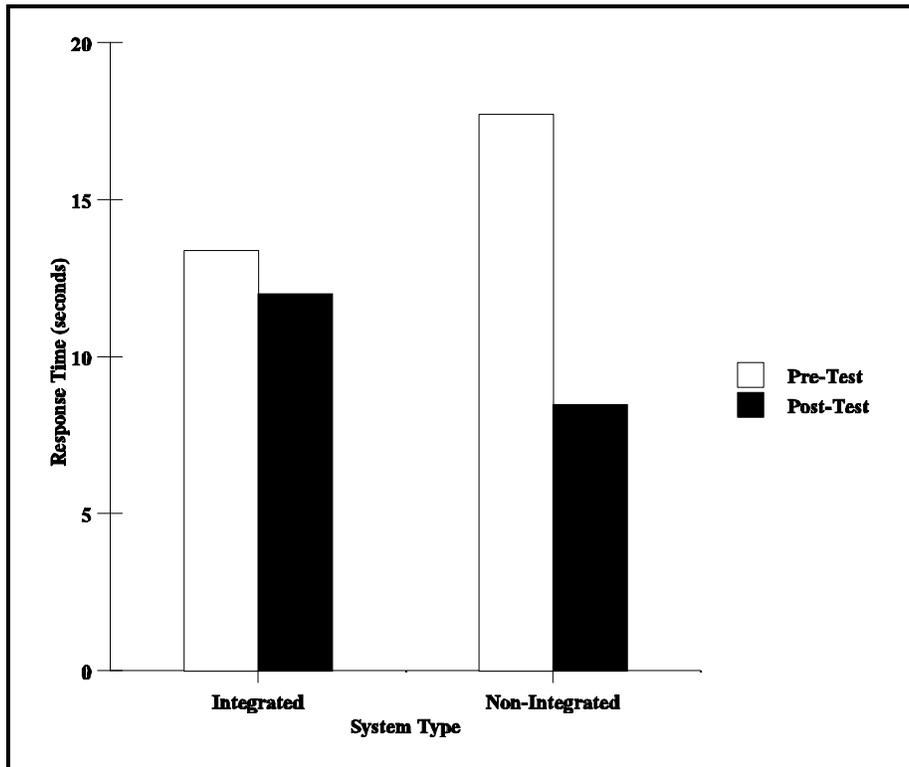


Figure 10. Response time as a function of system type and trial.

SIMILARITY RATING TASK²

For each of 5 trials, subjects completed a 15×15 matrix of similarity ratings. As subjects were not asked to rate the similarity of each variable with itself, the diagonal of each matrix was left blank. Because each matrix was a full (square) matrix, each pair of variables was rated twice. The two ratings (i.e., the top and bottom halves of the matrix) were averaged to produce a lower half matrix.

Further, two matrices were formed: one represented the average of all integrated subjects on trial 5, and the other represented the average of all non-integrated subjects on trial 5. Finally, a series of 16 matrices were formed, one to be correlated with each subject. To prepare these matrices, each subject was removed individually from the averaged trial 5 matrix. For example, Subject 2's matrix consisted of all integrated subjects except Subject 2. This prevented artificially inflated correlations due to the subject's own data contributing to the average matrix.

The lower-half matrices of each subject (trial 1 to 5) were correlated with their own comparison matrix (average trial 5 matrix of all members of their own group except for themselves). These correlations were then used as input for a 2 (system type) \times 5 (trial) repeated measures ANOVA. Two subjects (Subject 22 and 25) were removed from the analyses due to the instability of their

²The authors gratefully acknowledge the assistance of Dr. Alvah C. Bittner, Jr., during the analysis of these data.

response patterns. Results revealed no significant effect of system type. However, a significant main effect of trial was revealed that could be explained by the significant linear trend, $F(1, 12) = 14.78, p < 0.01$. This suggested a tendency for correlations to increase linearly from trial 1 to 5. Despite the strong linear trend, a plot of the data across trials revealed a more exponential function. As a result, a non-linear regression equation was applied to the data. The analyses revealed that the non-linear equation explained the data with a r of 0.99 ($p < 0.05$). Further, the results predicted an asymptote value of $r = 0.76$. The ANOVA table is presented in appendix R (table 28).

The correlation of the trial 5 integrated and non-integrated matrices was 0.99 after correcting for attenuation. To verify that there was no difference between the two matrices, the averaged trial 5 matrix of all integrated subjects was compared with the averaged trial 5 matrix of all non-integrated subjects using a 2 (System Type) \times 2 (Group Correlated) ANOVA. A significant interaction was obtained, $F(1, 14) = 6.29, p < 0.05$. Examination of the means revealed that, on trial 5, subjects in the integrated group actually correlated higher with the non-integrated group than with their own. Because there was no result that indicated that the integrated and non-integrated matrices were different, $F(1, 12) = 2.0, p > 0.05$, the two groups were averaged to form one matrix that incorporated all subjects. The ANOVA table is presented in appendix R (table 29).

This matrix, averaged over all subjects, was used as input for an exploratory factor analysis. Factors were extracted using principal components analysis. After varimax rotation, four factors emerged: Travel Mode, Communications, Travel Coordination, and Travel Plan. Factors 1 and 2 are plotted against each other and presented in figure 11. The arcs between each of the four factors (Travel Mode, Service Directory, Travel Coordination, and Communication) represent the distance. Note that this is actually a two-dimensional representation of a four-dimensional figure and that the actual distances are computed in four-dimensional space. As an example, the distance between travel plan and travel plan (1.595) is actually greater than the distance between communications and travel plan (1.318) because they reside on different planes.

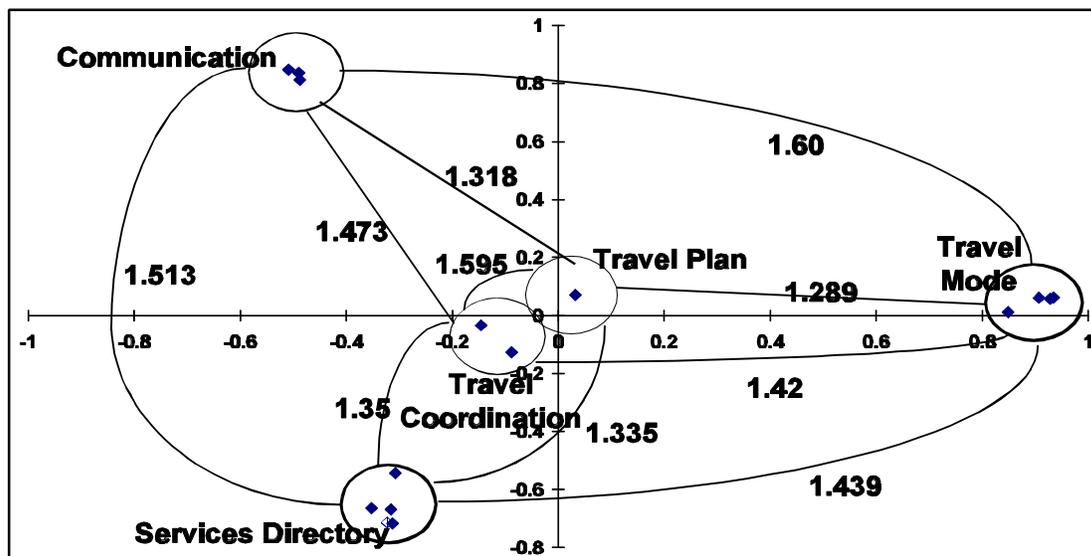


Figure 11. Factor loading pattern.

EXPERIMENT 2

The results will be described in two sections: (1) driving performance, and (2) roadway events. Data analyses were conducted using the BMDP software package. An alpha level of 0.05 was selected as the criterion for statistical significance. Complete ANOVA tables can be seen in appendix S.

DRIVING PERFORMANCE

Standard deviation of speed and rate of large steering reversals were the key variables examined to evaluate driving performance. Of primary importance were the hypothesized effects of ATIS Status and control-input type. Although effects of Route and Route Ordinal Position were expected, they were not of particular experimental interest and thus are only reported when relevant.

Moving Map Display

Baseline driving data were collected at three separate sections of each driving scenario, placed at the beginning, in the middle, and at the end of the scenarios. Each of these sections were 100 meters long. Subjects took 7 to 11 seconds to complete each section, depending on their speed. No roadway events or control input requests occurred during this time, nor were any navigation messages presented. In other words, the ATIS screen was blank in the ATIS Off condition, and was showing the moving map display in the ATIS On and ATIS On + Control Inputs conditions.

It was hypothesized that driving performance would be negatively impacted by the presence of a moving map display while driving. This hypothesis was not supported by the data. Figure 12 shows that standard deviation of speed did not vary as a function of ATIS status, $F(2, 182) = 1.68, p > 0.10$. Figure 13 shows that the rate of large steering reversals was also not affected by ATIS status, $F(2, 182) = 0.56, p > 0.50$.

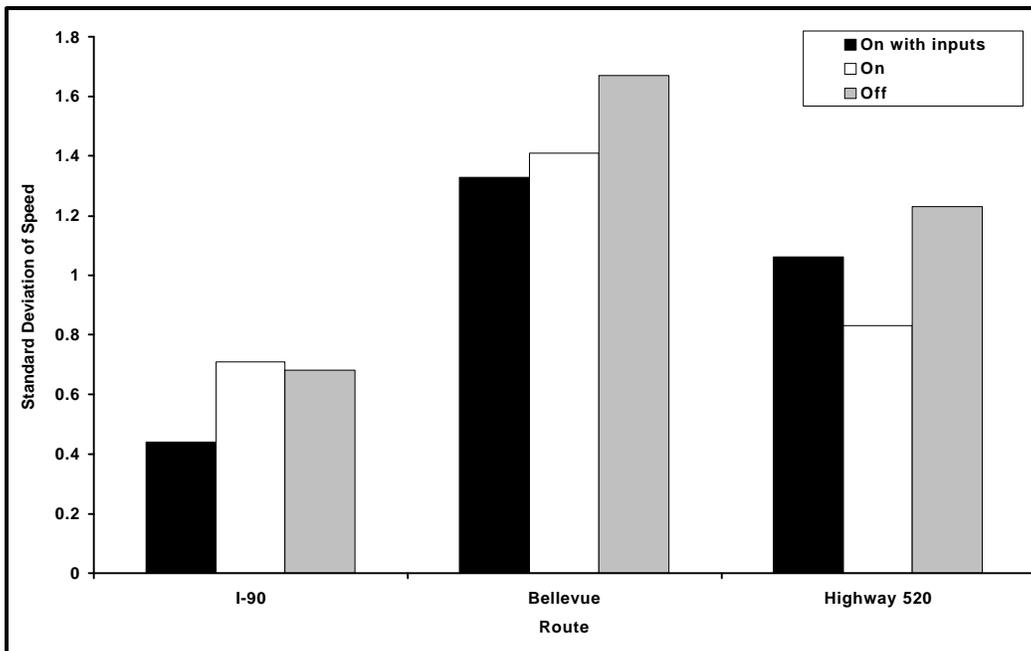


Figure 12. Standard deviation of speed on baseline segments as a function of route and ATIS status.

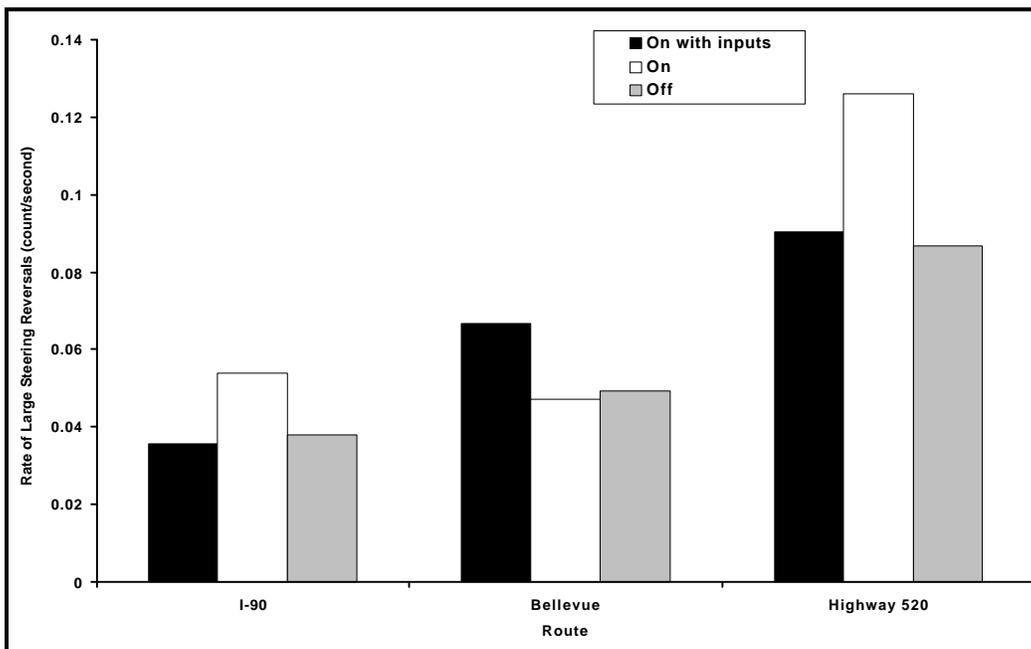


Figure 13. Rate of large steering reversals on baseline segments as a function of route and ATIS status.

It was observed that during several baseline segments, the standard deviation of speed had a value of zero, which indicates a constant speed throughout the 100-meter baseline segment. It might be argued that in such cases, since the subject was already maintaining a constant speed, there was no need to adjust the speed, and this measure is therefore not an indicator of driver performance.

Accordingly, a separate analysis was conducted to determine the distribution of zero speed deviations. Figure 14 shows the percentage of cases with zero speed deviations as a function of ATIS status and route. ANOVA revealed that the route main effect, $F(2, 182) = 32.81, p < 0.001$, and ATIS status \times route interaction, $F(4, 182) = 2.59, p < 0.05$, were significant. Post-hoc Tukey tests showed that the percentage of cases with zero speed deviations were higher on the I-90 than in Bellevue in all three ATIS Status conditions, and higher than on Highway 520 in the ATIS On with Control Inputs and ATIS Off conditions.

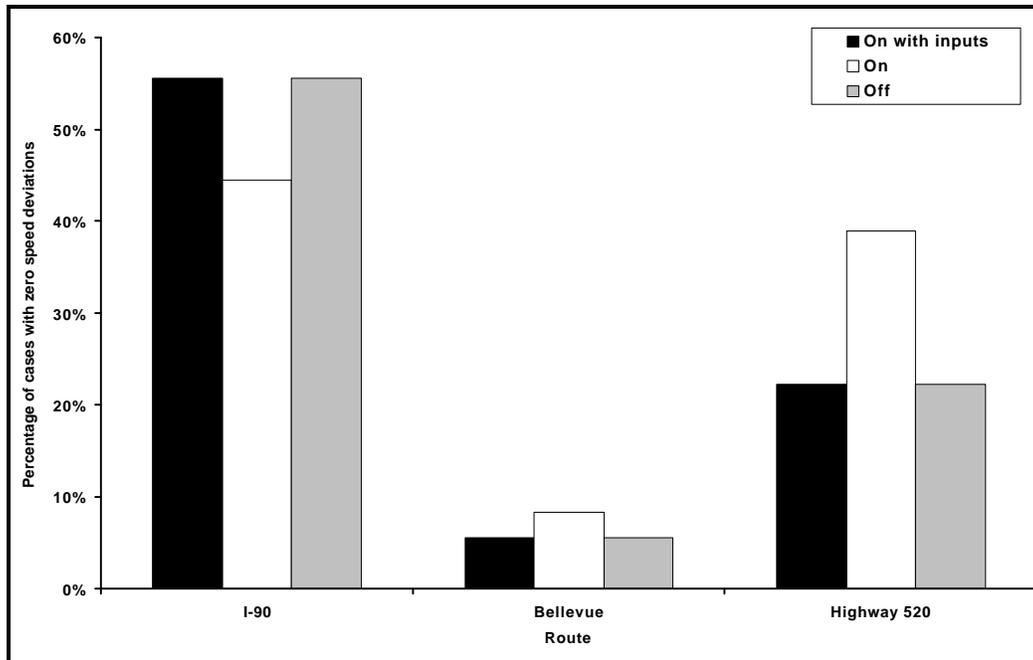


Figure 14. Percentage of cases with zero speed deviations as a function of ATIS status and route.

The importance of this interaction is unclear. Differences in speed deviation as a function of route undoubtedly reflect differences between highway vs. city driving, with much less speed variability exhibited on the highway. The results shown in figure 14 with respect to ATIS status are somewhat counterintuitive and are not replicated by any other results in this study. In particular, it is not clear why the “ATIS On” condition would be associated with more “zero speed deviations” than either the “ATIS On with Inputs” condition or the “ATIS Off” condition on Highway 520 or why the pattern of zero speed deviation would be so different across the three routes.

Control Inputs

To analyze how control inputs influenced driver behavior, driver performance data were collected each time a control input was requested from the subject. Data were collected during three different windows of time. The pre-input window spanned the 6 seconds immediately preceding the input request. The during-input window started with the message onset requesting a control input and ended when the input was complete. The post-input window followed the during-input window, and was 6 seconds long.

Figure 15 shows the influence of window and input type on standard deviation of speed. As expected, there was a main effect of window, $F(2, 66) = 10.81, p < 0.001$. Post-hoc Tukey tests showed that the standard deviation of velocity was significantly higher in the during-input window than in the pre-input window, $p < 0.05$, and than in the post-input window, $p < 0.05$. A window by type interaction was expected. More specifically, differences in input type were expected in the during- and post-input windows, but not in the pre-input window. This hypothesized interaction was not found, $F(2, 66) = 0.83, p > 0.10$.

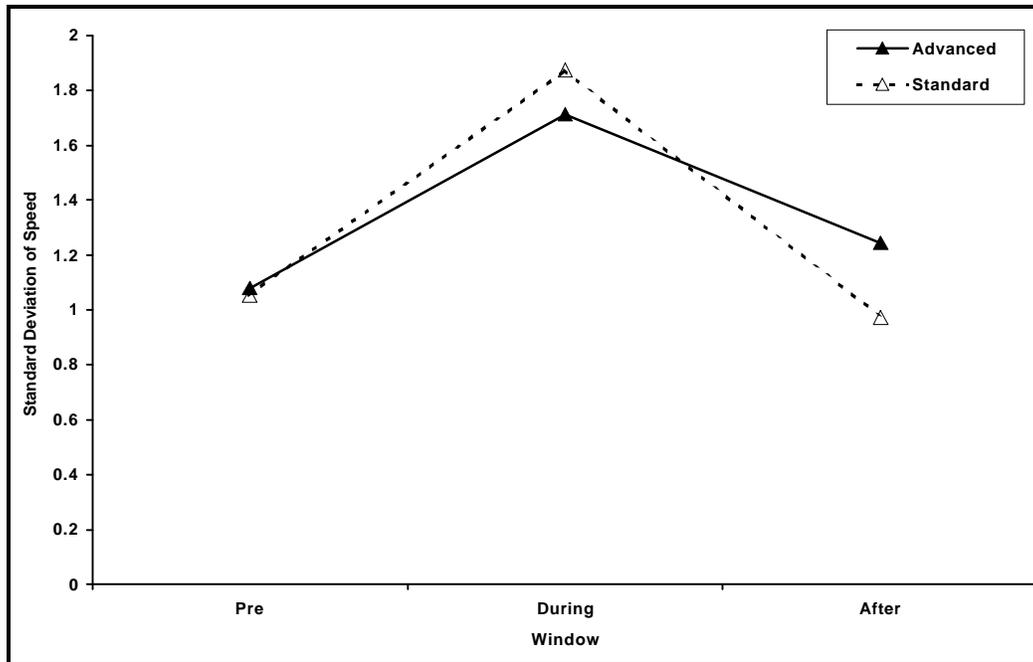


Figure 15. Influence of window and input type on standard deviation of speed.

Figure 16 shows the influence of window and input type on the rate of large steering reversals. There was a main effect of window, $F(2, 66) = 6.33, p < 0.005$. Post-hoc Tukey tests showed that the rate of large steering reversals was significantly higher in the during- and post-input windows than in the pre-input window, $p < 0.05$. Figure 16 also shows that standard inputs resulted in a larger rate of large steering wheel reversals than advanced inputs, $F(1, 33) = 21.77, p < 0.001$. However, since this difference was present in all three windows, it cannot be attributed to an effect of control input type.

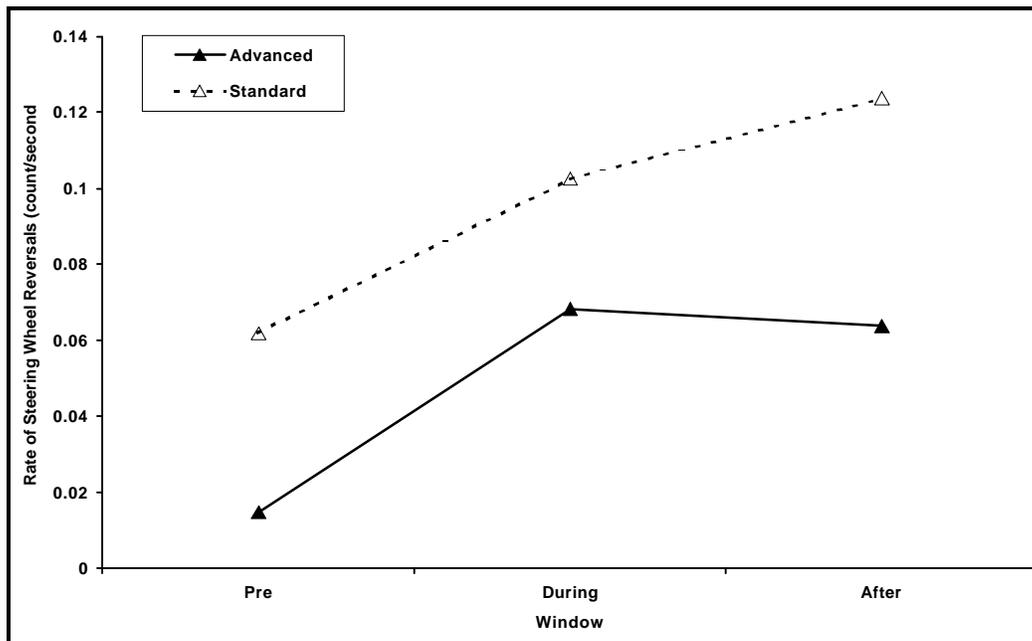


Figure 16. Influence of window and input type on the rate of large steering reversals.

Roadway Events

Of the 12 roadway events that were placed in the experimental scenarios, the most useful 6 were analyzed. Events 2 and 5 were speed events; events 7, 9, 10, and 11 were lane events (see table 8). Speed and lane events were analyzed separately.

Speed Events

In both speed events that were included in the analysis, the subjects were approaching a speed zone where they were required to reduce their speed. In one of these, the speed limit was reduced from 60 mi/h to 35 mi/h in a construction zone. The in-vehicle warning message was presented in the Notification/Visual-No Alert style. In the other event, the speed limit was reduced from 35 mi/h to 20 mi/h in a school zone. The relevant in-vehicle message was in the Notification/Visual-Auditory Alert style.

The results are consistent with our expectation that the ATIS messages would increase compliance rates and would allow subjects to react faster to the roadway events. Figure 17 shows, for both events, compliance and compliance before the road sign, in the presence and absence of an ATIS message. T-tests revealed that compliance in the construction zone was significantly higher in the presence of the in-vehicle message than without an in-vehicle message, $t(16) = 4, p < 0.005$. In the school zone, compliance was again higher in the presence of an ATIS message. Although the difference was not statistically significant, $t(16) = 1.46, p > 0.10$, this might be attributed to a ceiling effect. Compliance before the roadway sign also increased in the message condition in both events. However, only the difference in the school zone reached statistical significance, $t(16) = 2.31, p < 0.05$.

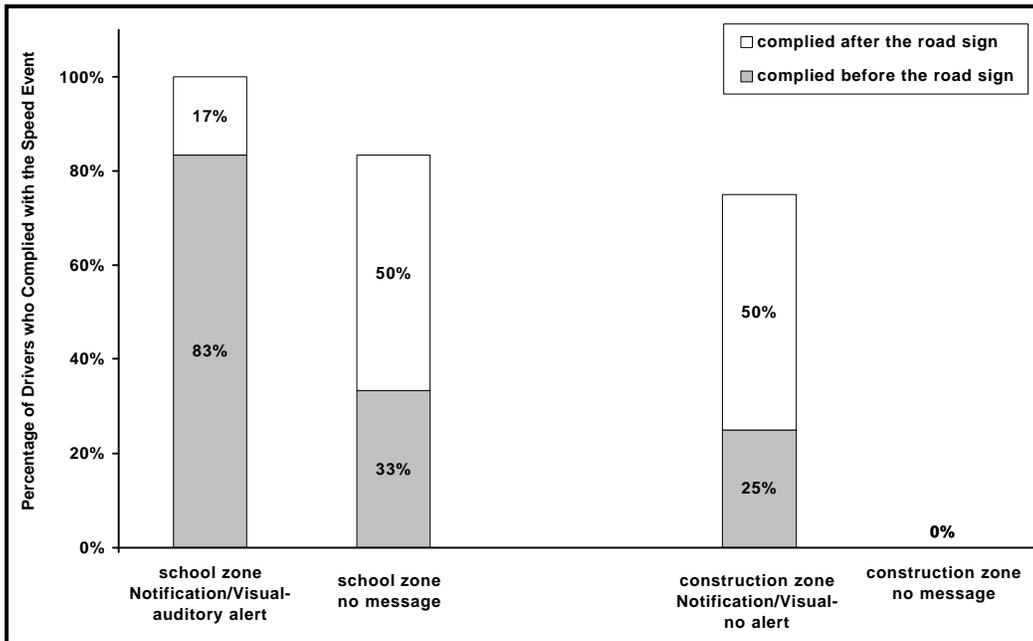


Figure 17. Percentage of subjects who complied with the speed events.

Figure 18 shows that percent compliance also increased with message presentation. In both events, percent compliance was higher in the presence of an in-vehicle message than without one; however, the difference was statistically significant only in the construction zone, $t(16) = 4.91$, $p < 0.001$.

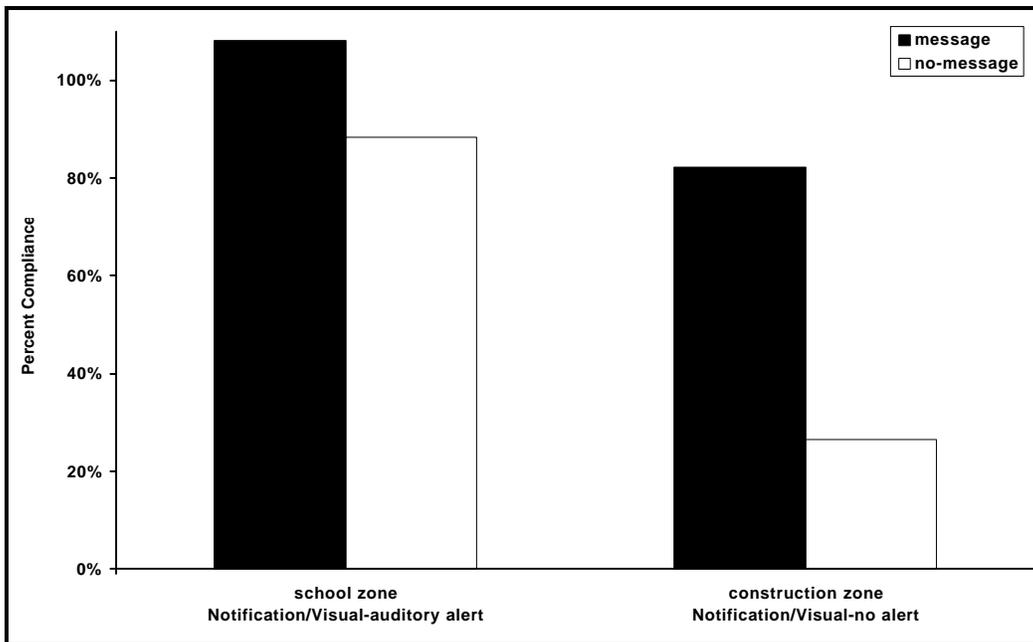


Figure 18. Percent compliance for the speed events.

Distance to the road sign at compliance and time to compliance are depicted in figures 19 and 20. These measures were obtained only for those subjects who complied. Comparisons could be done for only the school event, since in the construction event, none of the subjects in the no-message

condition slowed down to the goal speed. T-tests indicated that time to compliance was significantly lower, $t(15) = 3.59, p < 0.005$, and distance to the road sign was significantly higher, $t(15) = 3.58, p < 0.005$, in the message condition than in the no-message condition.

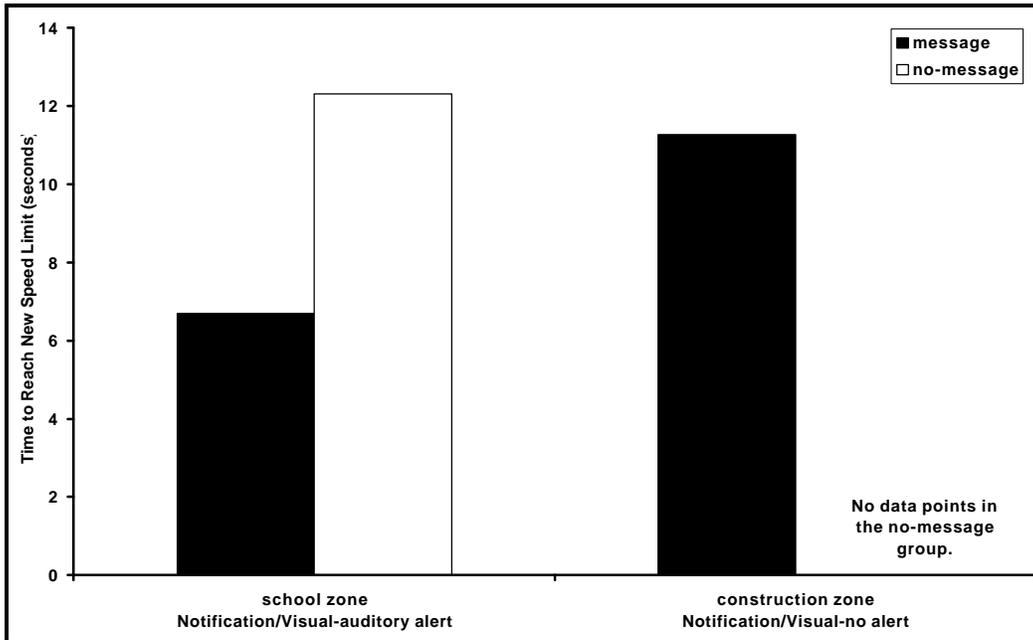


Figure 19. Time to compliance for the speed events.

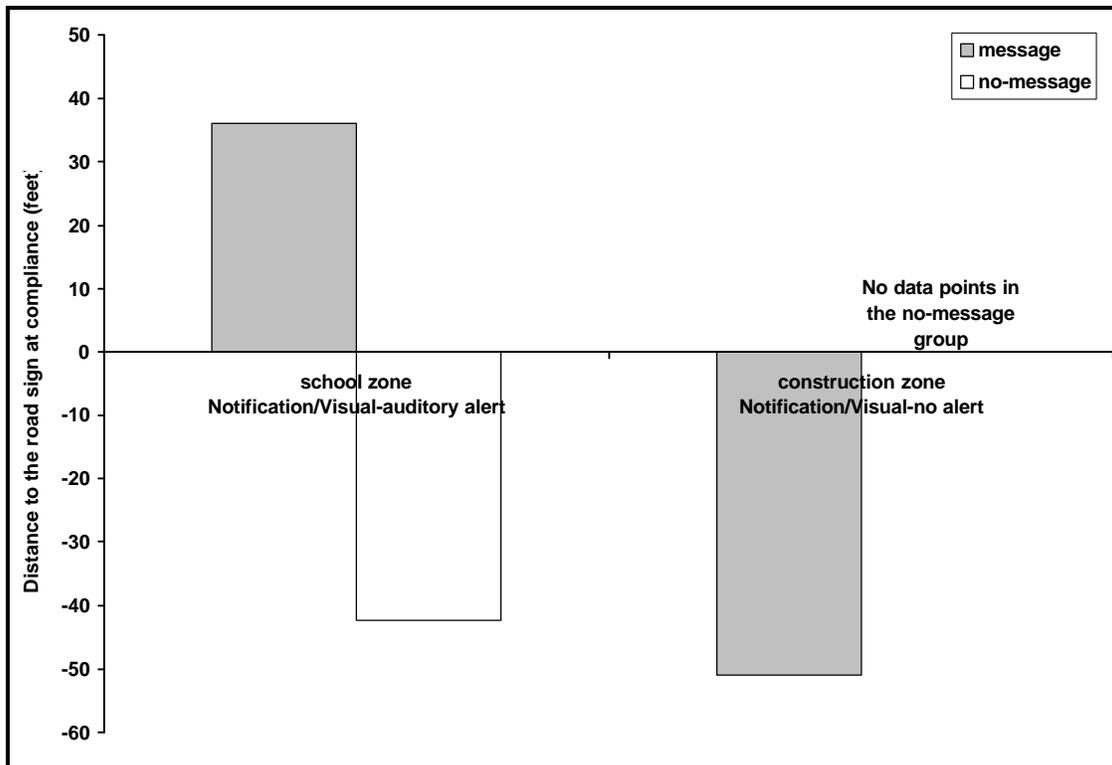


Figure 20. Distance to the road sign at compliance for the speed events.

An interesting finding was that in the construction event (where the ATIS message was presented visually with no auditory alert), message presentation increased compliance from 0 percent to 75 percent, and percent compliance from 26 percent to 82 percent (figures 19 and 20). These figures imply a powerful influence of the message itself, and suggest that whether the message is preceded by an auditory alert is of secondary importance. The influence of the auditory alert on compliance measures could not be directly evaluated due to the differences in the two roadway events.

Lane Events

The lane events that were analyzed involved a stationary object that was blocking the subject's lane, forcing the subject to change lanes. In all of them, all subjects were able to avoid the blocking object. In other words, compliance was 100 percent.

Figures 21 and 22 depict the effect of presence of an ATIS message on time to lane crossing and distance to the event (i.e., the blocking object) at lane crossing. Time to lane crossing was lower, $F(1, 48) = 5.51, p < 0.05$, and distance to the event at lane crossing was higher $F(1, 48) = 13.25, p < 0.001$, when an ATIS message was presented than when no in-vehicle messages were present.

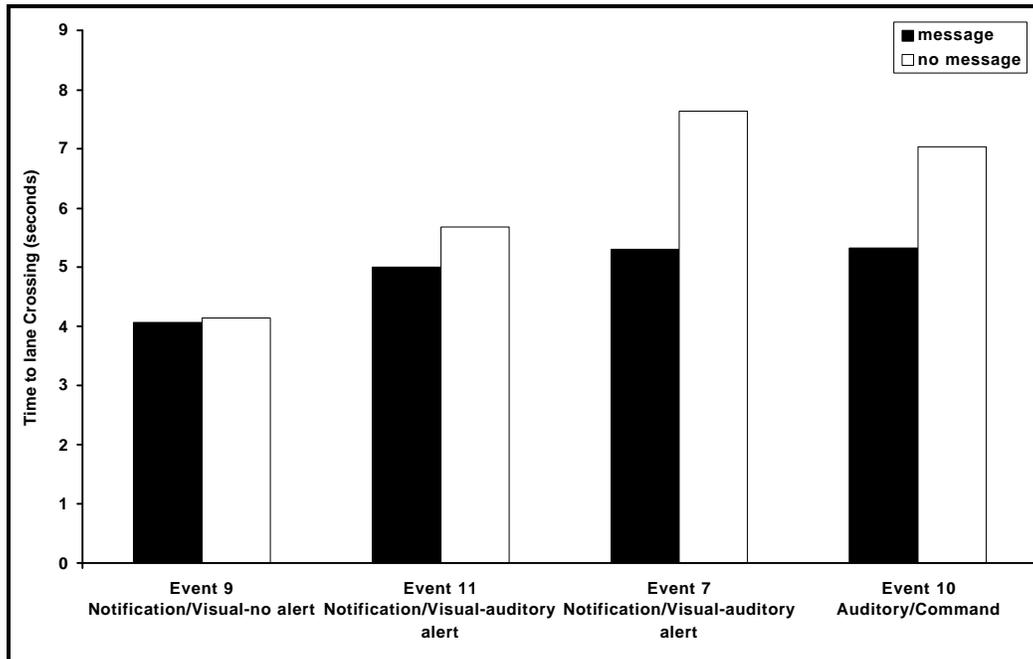


Figure 21. Time from message onset to lane crossing.

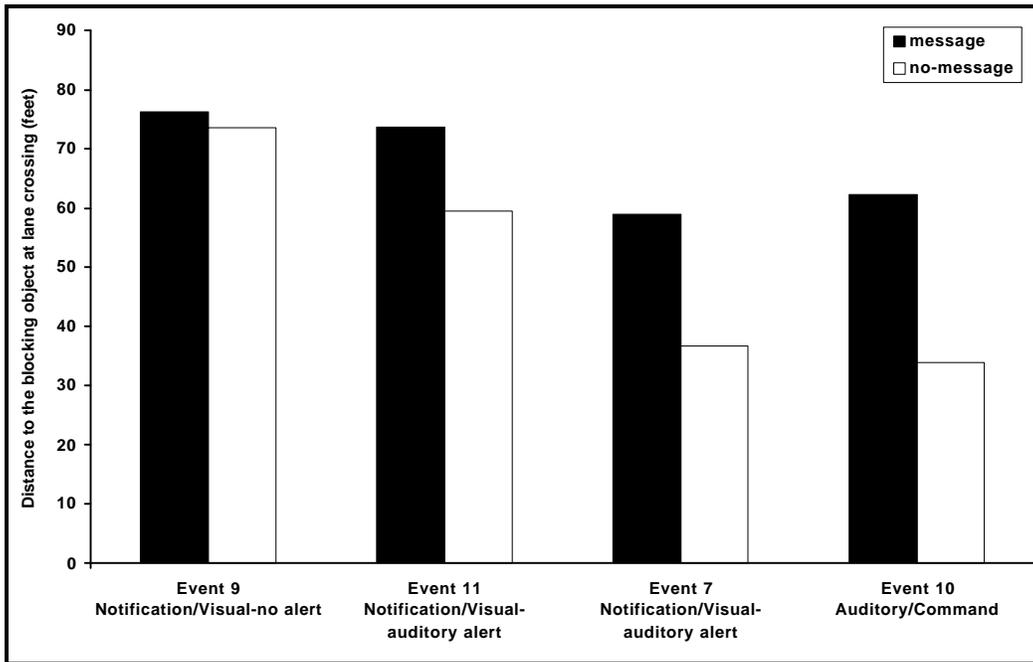


Figure 22. Distance to the blocking object at lane crossing.

DISCUSSION AND CONCLUSIONS

EXPERIMENT 1

The results for experiment 1 indicate that subjects experienced little difficulty in using and transitioning across the various pre-drive ATIS functions within the simulation, and they accomplished their experimental tasks swiftly. These results suggest that the cognitive demands in this experiment were low and associated with acceptable levels of ATIS task performance. This finding applies to both general performance with the scenarios as a whole, as well as function transitions within the scenarios. Thus, consistent with previous thinking in this area, pre-drive trip planning with an ATIS should be completed by drivers with few difficulties and within reasonable time limits. This conclusion is supported by the total trip planning completion times associated with this study, as well as by the low error rates and the infrequent need to access the on-line help system within the ATIS simulator.

In experiment 1, there were no consistent performance effects associated with the integrated versus non-integrated task conditions. Therefore, for the types of pre-drive scenarios investigated, there may be no performance-related advantages or disadvantages associated with an integrated versus a non-integrated screen design approach. This conclusion may also be applicable to kiosk, hotel, and other non-vehicle-based ATIS devices, since they do not involve driving concurrent with using an ATIS. However, both the complexity of the trip planning scenarios, as well as experience with the system (trials), were consistently associated with performance effects such as slower task completion times and less efficient performance (e.g., more requests for system help) with modified and early trials. Specifically, while the modified trials were slightly more difficult for subjects to complete, this difficulty declined after their first modified trip-planning session. As noted earlier, however, the system complexity and trial variables were included in the study primarily due to their potential moderating effects on the ATIS type variable (integrated versus non-integrated).

In experiment 1, the findings associated with the multiple choice CTA suggest that drivers may recognize ATIS screens within the same ATIS function faster and more accurately than ATIS screens between different system functions. Interestingly, this advantage to “within-function” operations over “between-function” operations did not lead to trip planning performance differences (e.g., latencies or errors) for pre-drive system operation. The multiple choice findings also suggest that drivers may recognize non-integrated ATIS screens faster and more accurately than integrated ATIS screens. That is, in terms of recognizing screens or, perhaps, maintaining an accurate mental model of the ATIS screens, there was an advantage to designing each ATIS function with a unique “look and feel,” as in the non-integrated condition.

In experiment 1, both screen colors (“look”), as well as the design and labeling of buttons (“feel”) distinguished the integrated versus the non-integrated conditions. However, it seems plausible that these different ATIS design parameters would have different implications for driver performance. Figure 23 shows the possible combinations of “look” and “feel,” and their relationship to the conditions investigated in this study. Future studies in this area may benefit by examining these design parameters separately; for example, by comparing a completely integrated ATIS design, to a design with unique background colors for each function, but identical button layout and labeling across all functions.

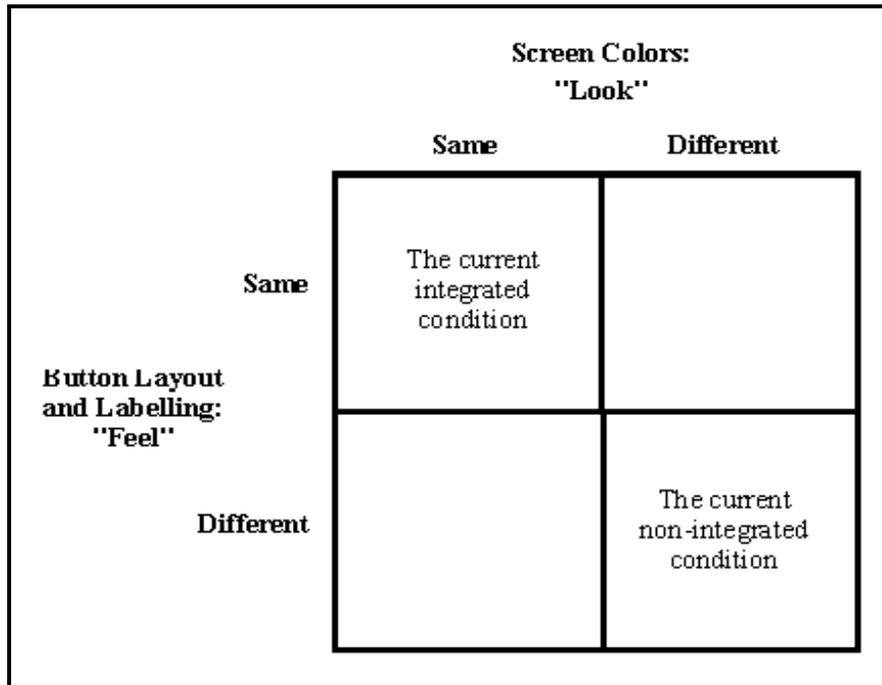


Figure 23. Combinations of "Look" and "Feel" relevant to ATIS screen design.

In experiment 1, the various CTA methods used in this study provide additional insight into the experimental conditions investigated, as well as contribute to the broader methodological literature associated with the development and use of CTA approaches. The perceived demand questionnaire results show relatively low levels of perceived visual, mental, and physical demands among the subjects. Thus, on the basis of our modified version of this frequently used workload measure, cognitive demands associated with pre-drive trip planning seem relatively low.

Again, the exact implications of these phenomena to ATIS design are not obvious, as task performance in experiment 1 was not affected by either the within-/between-function distinction or by the integrated/non-integrated distinction. In a real driving environment, our findings could suggest that transitions between different ATIS functions will be associated with increased time accessing ATIS information. Under real-world driving conditions, such a situation could lead to less time attending to the primary task of driving. The multiple choice CTA data support the findings of Kinghorn, Bittner, and Kantowitz (1994) who suggested that the number of ATIS functions should be minimized and that unwanted ATIS functions should be eliminated. Importantly, the differences between types of transitions as well as integrated versus non-integrated approaches highlight the importance of examining screen layout and consistency in the future using scenarios that include both driving tasks and higher levels of driver workload.

Both the ANOVA and the factor analysis results associated with the similarity rating task CTA suggest that, as subjects gained more experience with the ATIS, their understanding of the design of the system and the organization of individual functions became both more accurate and more consistent. This result further supports the conclusion that even a relatively complex ATIS with multiple functions can be learned, understood, and successfully used by drivers in a relatively

short period of time. Again, there were no effects of system complexity or of system type (integrated versus non-integrated).

With respect to methodology, the ATIS simulator used in this study was developed through an integrative process involving existing systems (e.g., TravTek), as well as future ATIS goals and functions as described in our previous reports (e.g., McCallum et al., 1996; Lee et al., 1997; Wheeler et al., 1996). Although fully interactive, the simulation was nonetheless a highly flexible and easily modifiable research tool, capable of collecting and storing data on numerous indices of subject behavior. The simulation was treated by subjects as a realistic device that could be used for planning trips. In general, the selection of functions, “look and feel” of individual screens, range of options and services presented, and methods of user control satisfied expectations for a future ATIS system. Similarly, the driving scenarios developed for use in the study were drawn from previous ATIS efforts and incorporated realistic goals, constraints, and function transitions.

The combination of CTA techniques used in this study provided interesting and useful information about the cognitive demands associated with various ATIS functions and design options. For some variables, the CTA findings were congruous with the performance data, and, for others, they were not. In particular, the CTA findings revealed some differences between the integrated and non-integrated approaches that were not seen in the performance data; specifically, that differences or inconsistencies in screen design across ATIS functions may provide advantages to drivers when transitioning from one system function to another. This finding contrasts with published human factors guidelines for navigation systems (e.g., Green et al., 1995) in which “be consistent” is identified as a primary design principle that should be applied routinely to all elements of user-interface design. A better approach to the notion of consistency is to consider consistency as a means to purposefully aid the driver’s interaction with in-vehicle devices, as suggested by Campbell and Walls (1992) in a handbook of design guidelines for automotive head-up displays. Within the Campbell and Walls framework, consistency should not be used just in order to “be consistent;” rather, it should be purposeful, directed at specific design variables, and used to accomplish explicit human performance objectives. In the current study, for example, the different screen colors associated with the ATIS functions may have facilitated the subjects’ understanding of the system and their ability to recognize the relationships among different screens within the system as a whole. Therefore, consistency should be applied in a purposeful way as a means to increase stimulus-response compatibility as described by Kantowitz et al. (1990).

In summary, the following conclusions may be drawn from experiment 1:

- ! Overall, the cognitive demands associated with ATIS function transitions during pre-drive trip planning were low and associated with acceptable levels of ATIS task performance.
- ! For pre-drive trip planning and, perhaps, for kiosk, hotel, and other non-vehicle-based applications of ATIS, there may be no performance-related advantages or disadvantages associated with an integrated versus a non-integrated screen design approach.
- ! Both the performance data and the CTA results in experiment 1 suggest that even a relatively complex ATIS with multiple functions can be learned, understood, and successfully used by drivers in a relatively short period of time.
- ! The CTA results suggest that transitions between different ATIS functions may be associated with increased cognitive demands; this further suggests that the number of ATIS functions should be minimized and that unwanted ATIS functions should be eliminated.
- ! The multiple choice CTA findings also suggest that drivers may recognize non-integrated ATIS screens faster and more accurately than integrated ATIS screens; that is, there may be certain advantages to designing each ATIS function with a unique “look and feel,” as in the non-integrated condition.
- ! Since many of the functions associated with ATIS (e.g., navigation, in-vehicle warnings) are associated with actual driving, cognitive demands should be investigated further in a high workload situation that requires subjects to drive while operating an ATIS.
- ! The hypermedia-based ATIS simulation developed for this study proved to be a powerful research tool that can be used to investigate a range of ATIS design issues.
- ! The CTA methodologies developed for this study provided insight into the experimental conditions investigated and can be used in the future to assess the cognitive demands of inexperienced users of advanced and novel automotive technologies.

EXPERIMENT 2

The results for experiment 2 suggest that driving performance, as indicated by vehicle speed and steering behaviors, was not negatively influenced by a moving-map ATIS. Although the tasks in experiment 2 were selected in order to place realistic cognitive and motor-control requirements on the driver, the presence of the ATIS did not lead to consistent problems with speed maintenance or lane tracking performance.

The experiment 2 results also indicated that, while control inputs had an effect on speed maintenance, inputs associated with the ATIS had no greater effect than control inputs to standard accessories such as the radio and HVAC systems. In fact, steering behavior was more strongly affected during inputs to these standard in-vehicle accessories than to the ATIS device.

The experiment 2 results indicated that both compliance and the speed of compliance to changing regulatory information (reduced speed zones) were improved in the ATIS conditions. Specifically, there was consistently better performance when the information was presented using the in-vehicle ATIS device than when it was presented using traditional roadway signs alone.

With respect to message potency, the combined visual/auditory alerts led to slightly better performance than visual alerts alone. However, there was a far greater and more meaningful performance benefit associated with visual messages compared with no in-vehicle message at all. While the addition of the auditory alert assisted performance, it only provided a negligible improvement over and above the visual alert alone.

In summary, the following conclusions may be drawn from experiment 2:

- ! Driving performance was not negatively affected by the presence of a moving-map ATIS device. Thus, the results suggested that an ATIS device will not represent an undue distraction for drivers.
- ! Making control inputs to the ATIS also had no greater effect on driving performance than did using standard secondary vehicle controls. These results suggest that drivers are able to self-regulate their use of the ATIS, and that time-sharing between the ATIS and the driving task can be accomplished.
- ! Improved compliance to regulatory messages in the ATIS conditions suggests a benefit to the in-vehicle presentation of such information.
- ! Although concurrent auditory and visual alerts may be beneficial, the results of this study suggest that visual messages alone are much better than no message at all and will lead to high levels of drive compliance to regulatory messages.
- ! While the simulator results suggest that drivers can use in-vehicle moving map displays without impacting driving safety, this finding should be verified with on-road testing. Possible differences in risk perception and driving styles between simulator vs. on-road testing require such validation of the simulator results.

SUMMARY

Overall, the two experiments reported here suggest that in-vehicle ATIS devices can be learned, understood, and successfully used by drivers for both pre-drive trip planning tasks and on-road driving conditions. ATIS devices have the potential to improve driver compliance to regulatory information, as compared with standard roadside signs. While concurrent visual and auditory ATIS alert messages may be beneficial, the visual ATIS messages alone are significantly better than roadside signage alone. While cognitive demands associated with ATIS transitions and ATIS complexity should continue to be a concern, these demands can be addressed by selecting ATIS functions with clear relationships and benefits to the driving task. The simulator results suggest that drivers can use in-vehicle moving map displays without impacting driving safety. However, this finding should be verified with on-road testing. Performance with a multi-function ATIS should be further examined using on-road driving tasks.

**APPENDIX A: INTEGRATED AND NON-INTEGRATED FIGURES
(FOR EXPERIMENT 1)**

This appendix provides a representative sample of both the integrated and non-integrated ATIS screens.

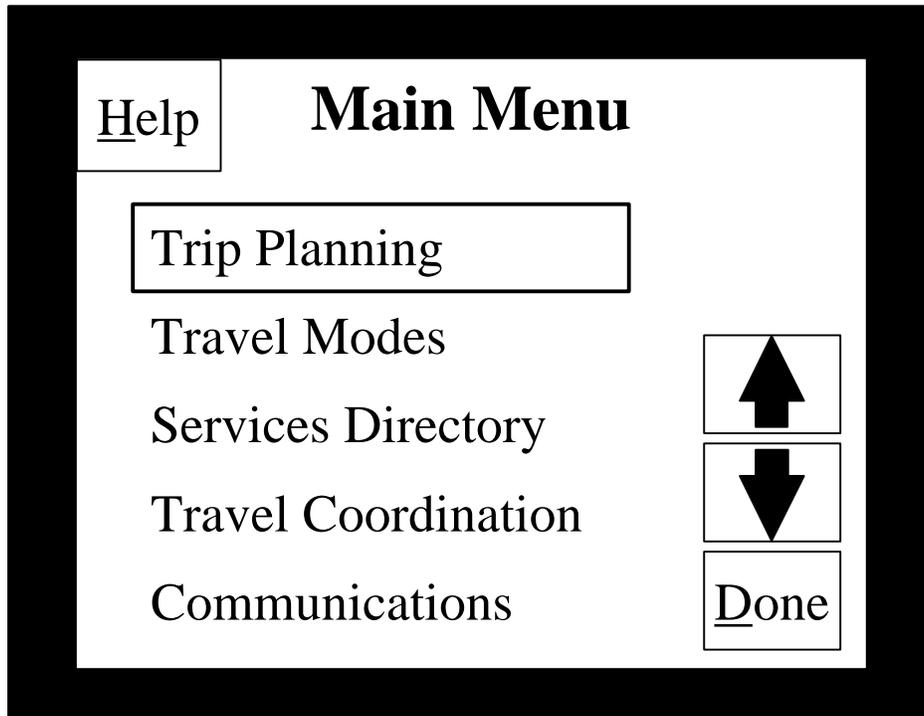


Figure 24. Main menu screen, integrated system.



Figure 25. Trip planning screen, integrated system.

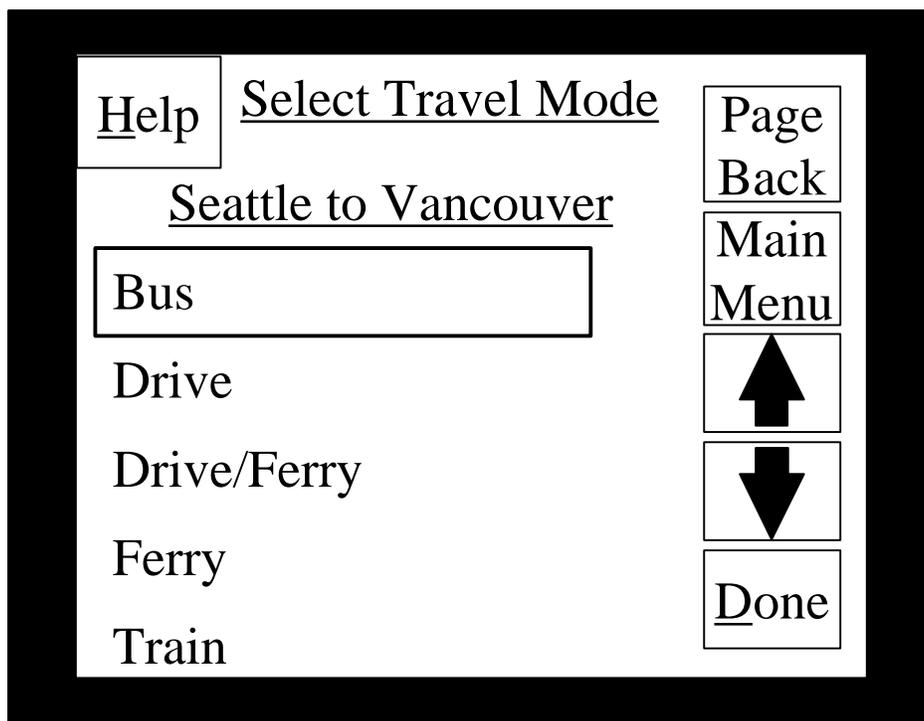


Figure 26. Travel mode screen, integrated system.

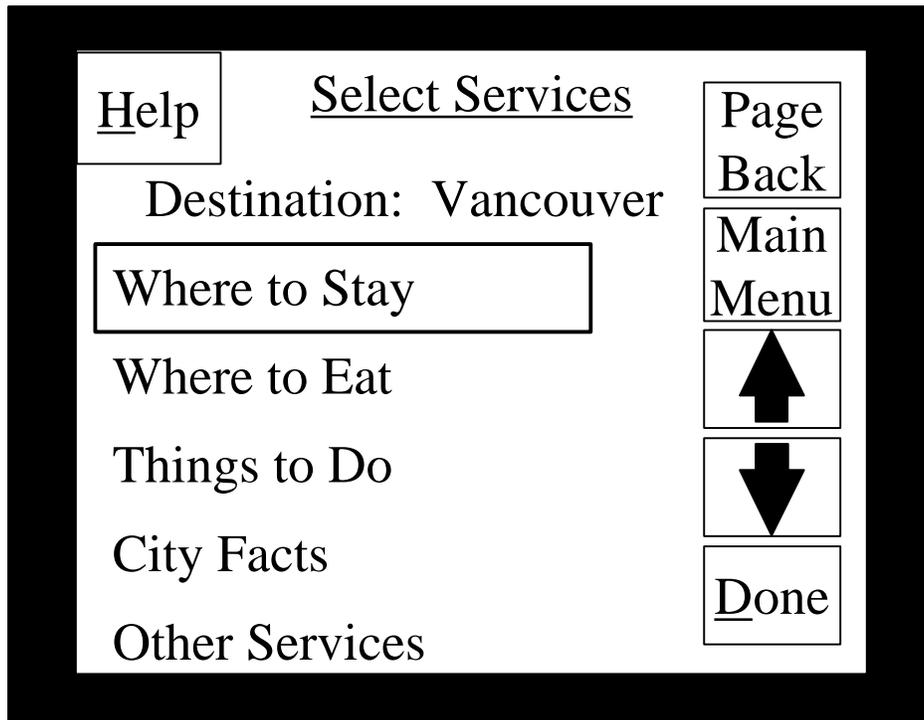


Figure 27. Services directory screen, integrated system.

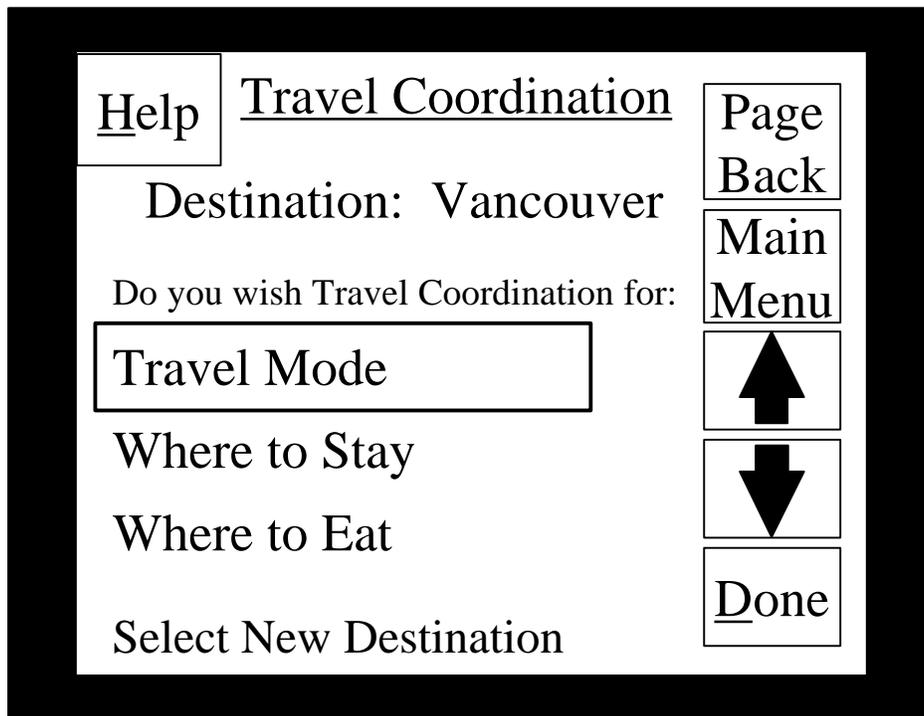


Figure 28. Travel coordination screen, integrated system.

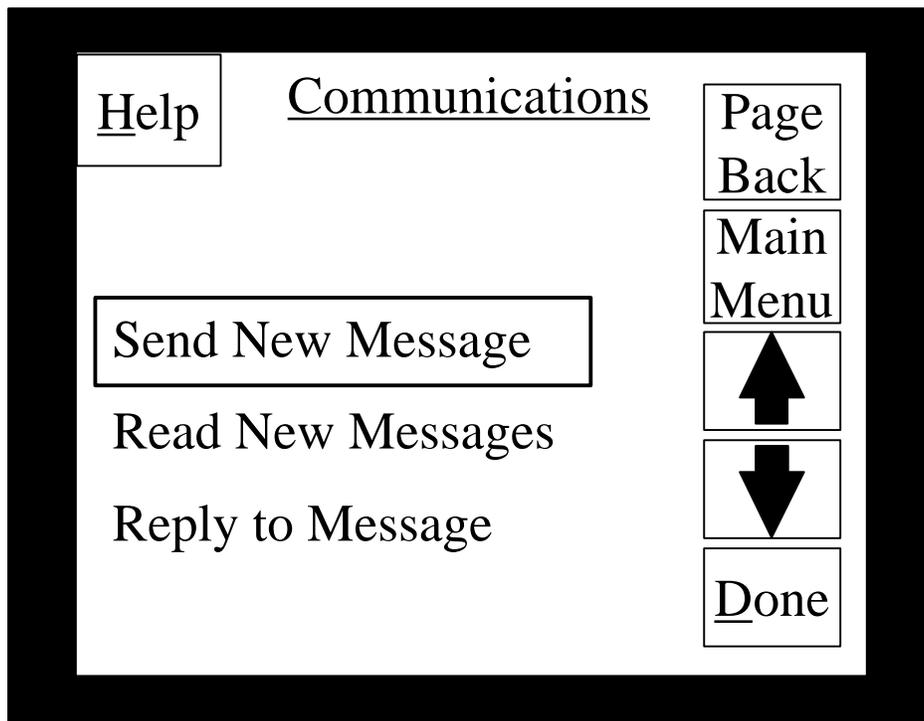


Figure 29. Communications screen, integrated system.

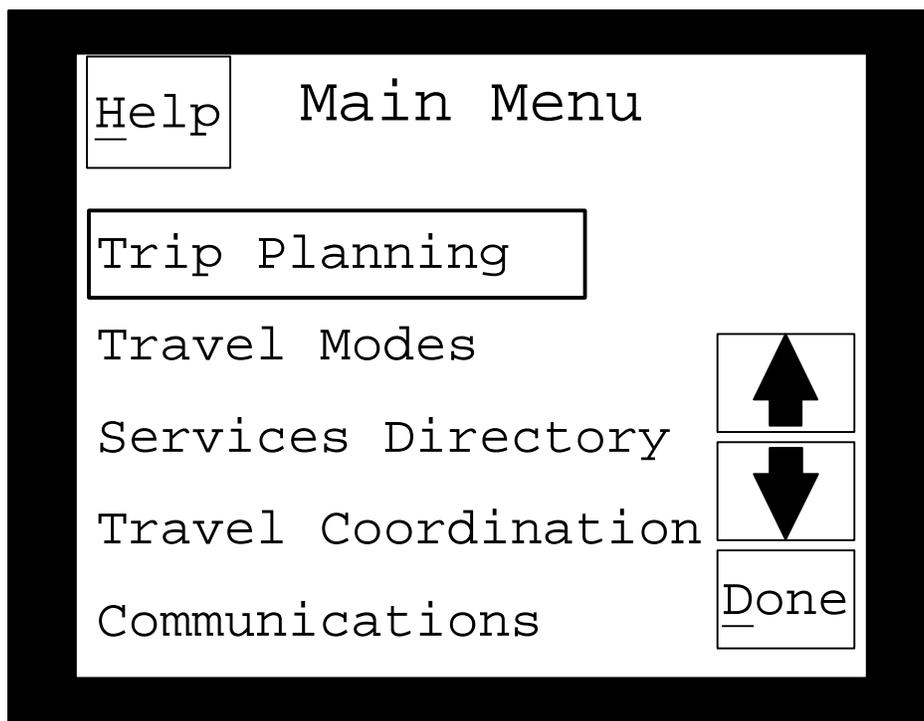


Figure 30. Main menu screen, non-integrated system.

<u>H</u> elp	<u>D</u> elete	<u>S</u> pace	<u>C</u> lear	Page Back
Enter Destination				
VANCOUVER				
A B	E F	I J	M N	Q R
C D	G H	K L	O P	S T
U V	Y Z	1 2	5 6	9 0
W X		3 4	7 8	
Q	<u>R</u>	S	T	<u>D</u> one

Figure 31. Trip planning screen, non-integrated system.

Select Travel Mode	
From:	Seattle
To:	Vancouver
<input type="checkbox"/> Bus <input type="checkbox"/> Drive <input type="checkbox"/> Drive/Ferry <input type="checkbox"/> Train	
	Help...

Figure 32. Travel mode screen, non-integrated system.

Select Services

Select Services for:

The Current Destination
A New Destination

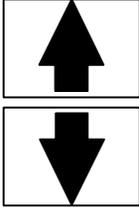


Figure 33. Services directory screen, non-integrated system.

Travel Coordination

Choose Travel Coordination for:

Option
Travel Mode
Accommodations
Food
Select New Destination
<input checked="" type="checkbox"/> OK
<input type="radio"/> Cancel
 HomeBse
 Help

Figure 34. Travel coordination screen, non-integrated system.

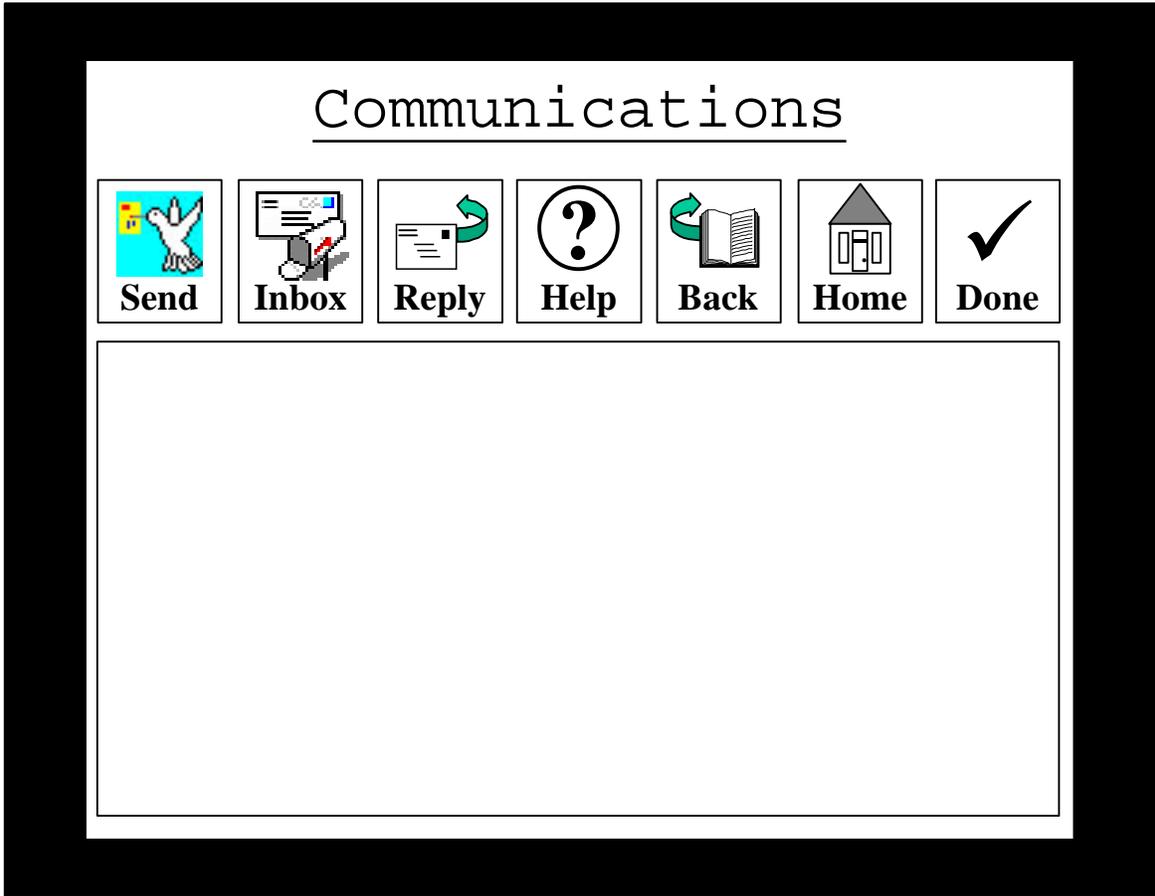


Figure 35. Communications screen, non-integrated system.

APPENDIX B: SCENARIOS (FOR EXPERIMENT 1)

PRACTICE SCENARIOS

Scenario A

Read Trip Highlights

You and Joe (a friend) are going to Sequim for a fishing trip. You decide to drive to Edmonds and take the ferry from there. You have to work until 2:00 pm and want to take the first available ferry after 2:00 pm. You will be fishing near the Dungeness Recreation Area, so find campgrounds there. You also want to find a seafood restaurant to eat at when you arrive (hopefully your fishing trip will be a success and that won't be the only seafood you will see). You recall that a restaurant on US 101 serves a terrific lobster dinner. At some point, you hope to take a break from fishing and see the Olympic Game Farm park that you've heard so much about. You will need to find their phone number so you can call for their hours. Also, whenever Joe says the word "Sequim" you are sure he is pronouncing it incorrectly. You better find out the correct pronunciation. Also, since Joe is starting to gain weight, he asked you to find the name of a local diet center. Don't forget to make reservations for the ferry, campgrounds, and restaurant. When you are done, send the following message to Joe, "fishing license." This will remind him not to forget it!

The following are your notes about your travel plans to Sequim to go fishing with your friend Joe. Use your ATIS to plan your trip in the most efficient way possible.

1. Go fishing with Joe in Sequim.
2. Select a ferry out of Edmonds. Get the first one available past 2:00 pm.
3. Find campgrounds to stay at. Find one at the Dungeness Recreation Area.
4. Find a seafood restaurant on US 101.
5. Find the phone number of the Olympic Game Farm park. (State answer aloud).
6. Find out the correct pronunciation of the word "Sequim." (State answer aloud).
7. Find out the name of the local diet center. (State answer aloud).
8. Make reservations for the ferry, campgrounds, and restaurant you've selected.
9. Once you've made the reservations, send a message to Joe stating, "fishing license."

Scenario B

Read Trip Highlights

You have to plan a business trip to Port Alberni. You decide to take the earliest ferry, and would like to stop in Victoria to visit a friend. You will need to find a hotel to stay at; look for one on Spring Rd. that has a 2-star rating. You will also need to find a restaurant to take your business client to. You think that a 3-star French restaurant should impress him. You would also like to take the client whale watching, but you better find out the price first. You are curious about how many people live in Port Alberni. Find out the population. Also, you hope to sell an antique vase while in Port Alberni and you would like to post an ad in the newspaper. Find out the name of the local newspaper. Make reservations for the ferry, hotel, and restaurant that you've selected. When you are done, check any messages that you might have from the WA State Ferry. Send a reply stating "Yes." Follow their suggestions.

The following are your notes about your business travel plans to Port Alberni. Use your ATIS to plan your trip in the most efficient way possible.

1. Travel to Port Alberni on business.
2. Take the ferry option that goes through Victoria. Take one leaving at 6:00 am. Select the corresponding connection to Nanaimo.
3. Find a hotel to stay at. Look for one on Spring Rd. that has a 2-star rating.
4. Find a 3-star French restaurant.
5. Find the price to go whale watching. (State answer aloud).
6. Find out the population of Port Alberni. (State answer aloud).
7. Find out the name of the newspaper. (State answer aloud).
8. Make reservations for the ferry, hotel, and restaurant you've selected.
9. Check message from the WA State Ferry and reply "Yes." Follow any suggestions they might have.

EXPERIMENTAL SCENARIOS

Scenario # 1

Read Trip Highlights

A friend from high school, who you haven't seen in years, just called and would like to meet you in Vancouver. She asked that if you would, on your way up from Seattle, pick up her friend in Lynden. From your last trip to Vancouver, you remember a hotel on Howe street that had a 3-star rating. While discussing Vancouver with your friend, she mentions that the elevation there is less than 50 ft. You are unsure about this and tell her you'll look into it. While reminiscing about high school, your friend asks you what happened to Jim, another high school friend. You tell her that Jim was working at a tanning salon in Vancouver, on SPF Way, but you can't remember the name of it. You agree to make all the arrangements including making the necessary reservations. Once the reservations have been made, you need to send a message to your home stating the following, "Out until Monday."

The following are your notes about your travel plans to Vancouver to visit your friend. Use your ATIS to plan your trip in the most efficient way possible.

1. Meet friend in Vancouver.
2. Use your car and stop in Lynden on the way.
3. Find a hotel to stay at. Must be on Howe Street, and have a 3-star rating.
4. Find out the elevation of Vancouver. (State your answer aloud).
5. Find out the name of the tanning salon on SPF Way. (State your answer aloud).
6. Make reservations for the hotel you've selected.
7. Once you've made the reservations, send a message to your home stating the following: "Out until Monday."

Scenario #2

Read Trip Highlights

You and your significant other have both been working long hours lately and decide on a few days away in Sequim. You decide to drive and plan to stop in Hoodspport for lunch. You decide to stay in a hotel, and you remember one on Jergens Street that has a 2-star rating. In your discussion, you disagree on the population of Sequim; your wife thinks that there are more than 3000 people there, but you think that there must be less than that. You tell her that you will look into this and find out. You also disagree on the name of the vet service on Ocean Park Way. You tell her that you will also find this out. Remember to make the reservations for the hotel that you select. When you are done, check your messages. Read any that the hotel may have sent and follow their recommendations.

The following are your notes about your travel plans to Sequim with your significant other. Use your ATIS to plan your trip in the most efficient way possible.

1. Travel to Sequim for the weekend.
2. Use your car and stop in Hoodspport on the way.
3. Find a hotel to stay at. Must be on Jergens Street and have a 2-star rating.
4. Find out the population of Sequim. (State your answer aloud).
5. Find the name of the vet service on Ocean Park Way. (State your answer aloud).
6. Make reservations for the hotel you've selected.
7. After your trip is planned, read any message you might have from the hotel. Follow any recommendations that they might have.

Scenario #3

Read Trip Highlights

Your parents will be in the area tonight and you decide to meet them in Port Townsend. Two things you must consider about this trip are that your car is in the shop and you have to work until 2:00 pm. You decide to take the train and would like to arrive in Port Townsend before 9:00 pm. On a previous trip to Port Townsend, you stayed at a motel on Plankton Ridge, and as you really like it, you decide to select it again. Your parents are especially fond of Chinese food. Though you have forgotten it's name, you recall a nice 2-star Chinese restaurant and would like to take your parents there. While in Port Townsend, you would like to go fishing, but money is a concern. Remember to make reservations for the train, motel, and restaurant. When you are done, check your messages and read any that your mom may have sent. Send her the following reply, "OK."

The following are your notes about your travel to Port Townsend to visit your parents. Use your ATIS to plan your trip in the most efficient way possible.

1. Meet parents in Port Townsend.
2. Take the train. Find one that leaves after 2:00 pm and arrives before 9:00 pm.
3. Find a motel on Plankton Ridge.
4. Find a place to eat. Your parents like Chinese food. Choose a 2-star Chinese restaurant.
5. Find the least expensive fishing charter in town. (State your answer aloud).
6. Make reservations for the train, motel, and restaurant.
7. Once you've made the reservations, check and read any messages that your mom may have sent. Send her a reply stating, "OK."

Scenario #4

Read Trip Highlights

You have to go and meet a business client in Walla Walla. Your boss tells you all the details and you have to make the arrangements. You are to find a train that leaves after 2 pm and arrives before 10:00 pm. You are to find a motel on Melrose Street, but your boss is cheap and it has to be a 1-star motel. You like American food and decide to find an American restaurant to eat at, but again because the budget is tight it must be a 1-star restaurant. For fun, the boss said that you could take the client on a hay ride. He tells you to select the one whose address is Windowbrook Rd. Remember to make reservations for the motel and restaurant. When you are done, check your messages and read any that your boss may have sent and follow his instructions. You must send a reply stating, "OK."

The following are your notes about your travel plans to Walla Walla for your business meeting. Use your ATIS to plan your travel. As always, plan this trip in the most efficient way possible.

1. Business trip to Walla Walla to meet client.
2. Take the train. Find one that leaves after 2 pm and arrives before 10:00 pm.
3. Find a 1-star motel on Melrose Street.
4. Find a place to eat. You like American food. Choose a 1-star American restaurant.
5. Find a hay riding place; address is Windowbrook Rd. (State your answer aloud).
6. Make reservations for the train, motel, and restaurant.
7. Check messages from your boss. Remember to send a reply stating "OK." Follow any instructions he might have.

Scenario #5

Read Trip Highlights

Your forgetful aunt has asked you to come visit her in Port Alberni. She tells you to catch the 1:00 pm ferry, but she doesn't remember where to catch it from. She asks if you would make reservations at this nice Italian restaurant on Georgian St, but she doesn't remember the name. You begin talking about the history of Port Alberni, and she tells you about the Captain who founded the city in 1793, but she can't remember his name. She tells you that when you get to Port Alberni, she will take you to her favorite place to shop, a brew supply store on 1st Street, but again she forgets it's name. She reminds you to make reservations for the ferry and the restaurant. Finally, she asks if you would send a message to Dr. Clark stating, "Make appointment Tuesday at 2:00." She will explain this when you get to Port Alberni.

The following are your notes about your travel plans to Port Alberni to visit your forgetful aunt. Use your ATIS to plan your trip in the most efficient way possible.

1. Meet aunt in Port Alberni.
2. Take the 1:00 pm ferry. Unsure of the terminal from where it leaves.
3. Find a place to eat. You are looking for an Italian restaurant on Georgian St.
4. Find the name of the founder of Port Alberni. (State your answer aloud).
5. Find the name of the brew supply store on 1st Street. (State your answer aloud).
6. Make reservations for the ferry and restaurant.
7. Once you've made the reservations, send a message to Dr. Clark stating, "Make appointment Tuesday at 2:00."

Scenario #6

Read Trip Highlights

The Vancouver Canucks hockey team has their season opening game tomorrow. A friend from Vancouver tells you that you can stay at his place while in town. You decide to take the bus and would like to catch one that leaves at 1:00 pm. Your friend will meet you at the station and buy the hockey game tickets. In return you offer to find a nice French restaurant (at least 3-star) to take your friend to. You know that the hockey arena is near Thurlow Street and would like to find a restaurant there. You are curious about the bus ride in terms of traveling from the mainland to an island. Vancouver is on an island isn't it? You better find out. While in Vancouver, you would like to find a billiard supply store so that you can have your cue fixed; find the address of such an establishment. Remember to make reservations for the bus and restaurant. Check your messages when you are done. Look for one from the restaurant and follow their suggestions.

The following are your notes about your travel plans to Vancouver to see a hockey game. Use your ATIS to plan your trip in the most efficient way possible.

1. Off to Vancouver for a hockey game.
2. Take the bus. Find one that leaves at 1:00 pm.
3. Find a 3-star French restaurant on Thurlow Street.
4. Find out if Vancouver is on an island. (State your answer aloud).
5. Find the address of a billiard supply store. (State your answer aloud).
6. Make reservations for the bus and restaurant.
7. Check messages from the restaurant. Follow suggestions they might have.

APPENDIX C: PERCEIVED DEMAND QUESTIONNAIRE (FOR EXPERIMENT 1)

SUBJECT _____

INSTRUCTIONS

Now that you have completed your trip, I am going to replay a recording of your trip planning activities for you, and ask you to answer some questions about the different activities that were required for your trip planning. What I will do is to replay a segment of the tape corresponding to an individual step or a set of related steps within your trip planning on this monitor. I will then stop the tape and ask you three questions about the visual, mental, and physical demands associated with using this ATIS system. We will repeat this procedure until we have gone through all of the steps listed on your note sheet for this trip.

For each question that I will ask you, I'll ask you to give me a response on a scale ranging from 0 to 100. The scale is the same for all of the questions. On this scale, a "0" corresponds to a rating of "Very Low," and a 100 corresponds to a rating of "Very High." Provide your rating by writing any number between 0 and 100 on the right side of the scale. Here is what the scale looks like.

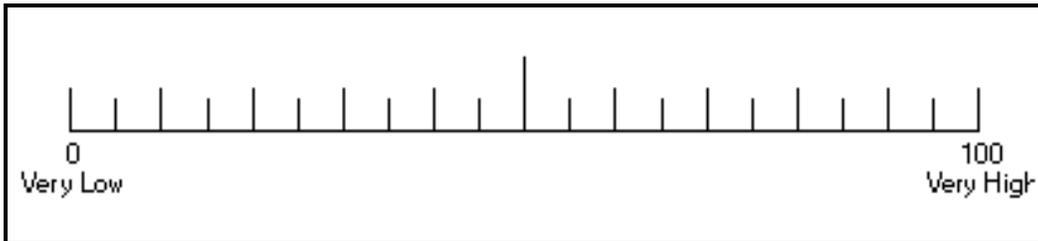


SCENARIO 1

Step(s): (1) - Travel to Vancouver (*example only*)

1. VISUAL DEMAND (perceiving)

How much visual searching on your screen was required to complete this function? For example, consider the work involved in reading the information on the screen in order to complete the tasks. Reading an oil light on your car is an example of a task that might be rated at or near 0. You don't put forth much visual effort when you just check a gauge. On the other hand, playing a video game, programming an on-screen videocassette recorder (VCR), or using a complex word processing application on a computer might be examples of tasks that would be rated at or near 100. Please give your response now.



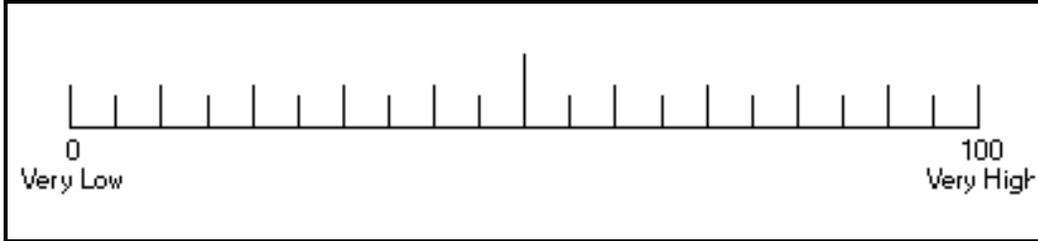
2. MENTAL DEMAND (thinking)

How much thinking was required to complete this function? For example, consider the work involved in thinking about the information on the screen, the decisions that you had to make, and the remembering that was required. Sleeping is an example of a task that might be rated at or near 0. You don't put forth any thinking effort when you are asleep. On the other hand, taking a very hard test in school might be an example of a task that would be rated at or near 100. Please give your response now.



3. PHYSICAL DEMAND (response)

How much physical activity was required to complete this function? Consider the work involved in selecting options and obtaining information. Relaxing in a hot tub is an example of a task that might be rated at or near 0. You don't put forth much physical effort when you are relaxing. On the other hand, a demanding physical activity such as lifting heavy weights is an example of a task that might be rated at or near 100. Please give your response now.



**APPENDIX D: SUBJECT SELECTION PHONE QUESTIONNAIRE
(FOR EXPERIMENT 1)**

Subject Name _____

Sub ID _____

Age _____

Gender ____ (1=M, 2=F)

Subject Selection Phone Questionnaire

Note To Experimenter: DO NOT read the following “Purpose” to subjects.

Purpose: Before a subject can be selected to participate in this study, he or she must have an active drivers license, drive at least twice per week, & 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 2 times/week.
- 3) Subjects must not experience motion sickness “often.”

**APPENDIX E: DRIVER DEMOGRAPHIC CHARACTERISTICS
PHONE QUESTIONNAIRE (FOR EXPERIMENT 1)**

Note To Experimenter: Do NOT read the following “Purpose” to subjects.

Purpose: 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. Town of residence: _____ Zip Code _____
(community, i.e., shoreline, Wedgewood etc.)
6. Gender: **G** Male **G** Female
7. Marital status: _____ [single, married, other]
8. Number of family members in household (including yourself): _____
9. Do you own your own automobile? **G** Yes **G** No

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?
 - G** less than 5,000
 - G** 5,000 - 9,999
 - G** 10,000 - 19,999
 - G** 20,000 - 39,999
 - G** 40,000 - 69,999

G 70,000 - 99,999

G more than 100,000

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 **G** Yes **G** No

13b. **!** anti-lock brakes (ABS) **G** Yes **G** No

13c. **!** cassette player **G** Yes **G** No

13d. **!** cellular phone/radio phone **G** Yes **G** No

13e. **!** cruise control **G** Yes **G** No

13f. **!** electronic dashboard displays **G** Yes **G** No

13g. **!** garage door opener **G** Yes **G** No

13h. **!** power brakes **G** Yes **G** No

13i. **!** power steering **G** Yes **G** No

13j. **!** power windows and door locks **G** Yes **G** No

13k. **!** radar detector **G** Yes **G** No

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			
Videocassette recorder (VCR)			
Hand-held calculator			
Cordless phone			
Microwave oven			
Personal computer (PC)			
! DOS			
! Windows			
! Macintosh			
Computer bulletin boards / e-mail	N/A		
Telephone answering machine / voice messaging			

- 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.)”

0									100	
Does not									Strongly	
Apply									Apply	

**APPENDIX F: FHWA RESEARCH PARTICIPATION CONSENT FORM
(FOR EXPERIMENT 1)**

You have been recruited to participate in a study that will examine use of an Advanced Traveler Information System (ATIS). One feature of an ATIS is that it provides information to help users plan trips. During this study, you will be using an ATIS to help make travel arrangements for six different simulated trips. The only risk associated with this study is that you may find it boring.

The information gathered in this study will allow us to better understand how people use an ATIS. Videotape will be used to record you using the ATIS. The recorder will be positioned such that your identity will remain anonymous (videotape will record your hands and arms only). These tapes will be played back to you as part of the procedures for this study. All data obtained, including the videotape, are for research purposes only, and will remain confidential. The information will be reviewed by Battelle and the Federal Highway Administration (FHWA) scientists, and the data will reside at Battelle and FHWA. It is your privilege to withdraw from this study at any time. If you withdraw, you will be paid for the time you have participated without the loss of benefits. For your participation in this study, we will compensate you at the rate of \$5.00 per hour.

If you have any questions or desire further information about this study, please contact Battelle.

I have read the attached statement and agree to permit the use of my responses for research purposes.

Signature of Participant

Date of Birth

Today's Date

Please Print Name

Social Security Number

Permanent Mailing Address:

Signature of Investigator

Today's Date

Record of Payment:

_____ hours @ \$____ per hour = \$____

Cash/Check _____

bonus = \$____

TOTAL = \$____

Signature of Participant

Today's Date

Signature of Investigator

Today's Date

APPENDIX G: EXPERIMENTER'S PROTOCOL AND INSTRUCTIONS (FOR EXPERIMENT 1)

EXPERIMENTER'S PROTOCOL

Reception Protocol

Meet participants down in the lobby area approximately 10 minutes prior to the time the study should begin [read introduction script (a)].

Escort them up to the lab. Be sure to point out the nearest rest rooms and drinking fountain on the way.

Sit in the lab lobby area and have them fill out the consent and demographic information forms [read introduction script(b)].

Move to the Route Guidance Simulator (RGS) room. Experimenter sits in the left seat, and the participant in the right seat. Read the following instructions.

Introduction - Script

(a) Introduce yourself stating who you are.

Hello. I am the scientist who will be conducting the study today. We are going to be moving into the laboratory area and this is where we will begin our study.

You will now be asked to complete the following consent form and, as I am sure you will notice, the bottom portion is regarding the payment for your participation. I would like to ask you to stop prior to reaching that point as we will be filling that section out at the conclusion of the study.

Participant Instructions - Script

Purpose of Study

Welcome. Today you will be involved in a study where you will be using an Advanced Traveler Information System (ATIS). In a moment, I will describe an ATIS to you.

This study will be divided into three main tasks.

(1) Your first task will be to plan trips. You will be given six different stories or "scenarios" that outline a trip you will be making arrangements for. Using the ATIS, you will plan all the details of the trip as outlined in the scenario.

(2) Your second task will be a “rating task.” You will be given a set number of points to work with and you are going to be asked to allocate these points to a number of different items. These items are all related, some more than others, and your task will be to assign different values to them accordingly. In the beginning, you may find this task very difficult but do not worry about the difficulty. You are not expected to know anything about the system so this rating task will be challenging. Do not worry as you will have four more opportunities to try out this system.

(3) The last task will be a short multiple choice quiz which we will be asking you to complete at the beginning and at the end of the session today.

The study should last anywhere between three and four hours. You will be paid at the end of the session today.

What Is an ATIS?

As noted, ATIS refers to an Advance Traveler Information System. The purpose of an ATIS is to provide users with information that will help them plan their trip and, depending on the functions of the system, navigate to their destination. In this study, we are interested in the ATIS functions that allow users to plan and make arrangements for a trip. These functions include: (1) choosing a destination, (2) providing information on how to get to that destination (i.e., options for travel mode such as drive, bus, train, and ferry), (3) providing information on the hotels, restaurants and other services available, (4) allowing the user to make reservation for the travel mode and other services, and (5) communicating with outside parties by sending, reading, and replying to messages. Today you will be testing an ATIS prototype that has these particular functions.

Where Would an ATIS Be Located?

There are several different locations for an ATIS. Examples include: (1) inside your vehicle, (2) in your hotel room, (3) at a kiosk in a hotel or airport lobby, or (4) from your PC at your home or office.

Study Scenarios

As noted, you will be using an ATIS to make arrangements for six different scenarios. You will be given all the information necessary to plan the details of the trip. Selecting and making reservations for a hotel is one typical arrangement that you might be asked to make. Note that all the details surrounding the arrangements may or may not be fictitious, but this is irrelevant to the purpose of this study. The purpose of this study concerns how well you are able to use the system and not with the accuracy of the database.

Your Responses

In terms of your performance on the tasks which will be required of you, I'd like to ask that you give your best possible effort and remain focused on the tasks. In this way, we will be best able to take the results of your efforts and use them in analyzing these types of systems. As these systems are just now being developed, you have a terrific opportunity to "put in your two-cents" and help make decisions about their design.

CTA #1

Before we start trip planning I am going to introduce you to the rating task. You will do this at five different times throughout the experiment. First, I will briefly outline the task for you.

This rating task will display a list of features that may be found on the ATIS. Your task will be to decide how similar each feature is to a comparison feature. This comparison feature will be highlighted in red at the top of each screen.

Base your ratings on your **expectations** of the system. I know you have not seen it yet, but I want to know how similar you perceive the various features to be.

You have a total of 1000 points to distribute. Features that you perceive as being very similar to the highlighted feature should receive a higher score than features that are not at all similar to the highlighted feature. **The computer will automatically keep track of your total for you, and will tell you how many points you have distributed at the bottom of the screen.**

You may change your ratings as many times as you wish.

When you are satisfied with all of your ratings, and have verified that the total is 1000, you may use the mouse to press the continue button. BUT, once you press the continue button, you will be advanced to a new screen and you will not be permitted to return to the previous screens to look at or change your answers. So be sure that you are finished before pressing continue.

There will be 15 screens.

Are there any questions? This task should become clearer once you see the list of ATIS features.

If you don't have any further questions right now, you may use the mouse to click on the begin button to see the first list of ATIS features.

Screen 1 of the CTA should be displayed. Experimenter should point to the items on the screen as he describes them.

This is the **list of ATIS** features. Remember, your job is to decide how similar each of these are to "DRIVE", the feature highlighted in the red box. You do not need to enter a number here [point to gray box], as it is not necessary to rate the similarity of drive and drive. You should also be putting a number in each box and zero's are not acceptable.

As you can see, you can use the **arrow keys** to move up and down - to select the cell that you would like to enter your rating in.

Use the **number pad** to enter your ratings.

You can always change your ratings by selecting the rating you want to change with the arrow key and typing a new rating. This new rating will automatically replace the old one.

This box *[point to total box]* will provide a running total of the points you have distributed. Remember, it has to equal 1000 when you are finished.

When you are finished, you should verify that you have entered a number in every cell except the gray one, and your total is 1000 - then press the “continue” button with the left mouse button. Remember this will automatically advance you to the next screen, and you will not be permitted to return to previous screens.

Do you have any questions? If no, then go ahead and start.

Remember: It is important that features that are very similar to the highlighted feature are rated higher than features that are not as similar.

You might want to just “jump in” and start entering your ratings because you can change your ratings as many times as you wish, until you press continue.

[Subject proceeds through 15 worksheets - Should end on the “thank-you” screen]

Experimenter: Type Ctl+q (Data screens scroll as the data is being transferred to DATA1.)

Experimenter: Type Ctl+l (15 worksheets should clear and leave program at begin screen)

Now we will be moving over to the ATIS room where there is a computer set up that will run us through our study and where I will be able to show you the various functions of the system.

[Move over to the ATIS room.]

We will begin the practice scenarios, where I will go through two scenarios and plan the details of a trip. You may ask any questions you like during these practice scenarios.

Afterwards, we will begin the first of your six trip planning scenarios. We will work through the scenarios and use the various functions that comprise this system (show the subject the following functions as you reach them in the practice scenario). However, once these practices are complete, the only help that you will be allowed will be that from the on-line Help function.

For both practice scenarios that we will be doing, I will be placing the list of notes where we will both be able to read them. For your list of notes during the actual study you can put them wherever they are best visible for you.

Do you have any final questions regarding the verbal explanations given? Things will certainly become a lot clearer as you go through them.

(Make sure subject is comfortable and then proceed with the Practice Scenario A).

(Read Practice Scenario A)

(Present the subject with a list of notes for the particular scenario.) Indicate to the subject that each of the steps has to have its criteria met prior to moving on to the next step.

Get the subject to press the “begin” button after the main (blue) screen has all the data entered on it. The experimenter should begin by introducing the subject to all the system functions on the screen (along with the ATIS Display section of this introduction protocol). Also, show how to correctly hit the button on the screen.

“HELP” should be shown at three spots throughout the practice. Once at the first Main Menu screen, again at the first enter destination screen, and finally at the other services screen.

Also, make sure to show all subjects in the practice scenario the grayed out function. When the option is available for you to choose, it will be yellow whereas when the option is not able to be chosen (maybe a ferry does not run, or a bus does not go to a particular area) it is grey.

Go through the steps as outlined in the list of notes and answer any questions that the subject may have regarding the tasks at hand.

Now, we are going to go through another practice scenario where I will again plan all the details associated with this trip. I am going to go through this one more quickly as it is essentially the same as the one that we have just completed. I will, however, slow down when we approach the new details of the scenario that you have not yet seen.

(Read Practice Scenario # 2)

Again, just as was done in the previous practice trial, here is the list of notes of the steps that will be involved in this scenario.

(Present subject with List of Notes for Practice Scenario # 2)

Complete the practice scenario #2

Do you have any final questions regarding the scenarios that were just completed? After the scenario has begun, all the help that you will require can be obtained from the on-line “help” function. Prior to your beginning the experimental scenarios, I am first going to be asking you to complete the same kind of rating task that you have previously completed, followed by a multiple choice task where you will be shown some pictures (which I mentioned earlier).

CTA #2

Now that you have seen the ATIS, and have seen most of the features that the system has to offer, I am going to ask you to re-rate the similarity of the features. Remember, you are rating the similarity of each ATIS feature to the highlighted feature at the top.

Now that you have seen the system, you may have a better understanding of what the features are. Feel free to change your answers from last time.

Remember: It is important that features very similar to the highlighted feature are rated higher than features that are not as similar.

[Subject proceeds through 15 worksheets - Should end on the “thank-you” screen]

Experimenter: Type Ctl+w (Data screens scroll as the data is being transferred to DATA 2.)

Experimenter: Type Ctl+l (15 worksheets should clear and leave program at begin screen)

Present CTA Pictures - #1

Before we go back to the ATIS room, I am going to give you a quick multiple choice quiz.

I am going to show you a picture of an actual ATIS screen (the target screen) and ask you to decide which screen was most likely to have come before and after the target. The screens appear exactly as they would on the computer.

Here is the first set. The picture in the middle is the target ATIS screen.

Your task is to choose which screen was most likely to precede this target screen. To make this task easier, I will provide you with four pictures, and you just have to choose the which one you think most likely came before the target screen.

Then, I will ask you to decide which screen most likely came after the target ATIS screen. Again, I will provide you with four choices, and you just choose the best answer.

The four choices are labeled A, B, C, and D. Just call out the letter that you have selected as your answer. Although it is very important that you consider your answer carefully, I am timing your response. Please work as accurately and quickly as possible.

I will uncover the target screen and allow you to study it for 20 seconds. Then, I will uncover the pictures on the left and ask you to decide which came before the target screen. Then, I will uncover the pictures on the right, and ask you to tell me which screen came after the target.

If you don't have any questions, we will begin the task.

Uncover the center picture when you are ready to begin.

[after picture is uncovered] Remember, you should be thinking about which screen most likely came before/after this target screen.

[after 20 seconds uncover Before screens and start timer]

[Experimenter records answer]

[As quickly as possible, experimenter should cover “before” pictures, and uncover the “after pictures]

Now, consider the actual ATIS screen again. Think about what the most likely screen to follow it might be. Now, look at the four pictures on the right. Select the one that you think most likely follows the actual ATIS screen. Again, just call out the letter you have selected.

[Repeat procedures for all six cards].

Now, we will do the same thing again. You will have 20 seconds to study the target screen.

This time, I will ask you first to choose from the pictures on the Right and decide which is the most likely screen that came AFTER the target screen.

Then, I will ask you to choose the most likely screen that came BEFORE the target screen.

[Return to ATIS computer - for Trips 1 and 2]

If no other questions, continue.

Type in the subject data on the blue “begin” screen. DO NOT HIT BEGIN.

(Read scenario # 1)

(Present the subject with their first list of notes).

Please wait for 3 seconds so that the camera will be activated on your data screen. When you are ready all you have to do is touch the “begin” button. This will begin the experiment and allow you to plan a trip just as I have modeled for you in the practice scenarios.

We have now completed all the tasks for scenario #1. We will move on to the second scenario. This will be in the same format as scenario #1, which you have just completed.

Type in the subject data on the blue “begin” screen. DO NOT HIT BEGIN.

(Read scenario # 2)

(Present the subject with their second list of notes). Please wait for 3 seconds so that the camera will be activated on your data screen. When you are ready all you have to do is hit the “begin” button. After you hit the begin button, this will begin the experiment and allow you to begin what I have just modeled for you in the practice scenarios.

At the conclusion of the scenario, press “esc” to stop the program.

We have now completed all the steps in scenario # 2.

Prior to beginning scenario #3, we will move over to the rating computer and begin the rating task. We will return to the ATIS room following the completion of the rating task.

CTA #3

Now that you have actually used the ATIS to plan two trips, I am going to ask you to re-rate the similarity of the features. Remember, you are rating the similarity of each ATIS feature to the highlighted feature at the top. It is important that features very similar to the highlighted feature are rated higher than features that are not as similar.

Now that you have used the system, your understanding of what the features are may change. Feel free to change your answers from last time.

[Subject proceeds through 15 worksheets]

[Should end on the “thank-you” screen]

Experimenter: Type Ctl+e (Data screens scroll as the data is being transferred to DATA 3.)

Experimenter: Type Ctl+l (15 worksheets should clear and leave program at begin screen)

[Return to ATIS computer - for Trips three and four]

Check on the status of the subject

We will move on to scenario # 3 so let's return to the ATIS room.

Type in the subject data on the blue “begin” screen. DO NOT HIT BEGIN.

(Read scenario # 3)

(Present the subject with their third list of notes). When you are ready all you have to do is hit the “begin” button. Again, please wait for 3 seconds so that the camera will be activated on your data screen. After you hit the begin button, this will begin the experiment and allow you to begin what I have modeled for you in the practice scenarios.

At the conclusion of the scenario, press “esc” to stop the program.

We have now completed all the tasks for scenario #3. We will now move on to the fourth scenario, which will be in the same format as the one you have just completed.

Type in the subject data on the blue “begin” screen. DO NOT HIT BEGIN.

(Read scenario # 4)

(Present the subject with their fourth list of notes). Please wait for 3 seconds so that the camera will be activated on your data screen. When you are ready all you have to do is hit the “begin” button. After you hit the begin button, this will begin the experiment and allow you to begin what I have modeled for you in the practice scenarios.

At the conclusion of the scenario, press “esc” to stop the program.

We have completed the fourth scenario. Again, we will move over to the rating computer and complete the rating tasks prior to jumping into scenario #5.

CTA #4

I am going to ask you to re-rate the similarity of the features. Remember, you are rating the similarity of each ATIS feature to the highlighted feature at the top. It is important that features very similar to the highlighted feature are rated higher than features that are not as similar. As before you are free to change your answers from last time.

[Subject proceeds through 15 worksheets]

[Should end on the “thank-you” screen]

Experimenter: Type Ctl+r (Data screens scroll as the data is being transferred to DATA 4.)

Experimenter: Type Ctl+l (15 worksheets should clear and leave program at begin screen)

[Return to ATIS computer - for Trips five and six]

Now, we will begin the fifth scenario, which will be in the same format as the others.

Type in the subject data on the blue “begin” screen. DO NOT HIT BEGIN.

(Read scenario # 5)

(Present the subject with their fifth list of notes). When you are ready all you have to do is hit the “begin” button. Just wait for 3 seconds so that the camera will be activated on your data screen. After you hit the begin button, this will begin the experiment and allow you to begin what I have just modeled for you in the practice scenarios.

At the conclusion of the scenario, press “esc” to stop the program.

We have now completed the fifth scenario. Again we will move on to the sixth scenario, which will be in the same format as the others.

Type in the subject data on the blue “begin” screen. DO NOT HIT BEGIN.

(Read scenario # 6)

(Present the subject with their sixth list of notes). Please wait for 3 seconds so that the camera will be activated on your data screen. When you are ready all you have to do is hit the “begin” button. After you hit the begin button, this will begin the experiment and allow you to begin what I have just modeled for you in the practice scenarios.

At the conclusion of the scenario, press “esc” to stop the program.

Now, for the final time we will be moving over to the rating computer and do the fifth and final rating task. This will be followed by the multiple choice task #2.

CTA #5

This is the last one. Again, please rate the similarity of each ATIS feature to the highlighted feature at the top. As you have gained substantial experience with the system now, your answers may be very different than previous times. That is OK.

[Subject proceeds through 15 worksheets]

[Should end on the “thank-you” screen]

Experimenter: Type Ctl+t (Data screens scroll as the data is being transferred to DATA 5.)

Experimenter: Type Ctl+l (15 worksheets should clear and leave program at begin screen)

Present CTA pictures - #2

Again, we have some pictures for you to look at. This will be the same multiple choice task that was required of you at the beginning of the experiment. You will be asked which of four pictures came before the target picture, which will be located in the center of the three pictures. Then you will be asked which of the four pictures on the right came after the target.

[Have subject complete the matching task].

Debrief

Ask if he/she has further questions.

Complete payment form and pay.

Thank and escort out.

EXPERIMENTER'S INSTRUCTIONS

ATIS Display

- | | | |
|---|------------------------------|--|
| ! | Main Menu Function | the first screen and starting point to access the system. |
| ! | Help Function | on-line help that provides information about a screen. |
| ! | Trip Planning Function | allows you to enter the name of a destination. |
| ! | Travel Modes Function | allows you to select available mode options, travel routes, and schedules. |
| ! | Services Directory | allows you to select available accommodations, restaurants, activities, and learn about your destination and other available services. |
| ! | Travel Coordination Function | allows you to make reservations for the travel mode selected, accommodations, and restaurant. |
| ! | Communications Function | allows you to send, read and reply to messages from outside parties. |

ATIS Setup

Turn on the two computers via their respective power bars located underneath the desk and placed toward the rear of the desk.

To run the ATIS system, get into the program on the small computer (the RGS) by typing “win” at the Vehicular Navigation and Information System (VNIS) prompt. This will get you into windows.

When in windows, enter into the Multimedia ToolBook 3.0 CBT Edition file and select the Multimedia ToolBook 3.0. Next, select your choice of the integrated or non-integrated type of scenario you are running (for example, c:\tb30\routes\non-integrated).

On the begin screen (the blue one), enter the information for the practice scenarios. This information should correspond to the subject which you are testing. For example, subject # for the first practice session with the first subject should be #1101 for the simple practice session and 1102 for the complex practice session. Your gender, as the experimenter, should match the subject's gender. Next, the trip #'s should be 98 and 99, respectively, for each subject.

For subject data on the begin screen:

- ! Subject #
- ! Gender of subject (0=female, 1=male)
- ! Type (integrated/non-integrated)
- ! Level (simple [no interrupts]/complex [w/ interrupts])
- ! Trial (1-3) - repetition of complexity type of scenario
- ! Trip (1-6) - number assigned to each scenario

To view the scene on the large monitor, select RGS, in windows. Scroll along the top menu to “windows.” Use the arrow keys to select the MICII program. When in the MICII program, select live view (the first icon on the left side) and line up the camera.

To record, make sure the camera is in the videotape record (VTR) mode. If you want to review the tape and not record, the camera can be in camera mode. This will only allow you to view for 5 minutes, then it will shut itself off.

Ensure the camera is properly aimed at the small computer screen (the one on the right side of the desk). The video input to the monitor should then be turned off by using the switch labeled BNC\D located on the far right on the control panel under the screen (the little flip door); or alternatively, by turning off the power via the power button. Then, to begin recording with the

camera, put the camera in the VTR mode and push record. Be sure to record the “begin” screen so as to enable subject recognition by their number and their corresponding scenario.

Each scenario will be recorded and replayed to the subject immediately after the completion of each scenario. To do this, the camera must be switched from the camera mode (on the little black button with the green top) to the VTR mode. Be sure to ensure that the large monitor is on (switched from the BNC\D button of the control panel to the right).

For the Rating Task/Computer Start-Up Procedure:

Before Subject arrives, turn on the computer to be used.

Open Excel.

Open the correct version: Int2.cta or Nonint.cta.

Make sure that the start screen is displayed.

Make sure all scroll bars, window tabs, tool bars, etc., are turned off.

Under “View” choose “Full Screen.”

Make sure NUM LOCK is ON, CAP LOCK is OFF, and SCROLL LOCK IS OFF!

Place two chairs at the computer. The right-hand one is for the subject, so they can access the number pad.

Place your paper over the rest of the keyboard.

Meet Subject - read Introduction script

Bring subject to CTA computer. Have them sit and be comfortable in the right-hand chair. Display the “Begin” screen, and tell subject they can read along as you describe the task to them.

Saving the Data for the CTA

- ! Choose DATA 1 to DATA 5 (Highlight with mouse while pressing CTL).
- ! Press right mouse button, and choose “Move or Copy” sheets.
- ! Choose “New book.”
- ! Click on box that says “create a copy.”
- ! New Book will open with Data1 to Data5.
- ! Save as CTA.X (where × = subject number).

Notes to Experimenter

Transferring Data

Ctl + q - Transfers data for CTA #1.

Ctl + w - Transfers data for CTA #2.

Ctl + e - Transfers data for CTA #3.

Ctl + r - Transfers data for CTA #4.

Ctl + t - Transfers data for CTA #5.

N.B.: Letters must be lower case!!

Clearing Spreadsheets

Ctl + l - Clears data and prepares for next CTA.**

**** USE THIS ONLY AFTER TRANSFERRING THE DATA (AS ABOVE). THIS CLEARS ALL DATA FROM THE FIRST 15 SPREADSHEETS. IF THE DATA HAVE NOT BEEN TRANSFERRED TO A NEW SPREADSHEET, THE DATA WILL BE LOST!!!!**

Possible Problems

If subject clicks on “Continue” but nothing happens:

Press return or click anywhere on the spreadsheet to enter their last number. Then press continue.

If subject moves spreadsheet using arrow keys:

Try to avoid this problem by watching subjects and asking them not to use arrow keys where not appropriate. If they do move spreadsheet, press HOME key.

In an emergency ONLY:

Control of the spreadsheet can be obtained by choosing TOOLS, OPTIONS, VIEW and clicking on options that you want to see (i.e. scroll bars, headers, and sheet tabs)

For the Multiple Choice Task - Start-up Procedure

Setup.

Make sure brown desk is clear.

Have the six picture boards ready. Make sure ALL are the right side up depending whether subjects are integrated or non-integrated.

Place out of the way so they do not distract the subject during the other CTA.

[Training 1 and 2]
[CTA - Ratings #2]

Protocol

Before we go back to the ATIS system, I am going to give you a quick multiple choice quiz. I am going to show you a picture of an actual ATIS screen and ask you to decide which screen was most likely to have come before it. To make this task easier for you, I will provide you with four possible screens, and you just have to choose the most likely of the four.

Do you have any questions?

Here is the first set. The picture in the middle is the actual ATIS screen. Choose from these four (point to set on left) to determine which is the most likely screen that came before. Don't worry about the pictures on the right, we will use those in a second.

As you can see, these pictures are labeled A, B, C, and D. Just call out the letter or point to the picture that you have selected as your answer.

If you don't have any questions, go ahead and select the screen that you think most likely came before the actual ATIS screen.

[Experimenter records answer]

Now, consider the actual ATIS screen again. Think about what the most likely screen to follow it might be. Now, look at the four pictures on the right. Select the one that you think most likely follows the actual ATIS screen. Again, just call out the letter, or point to the picture that you have selected.

[Repeat procedures for all six cards].

Scenario Overview

GIVE CTA RATINGS TASK #1 - control Q (to put data to Datasheet #1, then control L to clear)

BEGIN PRACTICE/TRAINING SESSIONS

Practice 1: Simple scenario with no interrupts. Answer questions throughout.

Practice 2: Complex scenario with interrupts. Answer questions throughout.

Ask if subject has any final questions.

GIVE CTA RATINGS TASK #2 - control W (data to Datasheet #2, control L to clear)

GIVE CTA MULTIPLE CHOICE TASK #1

BEGIN EXPERIMENTAL ATIS SCENARIOS #1 AND #2

Type in information on “Begin” screen. DO NOT HIT THE BEGIN BUTTON.

Read scenario. After, give list of “notes.”

Have subject hit the “Begin” button; this starts the timer.

When subject has completed planning trip, hit “ESC” to stop timer and return to “Begin” screen.

Review trip (either by videotape or Multimedia ToolBook [MTB] application); ask CTA questions. When complete, begin next scenario until all six scenarios are complete as described above.

GIVE CTA RATINGS TASK #3 - control E (data to Datasheet #3, control L to clear)

BEGIN EXPERIMENTAL ATIS SCENARIOS #3 AND #4

GIVE CTA RATINGS TASK #4 - control R (data to Datasheet #4, control L to clear)

BEGIN EXPERIMENTAL ATIS SCENARIOS #5 AND #6

GIVE CTA RATINGS TASK #5 - control T (data to Datasheet #5, control L to clear)

GIVE CTA MULTIPLE CHOICE TASK #2

DEBRIEF

Ask if he/she has further questions.

Complete payment form and pay.

Thank and escort out.

Common Errors and the Script of the Experimenter’s Possible Responses

- 1) If the subject deviates from the list of travel notes, the experimenter should hit the “p” key as soon as the subject returns to the Main Menu page, or the Services Directory page depending on where they are. If the subject is in a step that involves accommodations, restaurants, activities, or learning about their destination, then the experimenter should stop timer when the subject returns to the Services Directory menu. In any other situation, the timer should be stopped when the subject returns to the Main Menu.
- 2) If subject has deviated from the list of notes, experimenter should stop the subject and hit the “p” key as soon as the subject returns to the Main Menu. Next, the experimenter should ask the subject to carefully re-read their trip planning notes and ensure that they are doing everything as outlined in the notes. The experimenter should indicate to the subject to hit the “begin” option on the window that appeared when paused by the experimenter.

- 3) If subject continually attempts to enter the descriptor of the travel route (ex: Lynden) as the destination, experimenter should stop the subject and hit the “p” key as soon as the subject returns to the Main Menu. Experimenter should indicate to the subject that they should carefully re-read their trip planning notes to ensure that they are doing everything as outlined in the notes. The experimenter should indicate to the subject to hit the “begin” option on the window that appeared when paused by the experimenter.
- 4) If subject incorrectly exits a step (i.e., the subject has forgotten to hit done so as to put their answer in the database), experimenter should stop the subject and hit the “p” key as soon as the subject returns to the Main Menu. Experimenter should indicate to the subject that the database has not received their latest request and that they should re-do the last step ensuring that they enter/accept their choice. The experimenter should indicate to the subject to hit the “begin” option on the window that appeared when paused by the experimenter.
- 5) If subject just sits in front of the computer and does not understand what is required of them, experimenter should first state that there is a “help” button which may aid them. If problems still exist, indicate to the subject that it is time for them to perform just as was done by the experimenter in the practice scenarios. If there is still confusion, indicate that the first step is clearly outlined on the list in front of them.
- 6) If subject becomes lethargic and does not seem to care about what they are doing, the experimenter should hit the “esc” key and indicate to the subject that we are having some computer difficulties and that the experiment has to be interrupted. Experimenter should complete payment, thank the subject, and escort the subject out.
- 7) If subject forgets to cancel the reservation prior to re-booking it, experimenter should stop the subject and hit the “p” key as soon as the subject goes to the services menu instead of the travel coordination menu. Next the experimenter should indicate to the subject that they have taken a wrong step and that they should ensure that they have followed all the directions. If they are having problems remembering, simply let the subject know that the message will still be there and that they can re-look at the message any time they want and as often as they want.
- 8) Ensure the keyboard for the ATIS computer has been removed from in front of the ATIS computer and place it in front of the large monitor. This will enable the experimenter to have a keyboard while removing the temptation from the subject to inadvertently touch the keyboard and harm their program.

APPENDIX H: SIMULATOR VEHICLE DYNAMICS (FOR EXPERIMENT 2)

Engine Model Definitions

engine displacement (l)	1.9
engine inertia (kg.m ²)	1.0
engine stall speed (rad/s)	35.0
speed for peak torque (rad/s)	600.0
peak engine power (kW)	30.0
engine vibration frequency (Hz)	10.0

Transmission Model Definitions

first gear ratio	2.50
second gear ratio	1.60
third gear ratio	1.20
fourth gear ratio	0.80
reverse gear ratio	-2.09
no drive ratio	0.00
final drive ratio	3.08
final drive train efficiency	0.7

Transmission Upshift Speeds

shift speeds at idle	at full throttle
15.0	25.0
35.0	45.0
50.0	70.0
65.0	80.0

Vehicle Constants

coefficient of drag	0.430
vehicle frontal area (m ²)	1.40
wheel radius (m)	0.3048
wheel base (m)	2.601
vehicle width (m)	1.718
vehicle mass (kg)	1400
front axle load (N)	9800
rear axle load (N)	5000.0
brake system gain	65000.0
brake disc radius	0.25
brake friction coefficient	1.0
rot inertia of wheels (kg.m ²)	3.2
total rolling resistance (N)	175.0

Suspension Constants

spring const at each wheel (N/m)	4200.0
ratio of oscillation period to	2.0

Steering and Tire Constants

steering box ratio	10.3
steering power assist	5.0
damping of static tires	0.20
damping of rolling tires	0.00
scaling factor for overall damping	1.0
tire foundation stiffness (N/m ²)	3.0e6
tire contact patch (m)	0.18
tire patch width (m)	0.205
static friction coefficient	1.2
dynamic friction coefficient	1.0
air density (kg/m ³)	1.293
atmospheric pressure (Pa)	101325.0

APPENDIX I: GRECO-LATIN SQUARE DESIGN (FOR EXPERIMENT 2)

Subject Number	Gender	Order of Route*	Order of ATIS Status**
1	M	1, 2, 3	A, B, C
2	M	2, 3, 1	A, B, C
3	F	3, 1,2	A, B, C
4	F	1, 2, 3	A, C, B
5	F	2, 3, 1	A, C, B
6	M	3, 1, 2	A, C, B
7	M	1, 2, 3	B, A, C
8	M	2, 3, 1	B, A, C
9	F	3, 1, 2	B, A, C
10	F	1, 2, 3	B, C, A
11	F	2, 3, 1	B, C, A
12	M	3, 1, 2	B, C, A
13	M	1, 2, 3	C, A, B
14	M	2, 3, 1	C, A, B
15	F	3, 1, 2	C, A, B
16	F	1, 2, 3	C, B, A
17	F	2, 3, 1	C, B, A
18	M	3, 1, 2	C, B, A

*Order of Route

! 1 = Scenario 1 (I-90)

! 2 = Scenarios 2 and 3 (Bellevue)

! 3 = Scenario 3 (Highway 520)

** Order of ATIS Status

! A = ATIS On with Control Inputs

! B = ATIS On

C = ATIS Off

**APPENDIX J: SUBJECT SELECTION PHONE QUESTIONNAIRE
(FOR EXPERIMENT 2)**

Name _____ Phone Number _____

Age _____ Gender _____ (1 = M, 0 = F)

1) Do you have an active driver's license? _____ Yes (1) _____ No (2)

[Exclude subject if answer is NO]

2) How many times per week do you drive in Seattle?

_____ < 1X (1) _____ 1X (2) _____ 2 or more (3)

[Exclude subject if answer is not 2 or more.]

3) Do you ever experience motion sickness while driving or riding in a vehicle (e.g., car, bus, train, plane, boat)?

_____ Never (1) _____ Sometimes (2) _____ Often (3)

[If answer is sometimes or often, inform subject 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 people experience when traveling in a vehicle. Because you often experience motion sickness, there is a chance that you will experience simulator sickness. We do not want this to happen so must ask you not to participate in this study. We greatly appreciate your interest and will be glad to keep you on our list for future studies that do not involve the simulator, if you wish.]

4) Past research has suggested that this type of simulator research may not be suitable for individuals who experience migraine or tension headaches? Do you experience either of those?

_____ No (1) _____ Yes (2)

[If answer is yes, question the subject further. If they have experienced a migraine recently, or experience migraines frequently, inform subject 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 people experience when traveling in a vehicle. Research shows that people who experience migraines or tension headaches may be more susceptible to simulator sickness. Because you often experience migraines, there is a chance that you will experience simulator sickness. We do not want this to happen so must ask you not to participate in this study. We greatly appreciate your interest and will be glad to keep you on our list for future studies that do not involve the simulator, if you wish.]

5) Also, this type of simulator research may not be suitable for individuals who suffer from a serious heart condition. Do you suffer from a heart condition ?

_____ No (1) _____ Yes (2)

[If yes, inform the subject of the following:

Due to your heart condition, we must ask you not to participate in this study. We greatly appreciate your interest and will be glad to keep you on our list for future studies that do not involve the simulator, if you wish.]

6) If female: Also, simulator research may not be suitable for women that are pregnant. Are you pregnant?

_____No (1)

_____Yes (2)

[If yes, inform the subject 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 people experience when traveling in a vehicle. Because you are pregnant, and therefore prone to nausea, there is a chance that you will experience simulator sickness. We do not want this to happen so must ask you not to participate in this study. We greatly appreciate your interest and will be glad to keep you on our list for future studies that do not involve the simulator, if you wish.]

7) Do you suffer from any condition or take any medications that predispose you to nausea, blurred vision, or drowsiness?

_____No (1)

_____Yes (2)

[If yes, inform the subject 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 people experience when traveling in a vehicle. Because of your condition/medication, there is a chance that you will experience simulator sickness. We do not want this to happen so must ask you not to participate in this study. We greatly appreciate your interest and will be glad to keep you on our list for future studies that do not involve the simulator, if you wish.]

**APPENDIX K: DRIVER DEMOGRAPHIC CHARACTERISTICS PHONE
QUESTIONNAIRE (FOR EXPERIMENT 2)**

Subject ID: _____

1. Age: _____

2. Number of years as a licensed driver: _____

3. Number of years driving in Seattle: _____

4. Number of years lived in Seattle _____

4. Town of residence: _____ Zip code

5. Gender: G Male G Female

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

G less than 5,000

G 5,000 - 9,999

G 10,000 - 19,999

G 20,000 - 39,999

G 40,000 - 69,999

G 70,000 - 99,999

G more than 100,000

7. Where did you learn about this research? _____

APPENDIX L: FHWA RESEARCH PARTICIPATION INFORMATION SUMMARY (FOR EXPERIMENT 2)

You have been recruited to participate in a study examining driver response to Advanced Traveler Information Systems (ATIS). These systems provide the following types of information: in-vehicle road sign information; services and attractions; safety and warning; and navigation and routing information. The systems are designed to decrease traffic congestion and environmental impact, and to increase safety, efficiency, and productivity on the highway system.

If you agree to participate in this study, you will be asked to participate in a short practice session to familiarize yourself with the simulator and the advanced vehicle system located in the car. The practice session will be followed by 4 ten-minute driving sessions. The entire study should take no more than 3 hours to complete. For your participation, you will receive \$10 an hour for a total of \$30 for completion of the entire session.

You should know that a small number of people experience something similar to motion sickness when operating simulators. The effects are typically slight and usually consist of an odd feeling or warmth. If you feel uncomfortable, you may ask to quit at any time. Most people enjoy driving the simulator and do not experience any discomfort.

The information gathered in this study will give us a better understanding of the driver's perception of ATIS features and will help us to create better design guidelines for future ATIS devices. All data obtained are for research purposes only and will remain confidential. Names will not be associated with the questionnaires in any way and no data will be reported to licensing authorities or insurance companies. The information will be reviewed by both Battelle and Federal Highway Administration (FHWA) scientists, and the data will remain with Battelle and the FHWA. It is your privilege to withdraw from this study at any time. If you withdraw, you will be paid for the time that you have participated without the loss of any benefits.

If you have any questions or desire further information about this study, please contact Battelle.

APPENDIX N: EXPERIMENTAL PROTOCOL (FOR EXPERIMENT 2)

- ! Greet subject at Capriccios. Inform the subject that we will be walking over to the simulator and ask them if they would like to use the restroom or drinking fountain before you head over.
- ! Upon arrival at the simulator, provide subject with the information summary and the consent form and answer any questions they might have. Ensure that the consent form has been signed.
- ! Administer the comfort assessment and equilibrium tests and record the necessary information.
- ! Explain in more detail the purpose of the study and provide the subject with an overview of what they will be asked to do for this study.

For this study, we will be asking you to drive in our simulator while using an advanced vehicle system. This system is similar to the types of systems that might be used in vehicles in the future. This particular system can act as a navigation aid as well as provide you with in-vehicle messages regarding road signs, vehicle safety, and relevant traffic conditions. Its purpose is to help us determine what effects these systems might have on driving performance.

You are going to be seated inside of a Saturn test vehicle. All of the controls will be pointed out and the advanced vehicle system will be explained to you. When you feel comfortable with the system and all of your questions have been answered, we will begin the driving simulation and allow you to complete several practice drives to become familiar with the vehicles brakes and steering. Then we will begin the study. There will be four different trials each lasting approximately 10 minutes. You will be given a short break in between each of the trials. After all of the driving is completed you will be paid and given the opportunity to ask any questions that you may have.

Seat subject in the driving simulator and allow them to adjust the seat and mirrors. Point out all of the displays/controls they might need during the course of the study (e.g., accelerator, brake, speedometer, etc.) Let them know about the two-way communication system inside the vehicle as well.

Prepare the simulator for the practice drives.

The purpose of the practice drives is to give you a chance to get used to the steering and the braking in the simulator because you might find it to be a little different than what you are used to. Do you have any questions before we go through the practice drives?

- ! Begin practice scenario #1. [Break for 5 minutes - administer comfort assessment and equilibrium test]
- ! Begin practice scenario #2. [Break for 5 minutes - administer comfort assessment and equilibrium test]

- ! Begin practice scenario #3. [Break for 5 minutes - administer comfort assessment and equilibrium test]

- ! Prepare the simulator for the experimental scenarios.

- ! Activate the ATIS so that the map is on the display.

This is the Advanced Traveler Information System. The system is designed to show you the current location of the vehicle along the route. Therefore, as the route is being traveled, the vehicle location is constantly being tracked and will be updated on the map you see inside the vehicle.

As you drive, you will also receive messages informing you of upcoming road and traffic conditions. These messages will be either auditory or visual or a combination of the two, in which case you would receive an auditory alert (i.e., a tone) before the visual message appears. All of the visual messages will appear here (point) on the screen.

In addition to driving, you will be asked to perform several tasks. You will hear an auditory tone, which will alert you that a text message is being presented on the display. The messages will ask you to perform different tasks, some of which you will be familiar with, such as tuning a radio or adjusting the vehicle temperature. Others will require you to interact with the in-vehicle system located on the dashboard. Remember that the most important task today is to safely drive the vehicle to its destination. Therefore, tasks that the system asks you to perform should be completed only when you feel it is safe to do so. Do you have any questions?

OK, First, I will go over all of the different tasks that you might be asked to complete. Afterwards you will be allowed to practice and to ask any questions you might have.

Standard

Standard tasks will require you to use either the radio or the temperature controls. Most of these tasks will be familiar to you; however, we will go over them so that you are familiar with how they are done in this particular vehicle since some cars are slightly different.

The radio is turned on by rotating this knob clockwise. Please do not turn the radio up past this point where the two tape marks meet so that you can hear the in-vehicle messages which may be of importance.

The preset channels are located here. These are channels that someone has already programmed into the system.

A preset channel can be programmed by selecting the channel that you want, pressing the set button, and pressing the preset channel that you would like it to become. So, now you will always be able to find 101.5 on preset channel #2.

Manually tuning the radio is done by turning this knob.

This is the seek button, which allows you to skip over those stations which are not coming in.

The radio is turned off by rotating this knob counter clockwise.

The time can be set when the radio is off, by pressing the set button, then using the seek up and seek down buttons for adjusting the time. Seek up changes the minutes and seek down will change the hours. Once the time has been changed press the set button again.

Fan settings are changed by using this device.

Temperature can be changed by sliding this lever.

And the direction of the airflow can be changed by sliding this lever.

Allow the subject to practice performing some of the different tasks:

- 1) change time to 8:00
- 2) tune the radio to 94.1 FM manually and to 101.5 using seek
- 3) set 101.5 to become preset channel #1
- 4) change fan setting to defrost and low

Once they are done, turn off the fan and the radio.

Advanced

For tasks that require the advanced vehicle system, you can bring up the main menu by hitting the menu key. The arrow keys will allow you to move around inside the menu and with the enter key you can select the appropriate menu item.

If we use the arrow keys to select “compass” then press the enter key, notice that we can turn on or shut off the compass. Demonstrate this.

Next, we can use the arrow keys to select “rotate map” then press the enter key. Notice that we can rotate the map so that the driver’s heading is up. This will change the map so that the vehicle will appear to be heading toward the top of the map regardless of which way is true north. If we rotate the map north up, this will change the map so that north is at the top of the map regardless of the vehicle’s heading. Demonstrate both of these.

Zooming is also one of the functions listed on our menu. If we use the arrow keys to select zoom then press the enter key, notice that we can zoom in or out on the map. Demonstrate this.

We can also use the arrow keys to select “attraction information” then press the enter key. Once we do that you can see that there are several options listed for this particular drive. Use the arrow keys to select the attraction you are most interested in. Let’s choose the Kingdome. So, use the arrow keys to select the Kingdome and then press enter. The information regarding this attraction will appear on the display.

Allow the subject to practice performing some of the different tasks:

- 1) turning on/off compass
- 2) rotating map heading up/north up
- 3) zooming in/out
- 4) getting attraction information about the Kingdome

! Prepare the simulator for the experimental drives.

Do you have any questions before we start the experiment?

During the drive today you might see some things that look familiar as our drive will be taking place in Seattle. You will start at the Kingdome, head east on I-90, north through Bellevue, and then west on Highway 520 with a few rest stops along the way. Navigation instructions will be given to you aurally as you drive so that you do not miss the necessary exits and turns.

As you drive today I am going to ask you to stay in the right hand lane unless you need to pass. Once the passing maneuver is complete, please return to the right hand lane. Remember to obey all of the rules of the road, especially the speed limits signs, and remember that the most important task today is to safely drive the vehicle to its destination. Therefore, tasks that the system asks you to perform should be completed only when you feel it is safe to do so.

! Begin 1st scenario. [Break for 5 minutes - administer comfort assessment and equilibrium test]

! Begin 2nd scenario. [Break for 5 minutes - administer comfort assessment and equilibrium test]

! Begin 3rd scenario. [Break for 5 minutes - administer comfort assessment and equilibrium test]

! Begin 4th scenario. [Break for 5 minutes - administer comfort assessment and equilibrium test]

* Remind subject: **Drive in the right hand lane except to pass. Once the passing maneuver is complete, please return to the right hand lane.**

** Remember to download subject data after each trial.

- ! Debrief (answer any and all questions subjects may have regarding the study), pay subject, have subject sign form verifying receipt of payment, thank the subject and tell them that we appreciate their interest and hope to see them again.

- ! Make a copy of the signed payment receipt for our records, the original goes to Jacquie Mahoney.

APPENDIX P: POSTURAL DISEQUILIBRIUM TEST (FOR EXPERIMENT 2)

Subject # _____

Postural Disequilibrium Test Form

Test	Trial 1	Trial 2	Trial 3	Average	Percent Change (Pre-Post)/Pre × 100
Pre-test					N/A
Practice #1					
Practice #2					
Practice #3					
Scenario 1					
Scenario 2					
Scenario 3					
Post-test					

$$\text{Percent Change} = \frac{\text{Pre-Test Average} - \text{Post Test Average}}{\text{Pre-Test Average}} \times 100$$

Overall Percent Change = _____

PASSING CRITERIA

Percent change less than 50 percent PASS _____
 Percent change greater than 50 percent FAIL _____

Note: If subject does not meet the passing criteria, ask them to wait in the waiting room. Subjects can try the test again after 30 minutes. If they fail a second time, offer to call a taxi. Battelle will pay cab fare for the subject to return and pick up their car the next day. Be sure to record the post-test results on the Subject Status Sheet. This is required by Battelle’s Human Subject Committee and Legal Department.

APPENDIX Q: EXPERIMENTER INSTRUCTIONS (FOR EXPERIMENT 2)

Practice Scenario #1. For this scenario, please drive from the point at which you are currently situated (which is a fictional highway called Highway 22) to the very first intersection, which is Bow Road. When you reach this intersection, simply stop your vehicle, place the vehicle in park and turn off the engine. Remind the driver that the purpose of these practice scenarios is to get the feel of the vehicle and to get used to the way it accelerates, decelerates, and turns.

Practice Scenario #2. For your second scenario, you are beginning on Highway 22 at the intersection of Bow Road where you left off a couple of minutes ago. Now please drive to a 7-11 convenience store located on Highway 22. When you reach this store, simply stop your vehicle in the lane you are traveling in (there is no need to pull into the parking lot). Remind the driver that the purpose of the practice is to get the feel of the vehicle and get used to the way it accelerates, decelerates, and turns.

Practice Scenario #3. For your final practice scenario, we are asking you to drive to a ranch house, which is located at 378 Highway 22. This house is located on the right hand side of the road. When you reach this house, simply stop your vehicle in the lane you are currently in, place the vehicle in park, and turn the vehicle off.

Experimental Scenario #1. For this experimental scenario, you are asked to drive from the Kingdome in downtown Seattle to Bellevue Way NE. The navigation instructions will help you find this destination. Do you have any questions?

Experimental Scenario #2a. For this scenario you will be beginning at the Bellevue Way NE off ramp from the I-90. We will be asking you to drive to a 7-11 convenience store located just around the Bellevue Mall on Bellevue Way NE. The navigation instructions will help you find this destination. Do you have any questions?

Experimental Scenario #2b. For this scenario you will be asked to drive from NE 8th Street to a BP gas station on NE 84th Avenue. Please pull into the BP station when you arrive as though you are there to fill up your vehicle with gas. As always, the navigation instructions will help you to find this destination.. Do you have any questions?

Experimental Scenario #3. For this scenario you will be asked to drive from the BP gas station on 84th Avenue NE to downtown Seattle. The navigation instructions will help you to find this destination. Do you have any questions?

APPENDIX R: ANOVA TABLES (FOR EXPERIMENT 1)

Table 12. Trip latency.

Independent Variable	SS	df	MS	F	p
Type	1025.50	1	1025.50	0.04	0.8511
Error	62595.18	22	28422.51		
Complexity	193865.12	1	193865.12	52.59	0.0000
Complexity × Type	76.63	1	76.63	0.02	0.8867
Error	81093.72	22	3686.08		
Trial	240356.60	1.44[†]	120178.60	64.57	0.0000
Trial × Type	3604.04	1.44 [†]	1802.02	0.97	0.3644
Error	81889.85	31.66 [†]	1861.13		
Complexity × Trial	60153.89	1.91[†]	30076.95	10.24	0.0003
Complexity × Trial × Type	2584.29	1.91 [†]	1292.14	0.44	0.6384
Error	129262.34	42.10 [†]	2937.78		

[†]Degrees of freedom adjusted using the Greenhouse-Geisser correction

Table 13. Trip planning latency.

Independent Variable	SS	df	MS	F	p
Type	48.20	1	48.20	0.13	0.7244
Error	8317.05	22	377.91		
Complexity	107.75	1	107.75	0.85	0.3653
Complexity × Type	166.07	1	166.07	1.32	0.2635
Error	2774.41	22	126.11		
Trial	6504.77	1.73[†]	3252.38	26.80	0.0000
Trial × Type	182.82	1.73 [†]	91.41	0.75	0.4596
Error	5339.17	38.01 [†]	121.34		
Complexity × Trial	1107.85	1.95[†]	553.92	5.65	0.0070
Complexity × Trial × Type	92.69	1.95 [†]	46.34	0.47	0.6219
Error	4316.67	42.91 [†]	98.11		

[†]Degrees of freedom adjusted using the Greenhouse-Geisser correction

Table 14. Travel mode latency.

Independent Variable	SS	df	MS	F	p
Type	298.34	1	298.34	0.47	0.5007
Error	14001.24	22	636.42		
Complexity	507.07	1	507.07	1.76	0.1982
Complexity × Type	853.38	1	853.38	2.96	0.0993
Error	6337.73	22	288.07		
Trial	2379.25	1.95 [†]	1189.63	2.71	0.0792
Trial × Type	2195.46	1.95 [†]	1099.23	2.51	0.0945
Error	19296.18	42.81 [†]	438.55		
Complexity × Trial	802.45	1.68 [†]	401.22	1.19	0.3093
Complexity × Trial × Type	801.66	1.68 [†]	400.66	1.19	0.3098
Error	14855.02	36.99 [†]	337.61		

[†]Degrees of freedom adjusted using the Greenhouse-Geisser correction

Table 15. Service directory latency.

Independent Variable	SS	df	MS	F	p
Type	157.92	1	157.92	0.04	0.8465
Error	90544.76	22	4115.67		
Complexity	43828.19	1	43828.19	46.31	0.0000
Complexity × Type	3676.62	1	3676.62	3.88	0.0614
Error	20823.15	22	946.51		
Trial	40865.04	1.65[†]	20432.52	24.43	0.0000
Trial × Type	1584.79	1.65 [†]	792.39	0.95	0.3814
Error	36807.43	36.29 [†]	836.53		
Complexity × Trial	15461.99	1.48[†]	7730.99	9.61	0.0014
Complexity × Trial × Type	856.44	1.48 [†]	428.22	0.53	0.5392
Error	35412.53	32.53 [†]	804.83		

[†]Degrees of freedom adjusted using the Greenhouse-Geisser correction

Table 16. Travel coordination latency.

Independent Variable	SS	df	MS	F	p
Type	1157.11	1	1157.11	0.74	0.3976
Error	34199.30	22	1554.51		
Complexity	101546.79	1	101546.79	196.19	0.0000
Complexity × Type	584.14	1	584.14	1.13	0.2996
Error	11387.11	22	517.60		
Trial	12240.03	1.90[†]	6120.01	19.22	0.0000
Trial × Type	1090.82	1.90 [†]	545.41	1.71	0.1940
Error	14008.33	41.71 [†]	318.37		
Complexity × Trial	5726.23	1.55[†]	2863.11	15.12	0.0001
Complexity × Trial × Type	1012.18	1.55 [†]	506.09	2.67	0.0955
Error	8331.25	34.02 [†]	189.35		

[†]Degrees of freedom adjusted using the Greenhouse-Geisser correction

Table 17. Communications latency.

Independent Variable	SS	df	MS	F	p
Type	436.94	1	436.94	0.37	0.5488
Error	25919.12	22	1178.14		
Complexity	9970.54	1	9970.54	44.11	0.0000
Complexity × Type	834.87	1	834.87	3.69	0.0677
Error	4972.90	22	226.04		
Trial	2934.76	1.90 [†]	1467.38	1.69	0.1984
Trial × Type	6828.32	1.90[†]	3414.16	3.93	0.0292
Error	38257.99	41.82 [†]	869.50		
Complexity × Trial	199.98	1.93 [†]	99.99	0.12	0.8801
Complexity × Trial × Type	2796.98	1.93 [†]	1398.49	1.69	0.1976
Error	36425.70	42.50 [†]	827.86		

[†]Degrees of freedom adjusted using the Greenhouse-Geisser correction

Table 18. Main menu latency.

Independent Variable	SS	df	MS	F	p
Type	1832.66	1	1832.66	2.01	0.1699
Error	20017.86	22	909.90		
Complexity	22752.93	1	22752.93	86.84	0.0000
Complexity × Type	359.35	1	359.35	1.37	0.2541
Error	5764.46	22	262.02		
Trial	11665.37	1.23[†]	5832.69	30.73	0.0000
Trial × Type	212.47	1.23 [†]	106.23	0.56	0.4952
Error	8352.64	27 [†]	189.83		
Complexity × Trial	2840.10	1.29[†]	1420.05	8.47	0.0040
Complexity × Trial × Type	493.63	1.29 [†]	246.81	1.47	0.2418
Error	7378.72	28.48 [†]	167.70		

[†]Degrees of freedom adjusted using the Greenhouse-Geisser correction

Table 19. On-line help frequency.

Type	Complexity	Trial 1	Trial 2	Trial 3	Total (Complexity)	Total (Type)
Integrated	Unmodified	0	0	0	0	3
	Modified	3	0	0	3	
Non-integrated	Unmodified	0	0	1	1	8
	Modified	6	1	0	7	
Total (trial)		9	1	1		

Table 20. Number of help requests.

Independent Variable	SS	df	MS	F	p
Type	0.17	1	0.17	1.54	0.2282
Error	2.49	22	0.11		
Complexity	0.56	1	0.56	4.30	0.0499
Complexity × Type	0.06	1	0.06	0.48	0.4964
Error	2.88	22	0.13		
Trial	0.88	1.21[†]	0.44	4.82	0.0307
Trial × Type	0.06	1.21 [†]	0.03	0.30	0.6314
Error	4.06	26.69 [†]	0.09		
Complexity × Trial	1.16	1.23[†]	0.58	7.00	0.0095
Complexity × Trial × Type	0.17	1.23 [†]	0.08	1.00	0.3439
Error	3.67	27.13 [†]	0.08		

[†]Degrees of freedom adjusted using the Greenhouse-Geisser correction

Table 21. Error message frequency.

Type	Complexity	Trial 1	Trial 2	Trial 3	Total (Complexity)	Total (Type)
Integrated	Unmodified	1	3	0	4	8
	Modified	2	1	1	4	
Non-integrated	Unmodified	3	0	2	5	10
	Modified	3	2	0	5	
Total (trial)		9	6	3		

Table 22. Number of error messages.

Independent Variables	SS	df	MS	F	p
Type	0.03	1	0.03	0.11	0.7400
Error	5.39	22	0.24		
Complexity	0.00	1	0.00	0.00	1.0000
Complexity × Type	0.00	1	0.00	0.00	1.0000
Error	1.67	22	0.08		
Trial	0.38	1.98 [†]	0.19	1.45	0.2460
Trial × Type	0.26	1.98 [†]	0.13	1.02	0.3685
Error	5.69	43.50 [†]	0.13		
Complexity × Trial	0.04	1.88 [†]	0.02	0.24	0.7800
Complexity × Trial × Type	0.54	1.88 [†]	0.27	3.18	0.0550
Error	3.75	41.29 [†]	0.09		

[†]Degrees of freedom adjusted using the Greenhouse-Geisser correction

Table 23. Pause frequency.

Type	Complexity	Trial 1	Trial 2	Trial 3	Total (Complexity)	Total (Type)
Integrated	Unmodified	2	0	0	2	10
	Modified	4	1	3	8	
Non-integrated	Unmodified	1	0	1	2	11
	Modified	6	3	0	9	
Total (trial)		13	4	4	21	

Table 24. Pause frequency.

Independent Variables	SS	df	MS	F	p
Type	0.44	1	0.44	0.54	0.4702
Error	18.11	22	0.82		
Complexity	2.78	1	2.78	9.02	0.0066
Complexity × Type	0.11	1	0.11	0.36	0.5543
Error	6.78	22	0.31		
Trial	1.72	1.41 [†]	0.86	2.80	0.0925
Trial × Type	0.06	1.41 [†]	0.03	0.09	0.8473
Error	13.56	30.96 [†]	0.31		
Complexity × Trial	0.39	1.71 [†]	0.19	1.37	0.2633
Complexity × Trial × Type	0.72	1.71 [†]	0.36	2.55	0.0988
Error	6.22	37.60 [†]	0.14		

[†]Degrees of freedom adjusted using the Greenhouse-Geisser correction

Table 25. Perceived demand questionnaire.

Independent Variables	SS	df	MS	F	p
Gender	4824.490	1.00	4824.490	0.89	0.3981
Type	402.820	1.00	402.820	0.07	0.7983
Gender × Type	581.870	1.00	581.870	0.11	0.7592
Error	21606.260	4.00	5401.570		
Dimension	3826.890	1.30[†]	1913.450	26.13	0.0027
Dimension × Gender	303.330	1.30 [†]	151.670	2.07	0.1885
Dimension × Type	497.010	1.30 [†]	248.510	3.39	0.1201
Dimension × Gender × Type	115.240	1.30 [†]	57.620	0.79	0.4491
Error	585.890	5.21 [†]	73.240		
Level	13.190	1.00	13.190	0.69	0.4535
Level × Gender	28.930	1.00	28.930	1.51	0.2868
Level × Type	0.089	1.00	0.089	0.00	0.9491
Level × Gender × Type	65.550	1.00	65.550	3.42	0.1382
Error	76.750	4.00	19.180		
Trial	292.000	1.25 [†]	146.000	2.70	0.1625
Trial × Gender	7.860	1.25 [†]	3.930	0.07	0.8487
Trial × Type	105.440	1.25 [†]	52.720	0.97	0.3928
Trial × Gender × Type	74.720	1.25 [†]	37.360	0.69	0.4768
Error	433.150	4.99 [†]	54.140		
Dimension × Complexity	3.900	1.75 [†]	1.950	0.54	0.5817
Dimension × Complexity × Gender	3.780	1.75 [†]	1.880	0.53	0.5904
Dimension × Complexity × Type	10.660	1.75 [†]	5.330	1.48	0.2864
Dimension × Complexity × Gender × Type	8.090	1.75 [†]	4.040	1.13	0.3676
Error	28.770	7.00 [†]	3.590		
Dimension × Trial	17.600	2.07 [†]	4.400	0.73	0.5152

Independent Variables	SS	df	MS	F	p
Dimension C Trial × Gender	2.600	2.07 [†]	0.650	0.11	0.9046
Dimension × Trial × Type	1.160	2.07 [†]	0.290	0.05	0.9572
Dimension × Trial × Gender × Type	12.990	2.07 [†]	3.250	0.54	0.6086
Error	96.530	8.27 [†]	6.030		
Complexity × Trial	95.010	1.11 [†]	47.510	1.48	0.2904
Complexity × Trial × Gender	12.340	1.11 [†]	6.170	0.19	0.8284
Complexity × Trial × Type	19.100	1.11 [†]	9.550	0.30	0.6342
Complexity × Trial × Gender × Type	91.270	1.11 [†]	45.640	1.43	0.2993
Error	256.170	4.44 [†]	32.020		

[†]Degrees of freedom adjusted using the Greenhouse-Geisser correction

Table 26. Multiple choice task accuracy.

Independent Variable	SS	df	MS	F	p
Type	6994.06	1	6994.06	3.71	0.0745
Error	26361.41	14	1882.96		
Time	7976.24	1	7976.24	5.29	0.0373
Time × Type	1153.59	1	1153.59	0.77	0.3963
Error	21089.38	14	1506.38		
Transition	19625.05	1	19625.05	23.33	0.0003
Transition × Type	6233.64	1	6233.64	7.41	0.0165
Error	11778.08	14	841.29		
Question	1131.00	1	1131.00	2.14	0.1655
Question × Type	20.85	1	20.85	0.04	0.8454
Error	7397.12	14	528.37		
Time × Transition	1450.44	1	1450.44	1.89	0.1907
Time × Transition × Type	2034.04	1	2034.04	2.65	0.1257
Error	10740.16	14	767.16		
Time × Question	1101.24	1	1101.24	1.16	0.3005
Time × Question × Type	1153.58	1	1153.58	1.21	0.2898
Error	13339.39	14	952.81		
Transition × Question	184.57	1	184.57	0.20	0.6651
Transition × Questions × Type	605.67	1	605.67	0.64	0.4366
Error	13218.55	14	944.18		
Time × Transition × Question	726.24	1	726.24	0.51	0.4858
Time × Transition × Question × Type	684.83	1	684.83	0.48	0.4983
Error	19839.38	14	1417.09		

Table 27. Multiple choice task latency.

Independent Variable	SS	df	MS	F	p
Gender	350.43	1	350.43	1.36	0.2667
Type	19.10	1	19.10	0.07	0.7903
Gender × Type	131.09	1	131.09	0.51	0.4898
Error	3099.24	12	258.27		
Time	917.39	1	917.39	8.62	0.0125
Time × Gender	65.94	1	65.94	0.62	0.4464
Time × Type	524.55	1	524.55	4.93	0.0464
Time × Gender × Type	21.81	1	21.81	0.21	0.6588
Error	1276.85	12	106.40		
Transition	2831.65	1	2831.65	24.33	0.0003
Transition × Gender	303.21	1	303.21	2.61	0.1325
Transition × Type	52.26	1	52.26	0.45	0.5155
Transition × Gender × Type	5.05	1	5.05	0.04	0.8384
Error	1396.55	12	116.38		
Question	633.28	1	633.28	10.87	0.0064
Question × Gender	229.18	1	229.18	3.94	0.0706
Question × Type	105.38	1	105.38	1.81	0.2034
Question × Gender × Type	27.14	1	27.14	0.47	0.5078
Error	698.90	12	58.24		
Time × Transition	201.34	1	201.34	2.30	0.1556
Time × Transition × Gender	90.68	1	90.68	1.03	0.3293
Time × Transition × Type	144.09	1	144.09	1.64	0.2241
Time × Transition × Gender × Type	57.28	1	57.28	0.65	0.4347
Error	1052.47	12	87.71		
Time × Question	109.47	1	109.47	2.40	0.1477
Time × Question × Gender	79.96	1	79.96	1.75	0.2106
Time × Question × Type	74.13	1	74.13	1.62	0.2269
Time × Question × Gender × Type	17.66	1	17.66	0.39	0.5458
Error	548.44	12	45.70		
Transition × Question	31.03	1	31.03	0.66	0.4318
Transition × Question × Gender	142.81	1	142.81	3.05	0.1065
Transition × Question × Type	119.11	1	119.11	2.54	0.1370
Transition × Question × Gender × Type	129.74	1	129.74	2.77	0.1221
Error	562.70	12	46.89		
Time × Transition × Question	51.56	1	51.56	1.10	0.3145
Time × Transition × Question × Gender	77.27	1	77.27	1.65	0.2230
Time × Transition × Question × Type	43.08	1	43.08	0.92	0.3562
Time × Transition × Question × Gender × Type	0.66	1	0.66	0.01	0.9073
Error	561.47	12	46.79		

Table 28. Similarity rating task (Type × Trial).

Independent Variable	SS	df	MS	F	p
Type	0.060	1	0.060	1.20	0.2943
Error	0.640	12	0.050		
Trial (1)	0.200	1	0.200	14.78	0.0023
Trial (1) × Type	0.002	1	0.002	0.20	0.6628
Error	0.160	12	0.010		
Trial (2)	0.030	1	0.030	1.99	0.1836
Trial (2) × Type	0.001	1	0.001	0.07	0.7900
Error	0.200	12	0.020		
Trial (3)	0.003	1	0.003	0.31	0.5888
Trial (3) × Type	0.001	1	0.001	0.12	0.7344
Error	0.130	12	0.010		
Trial (4)	0.000	1	0.000	0.00	0.9736
Trial (4) × Type	0.000	1	0.000	0.08	0.7872
Error	0.050	12	0.004		
Trial	0.240	4	0.060	5.23	0.0123
Trial × Type	0.010	4	0.001	0.12	0.8894
Error	0.540	48	0.010		

Table 29. Similarity rating task (Type × Group Correlated).

Independent Variable	SS	df	MS	F	p
Type	0.080	1	0.080	1.64	0.2208
Error	0.710	14	0.050		
Group Correlated	0.002	1	0.002	1.13	0.3058
Group Correlated × Type	0.010	1	0.010	6.29	0.0251
Error	0.020	14	0.001		

APPENDIX S: ANOVA TABLES (FOR EXPERIMENT 2)

BASELINE DRIVING ANALYSIS

Table 30. ANOVA on standard deviation of speed.

Source	Sum of Squares	Degrees of Freedom	Mean square	F	Tail Probability
subject	30.10064	17	1.77063	2.62	0.0008
ATIS status	2.26765	2	1.13382	1.68	0.1901
route	27.41255	2	13.70627	20.25	0.0000
baseline	0.40623	2	0.20312	0.3	0.7411
scenario ordinal position	1.51806	2	0.75903	1.12	0.3280
ATIS status × route	2.93734	4	0.73434	1.09	0.3653
baseline × scenario ordinal position	2.88201	4	0.7205	1.06	0.3754
ERROR	123.1625	182	0.67672		

Table 31. ANOVA on rate of large steering reversals.

Source	Sum of Squares	Degrees of Freedom	Mean square	F	Tail Probability
subject	0.20849	17	0.01226	1.32	0.1821
ATIS status	0.01039	2	0.00519	0.56	0.5719
route	0.10866	2	0.05433	5.86	0.0034
baseline	0.0674	2	0.0337	3.64	0.0283
scenario ordinal position	0.01728	2	0.00864	0.93	0.3955
ATIS status × route	0.01885	4	0.00471	0.51	0.7296
baseline × scenario ordinal position	0.02264	4	0.00566	0.61	0.6554
ERROR	1.68678	182		0.00927	

Table 32. ANOVA on frequency of zero speed deviations.

Source	Sum of Squares	Degrees of Freedom	Mean square	F	Tail Probability
subject	7.62222	17	0.44837	3.89	0.0000
ATIS status	0.03333	2	0.01667	0.14	0.8655
route	7.56481	2	3.78241	32.81	0.0000
baseline	0.62037	2	0.31019	2.69	0.0705
scenario ordinal position	1.00185	2	0.50093	4.35	0.0143
ATIS status × route	1.1963	4	0.29907	2.59	0.038
baseline × scenario ordinal position	0.68519	4	0.1713	1.49	0.2082
ERROR	20.97963	182	0.11527		

CONTROL INPUTS ANALYSIS

Table 33. ANOVA on standard deviation of speed.

Source	Sum of Squares	Degrees of Freedom	Mean square	F	Tail Probability
subject	47.10169	17	2.77069	2.38	0.0161
input type	0.00653	1	0.00653	0.01	0.9408
subject × input type	14.72851	17	0.86638	0.74	0.7381
ERROR	38.45197	33	1.16521		
window	23.12326	2	11.56163	10.81	0.0001
window × subject	31.41036	34	0.92383	0.86	0.6741
window × input type	1.76605	2	0.88302	0.83	0.4424
window × subject × input type	16.89009	34	0.49677	0.46	0.9918
ERROR	70.57245	66	1.06928		

Table 34. ANOVA on rate of large steering reversals.

Source	Sum of Squares	Degrees of Freedom	Mean square	F	Tail Probability
subject	0.14977	17	0.00881	1.56	0.1347
type	0.12317	1	0.12317	21.77	0
subject × input type	0.0847	17	0.00498	0.88	0.5988
ERROR	0.18669	33	0.00566		
window	0.14353	2	0.07177	6.33	0.0031
window × subject	0.25892	34	0.00762	0.67	0.8966
window × input type	0.01199	2	0.006	0.53	0.5917
window × subject × input type	0.179	34	0.00526	0.46	0.9918
ERROR	0.74819	66	0.01134		

LANE EVENTS ANALYSIS

Table 35. ANOVA on time to lane crossing.

Source	Sum of Squares	Degrees of Freedom	Mean square	F	Tail Probability
event	38.07563	3	12.69188	6.79	0.0007
subject	93.9252	17	5.52501	2.96	0.0016
ATIS message	10.30484	1	10.30484	5.51	0.0231
ERROR	89.74345	48	1.86966		

Table 36. ANOVA on distance to the event at lane crossing.

Source	Sum of Squares	Degrees of Freedom	Mean square	F	Tail Probability
event	6811.562	3	2270.521	13.63	0
subject	8292.843	17	487.8143	2.93	0.0018
ATIS message	2207.097	1	2207.097	13.25	0.0007
ERROR	7996.639	48	166.5967		

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