Development of Human Factors Guidelines for Advanced Traveler Information Systems (ATIS) and Commercial Vehicle Operations (CVO): Display Formats and Commercial Vehicle Operator (CVO) Workload

PUBLICATION NO. FHWA-RD-96-152

SEPTEMBER 1997

U.S. **Department of Transportation**
Federal Highway Administration

Research, Development, and Technology
Turner-Fairbank Highway Research Center
6300 Georgetown Pike
McLean, VA 22101-2296

FOREWORD

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

This report documents a study that was performed to determine the effects of display modality, level of interaction, and amount of information on the driving performance and system operation performance of commercial drivers.

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Michael F. Trentacoste
Director, Office of Safety
Research and Development

NOTICE

Technical Report Documentation Page

1. Report No. FHWA-RD-96-152	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle DEVELOPMENT OF HUMAN FACTORS GUIDELINES FOR ADVANCED TRAVELER INFORMATION SYSTEMS (ATIS) AND COMMERCIAL VEHICLE OPERATIONS (CVO): DISPLAY FORMATS AND COMMERCIAL VEHICLE OPERATOR (CVO) WORKLOAD		5. Report Date September 22, 1997 6. Performing Organization Code
7. Author(s) Michael A. Mollenhauer, Thomas A. Dingus, Jonathan M. Hankey, Cher Carney, Vicki L. Neale		8. Performing Organization Report No.
9. Performing Organization Name and Address Center for Transportation Research Virginia Polytechnic Institute and State University 1700 Kraft Drive, Suite 2000 Blacksburg, VA 24061-0536		10. Work Unit No. (TRAIS) 3B4C 11. Contract or Grant No. DTFH61-92-C-00102
12. Sponsoring Agency Name and Address Office of Safety and Traffic Operations R&D Federal Highway Administration 6300 Georgetown Pike McLean, VA 22101-2296		13. Type of Report and Period Covered Final Report 14. Sponsoring Agency Code
15. Supplementary Notes Contracting Officer's Technical Representative (COTR) -M. Joseph Moyer, HRDS; Thomas M. Granda, HRDS (formerly with SAIC)		

16. Abstract

The objective of this study was to determine the effects of display modality, level of driver interaction, and amount of information on the driving performance and system operation performance of commercial drivers. Introducing any level of interaction with an ATIS will probably result in some level of increased workload for the driver. However, it is possible that the increase in workload would not result in unsafe driving behavior. A secondary objective of this study was to determine at what level of ATIS task demand driving performance begins to degrade to the point of becoming unsafe.

To test the impact of having commercial drivers operate a multi-function ATIS, a prototype display was developed that would provide a variety of tasks to be performed while driving. The prototype for this experiment consisted of baseline information that was always presented to the driver in addition to an underlying menu structure that allows the driver to perform more complex information retrieval functions. The baseline ATIS display used for both taxi and truck drivers was identical, while the underlying menu structures were different to reflect the different types of information the drivers might require or desire. The system was designed for use as a visual-only system or as a combination visual and auditory system. An auditory-only system was not tested because it was felt that any feasible system would include at least some visual elements.

Based upon the results of this research, guidelines have been developed to aid in the design of ATIS.

17. Key Words Advanced Traveler Information Systems, Commercial Vehicle Operations		18. Distribution Statement No restrictions. This document is available to the public through the National Technical Information Service, Springfield, VA 22161.	
19. Security Classif. (of this report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No. of Pages 114	22. Price

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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yards	0.836	square meters	m^2
ac	acres	0.405	hectares	**ha**
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3

NOTE: Volumes greater than 1000 l shall be shown in m^3

Symbol	When You Know	Multiply By	To Find	Symbol
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or “metric ton”)	Mg (or "t")
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5(F-32)/9 or (F-32)/1.8	Celcius temperature	°C
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS TO SI UNITS

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

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

(Revised September 1993)

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LIST OF ABBREVIATIONS

ANOVA	Analysis of Variance
ATIS	Advanced Traveler Information System
AVI	Automatic Vehicle Identification
CVO	Commercial Vehicle Operator
FHWA	Federal Highway Administration
IDS	Iowa Driving Simulator
IMSIS	In-vehicle Motorist Services Information Systems
IRANS	In-vehicle Routing and Navigation Systems
ISIS	In-vehicle Signing and Information Systems
ITS	Intelligent Transportation Systems
MANOVA	Multivariate Analysis of Variance
SWAT	Subjective Workload Assessment Technique

EXECUTIVE SUMMARY

The future of Commercial Vehicle Operators (CVO) will likely include an increase in the already burgeoning implementation of emerging Intelligent Transportation Systems (ITS) technologies as in-vehicle systems. One of these systems is the Advanced Traveler Information System (ATIS). The result of providing robust functionality within an ATIS is that commercial vehicle operators will probably either desire or be required to operate them while driving their vehicles to improve efficiency. These systems will provide additional features and functions that promise to improve productivity and safety, but they may also increase workload while the driver is engaged in the task of driving. As a whole, CVOs often tend to be more experienced drivers and are formally trained in how to operate their equipment, but there is considerable variance in skill depending on the type of commercial vehicle driver being considered. However, it is not known to what extent experience and training will benefit CVOs with the task of operating an in-vehicle system while driving.

There are many different types and categories of CVOs that could benefit from using ATIS technologies. From an experimental design point of view, it was not feasible to include drivers from all possible categories of commercial driver. Instead, two groups were chosen that represent the wide variation in training and types of equipment. These two groups were over-the-road truck drivers and taxi drivers. The truck drivers are typically more formally trained and operate larger, more complex equipment. Taxi drivers are typically not formally trained and operate equipment that is comparable to standard passenger vehicles. Ten drivers from each group were recruited to complete this experiment.

The objective of this study was to determine the effects of display modality, level of interaction, and amount of information on the driving performance and system operation performance of commercial drivers. Introducing any level of interaction with an ATIS will probably result in some level of increased workload for the driver. However, it is possible that the increase in workload would not result in unsafe driving behavior. A secondary objective of this study was to determine at what level of ATIS task demand driving performance begins to degrade to the point of becoming unsafe.

To test the impact of having commercial drivers operate a multi-function ATIS, a prototype was developed that would provide a variety of tasks to be performed while driving. The prototype for this experiment consisted of baseline information that was always presented to the driver in addition to an underlying menu structure that allows the driver to perform more complex information retrieval functions. The baseline ATIS display used for both taxi and truck drivers was identical, while the underlying menu structures were different to reflect the different types of information the drivers might require or desire. The system was designed for use as a visual-only system or as a combination visual and auditory system. An auditory-only system was not tested because it was felt that any feasible system would include at least some visual elements.

The University of Iowa's Iowa Driving Simulator (IDS) was used to provide a high fidelity driving environment to test the drivers while collecting a variety of data. Objective measures of driving performance, subjective workload measures, ATIS task performance measures, eye glance behavior, and subjective questionnaire responses were collected and analyzed.

The experimental design used to compare ATIS configurations in this study was a 2 x 4 completely within-subjects factorial design manipulating the sensory mode of display (visual only, combination visual and auditory) and ATIS task difficulty (low, medium, high, super high). The task levels varied in the number of interactions required and the amount of visual information presented on the display screen. Comparisons were also made with a baseline task level to determine differences between normal driving and driving while operating the ATIS prototype. No direct comparisons were made between the truck and taxi drivers because the systems used to test each group were different, and there appears to be no clear benefit to making comparisons between driver groups. The results were analyzed and discussed as two separate sections of this report.

Overall, truck drivers appear to be relatively good at self-regulation when it comes to dividing their attention between obtaining information from the system and controlling the vehicle. As hypothesized, the introduction of any ATIS task resulted in an increase in driver workload beyond the baseline driving level, as indicated by the driver performance measures. It is also possible to increase task demands to a point where driving performance declines significantly. This point seems to lie somewhere between the high and super high task levels, which are differentiated by the number of interactions required. The lack of apparent differences between the medium and high task levels, especially in eye glance behavior, provides additional evidence that the number of interactions has a greater potential to increase workload than the amount of information being presented. The amount of information on the display was doubled between these conditions, yet no differences were shown between the frequency or duration of glances between these or any other performance measures collected in this experiment. The super high task level, however, almost always resulted in differences, indicating a substantial increase in driver workload.

There was a very small performance difference shown between the visual-only and combination auditory and visual systems. No statistical differences were found between sensory modes for the eye glance data or the subjective workload data. There were also no statistical differences found between the visual-only and combination auditory and visual displays in the subjective responses that were collected through the questionnaire. The lack of benefits shown by adding the auditory information to the display could be due to a lack of a performance advantage for this population for CVO types of tasks.

For the taxi drivers, a trend emerged that seemed to exist among many of the performance variables collected for this experiment. There was a natural division in performance between the low and medium task levels. The baseline and low task levels resulted in values that would indicate that the driver was experiencing less workload than those found for the medium, high, and super high task levels. This was true of several variables found to be significant, including standard deviations of steering wheel position and lane position, and the number of glances per task. The characteristic difference between the task level divisions in performance that occurred was manual interaction with the system to obtain the desired data from the system. In the medium, high, and super high task levels, the driver was required to make menu choices by pushing buttons on the steering wheel to obtain the desired information from the system. There were no differences in the amount of information being presented on the display between the low and medium task levels. Therefore, it appears that the interaction with the system, rather than the amount of information on the display, had the greatest effect on the driving performance variables.

These results would seem to indicate that the taxi drivers showed increases in workload when they were required to interact with the system. Still, this increase did not seem to depend on the number of interactions or button presses required, as supported by the lack of differences between the medium, high, and super high task levels.

A significant difference between the results for the visual-only and combination auditory and visual conditions was found for the number of lane deviations per task. For this measure, it appears that there was some benefit shown by adding the auditory component to the display.

The results of this experiment suggest that impacts of applying ATIS technologies to taxi drivers may warrant additional consideration. This research indicates that any interaction with an ATIS resulted in an increase in driver workload. What is not known is how much this increase might affect driving safety. It is possible that the increase in workload may not decrease driving safety. More research is necessary to make a determination of the amount of interaction that should be allowed while driving.

Based upon the results of this research, guidelines have been developed to aid in the design of ATIS. The following guidelines have been developed for ATIS that will be operated specifically by commercial truck drivers:

- It is possible to overload truck drivers as they interact with the system while driving. Minimize the level of interaction required by the system while driving by keeping the number of control manipulations to a minimum (less than four). The number of control activations has a greater effect on driver performance than the amount of information presented on the display.

- If the number of control activations is kept to a minimum (i.e., less than four, as with the medium and high task loads), there are no apparent benefits with the addition of a redundant auditory cue providing confirmation of option selection.

- For truck drivers, navigation and vehicle condition information is considered more useful than warning and road sign information presented by an ATIS while driving.

The following set of guidelines has been developed for ATIS that will be operated specifically by taxi drivers:

- For taxi drivers and other drivers with minimal training, minimize the amount of interaction required by an ATIS if the interaction is time-dependent. Drivers in this experiment were more comfortable delaying control activations until they felt it was safe to do so.
- The ATIS should be designed to supply navigation and general communication information first. The taxi drivers that participated in this experiment rated the

navigation and general communication information more useful and were also willing to pay more money for it.

CHAPTER 1: INTRODUCTION

Vehicles driven by CVOs include any motor vehicle of public or private ownership, regularly used to carry freight and passengers, used in commerce, or used to provide emergency response. In general, ITS technologies are emerging as the key tools that CVOs have available to reduce costs and improve productivity. New ITS technologies are making faster dispatching, fuel-efficient routing, and more timely pick-ups and deliveries possible. These ITS technologies will also have an impact on safety. Devices such as blind-side and near-obstacle detection systems can make highways safer and more productive. The functional areas being addressed strive to achieve three basic goals: (1) improved productivity; (2) improved efficiency and effectiveness of traffic management and administration by transit agencies and state and local governments; and (3) improved safety for CVOs and others affected by them.

CVO research conducted to date focuses on three key technologies: (1) Automatic Vehicle Identification (AVI), (2) displays, and (3) communications. In general, as with automotive aspects of ATIS, CVO literature to date primarily includes planning and feasibility evaluations of proposed systems or projects. Displays are a major focus in CVO assessment papers. A general assumption is that any in-cab device diverts valuable attention from the road and should be accepted with critical consideration of the safety impact. An internal memo from the Federal Highway Administration (FHWA) summarizes the weakening of the 1952 Federal Motor Carrier Safety Regulations on the location of a video display terminal in the cab. These regulatory findings bode well for future use of in-cab displays. Another study inventoried more than 50 supplemental in-cab devices (Burger, Smith, and Ziedman, 1989) in which six categories of systems were discussed:

1. Single/integrated displays.
2. Vehicle information.
3. Vehicle navigation.
4. Vehicle positioning.
5. Text communication.
6. Vehicle safety.

Burger et al. (1989) estimate that a broad proliferation of these devices could pose a significant safety problem. Plans to model current truck driver workload are presented as key to the safety evaluation of future systems. The same considerations must also be made when attempting to apply these same technologies to other CVO applications, such as taxi drivers, where there is typically less driving experience, training, and regulation than with the truck driver population.

DRIVER ATTENTION

The driving task does not require a constant level of attention demand since some driving conditions require more attention than others (Mourant and Rockwell, 1970). For example, two-lane streets require more attention than interstates; curved roads require more attention than straight roads; heavy traffic requires more attention than light traffic (Hulse and Dingus, 1989). Dingus and Hulse (1993) hypothesized that when the difficulty of the composite driving task exceeds the resources of the driver, no amount of expended effort will keep performance constant. At this point of overload, performance in driving (and ATIS-related tasks) begins to decline. Thus, it is important to keep driver attention below the point of overload.

The majority of the systems under development (or planned for the future) will be demanding enough to warrant the designation of tasks to be performed by the driver as “pre-drive” and “in-transit.” “Pre-drive” consists of the complex planning and attention-demanding tasks. “In-transit” consists of a relatively small subset of tasks that are necessary for efficient system usage while the vehicle is in motion (Lunenfeld, 1990). Such a delineation is necessary due to the attention and information processing constraints present in the driving environment.

The in-transit functions should be limited based on the value, necessity, and convenience associated with the function. For example, the only functions that are required for navigation while the vehicle is in motion are those associated with point-by-point decisions while traveling from a current location to a destination. Proper selection and design of in-transit functions can allow successful navigation to destinations without substantial driving task interference (Dingus and Hulse, 1993).

Another argument for minimizing in-transit information is the problem of “out-of-the-loop” loss of familiarity (Dingus and Hulse, 1993). Presently, the driver is required to obtain most information from the outside driving environment (e.g., street signs and stop lights). The more information readily accessible within the vehicle, the less likely the driver will obtain the same information from the driving environment. Thus, any problem, deficiency, or inconsistency that requires the driver to shift attention to the driving environment will potentially result in a delay and increased effort since the driver will have become accustomed to having the information provided within the vehicle. Thus, there is a tradeoff: the more powerful and informative the system, the more the driver will rely on it to provide information rather than search the driving environment for the information it provides (Dingus and Hulse, 1993).

Changing the scheme of tasks a driver must perform often leads to speculation about the resulting impact on driving performance and safety. It is important not to overload the driver at critical times during the driving task (Perel, Brewer, and Allen, 1990; Smiley, 1989; Walker, Alicandri, Sedney, and Roberts, 1990). Walker et al. (1990) reported that subjects using complex navigation devices drove more slowly than those using less complex devices. These effects were also more prevalent in older drivers (55 years and older) than in younger drivers. If the driver is traveling at a faster speed or on a more complex road (i.e., more curves), shorter viewing time of any display will be required as compared with traveling at a slower speed or on less complex turns (Senders, Kristofferson, Levison, Dietrich, and Ward, 1967). Dingus, Antin, Hulse, and Wierwille (1989), Plude and Hoyer (1985), and Madden (1990) also report that driving attention demands for older drivers are increased due to decreased capacity.

To limit attention demands, Smiley (1989) recommended that signs outside the vehicle should contain no more than six key words if the content is to be remembered. Dingus et al. (1989) recommended that in-vehicle systems increase the proportion of time that critical information is available on a visual display and limit information that is not needed at a given point in time.

The ability to convey information to the user is important in the development of ITS. Incorrect display formats, styles, and colors can make the system all but unusable to the drivers. Studies have shown that certain types of warning symbols, signing material choices, and lighting conditions affect the user's perception of the importance of display information (Zwahlen, 1988; Zwahlen, Hu, Sunkara, and Duffus, 1991).

Visual attention is particularly important to assess in driving since most information is gathered visually by the driver (Rockwell, 1972). Despite the almost sole reliance of driving on the visual modality, between 30 percent and 50 percent of visual attention, in most circumstances, may be devoted to tasks other than driving (Hughes and Cole, 1986). It is the availability of this spare resource that makes the inclusion of in-transit visual display information feasible. Designers must make displayed information usable to drivers even under extenuating circumstances, since the visual attention required by the driving task can change drastically at any given time (e.g., including a curve, the presence of traffic, or a change in type of roadway) (Dingus and Hulse, 1993). Therefore, displayed information must be usable under the most demanding circumstances. A visual display that requires frequent and lengthy glances may prevent adequate monitoring of the driving environment. In fact, research has shown that deviation from the roadway lane center increases with longer eyes-off-the-road time (Zwahlen and DeBald, 1986).

It appears that the presentation of auditory navigation information is superior to visual presentation of information in many circumstances. A major advantage of auditory presentation is efficient allocation of information processing resources. Allocating supplemental tasks to the auditory modality (particularly in situations of high visual attentional demand) has the potential for making the composite task of driving easier and safer (Dingus and Hulse, 1993).

Another demand on attention resources is cognitive attention. The driver may be concentrating on one thing while his/her eyes are directed toward something totally unrelated (Cohen, 1971). For example, the driver could be daydreaming, listening to the radio, or attending to an auditory display and not attending to the road. Therefore, if navigation information is presented to the driver aurally, it will require cognitive attention even though the driver's eyes are on the road.

DRIVER WORKLOAD

Workload is a complex, multivariate construct that is an important consideration for ATIS. As stated by Kantowitz (1992), the practical benefit of measuring driver workload is a means to assess safety. Workload overload will result in unsafe circumstances. Since safety cannot be proactively and directly measured in driving (i.e., without installing a system and measuring accidents), human factors professionals must rely on indirect measures such as workload assessment. Kantowitz (1992) discusses the application of workload techniques traditionally used for aircraft applications to driving heavy vehicles. A summary of existing driving workload research can be found in a report by Smiley (1989). According to Smiley, systems could be designed to automatically avoid overload. For example, if the cellular phone is in use, then the map details are reduced on a navigation display. Workload can also be reduced by programming the system's "smart cards" to determine user characteristics such as reaction time, age, experience, and so on. In this way, a support system could be tuned to the particular needs of each driver. Information should also be prioritized within the system to match the environment. For example, map information could be reduced when the driver is actually driving through an intersection. This allows the driver to devote full attention to the road at the appropriate time and not to the display.

An experiment conducted by Noy (1989) used the secondary task method of workload measurement to determine what effects added tasks and task complexity have on driving performance. This study showed that as visual tasks in automobiles increase, headway and speed control suffer and lane deviation increases. Each of these elements cannot be compromised, since the safety costs are too great. Therefore, Noy recommended that workload testing be conducted before allowing systems to be produced and used by the general public. A tool being developed in Japan may aid in the ease of this testing. Atsumi, Sugiura, and Kimura (1992) have developed a method of workload testing based upon heart rate analysis.

PURPOSE OF STUDY

Drivers of commercial vehicles often have a higher workload level than the everyday driver. Besides being used to get from one point to another, the vehicle often doubles as the driver's office in the case of trucks, buses, limousines, and taxis. In addition to the task of operating the vehicle, commercial drivers must attend to and derive information from various sources (e.g., the dispatcher, various gauges concerning the operation of the vehicle, and other commercial vehicles). Commercial vehicles must also supply information on items such as vehicle identification, weight of the vehicle, cargo, and present location, to name a few. With the introduction of ATIS, much of this information presentation can be automated for the driver. This automation can reduce some of the operator workload for tasks currently performed by CVOs (e.g., less paper work for truck drivers). While ATIS will provide additional features and functions that promise to improve productivity and safety, it may also increase workload while the driver is engaged in the task of driving. Driver workload will most likely vary by the methods with which the information is presented to the driver, in addition to the amount of information presented or control provided. Since many operations must be completed while driving the vehicle, it is necessary to investigate methods for presenting information to the driver that will not increase workload to dangerous levels.

Because commercial drivers operate vehicles for their occupation, they are typically more experienced and in some cases are more trained than the average driver on the road. It has been hypothesized that because of this additional experience and training, commercial drivers will be better able to cope with the additional workload that may be present while interacting with ATIS. To help define the impacts of increasing workload on commercial drivers, it is necessary to evaluate their driving and ATIS task performance across varying levels of interaction. To define where performance begins to seriously deteriorate, it will be necessary to study drivers over a range of task difficulties from a nominal or baseline level up to driver overload.

OBJECTIVES OF STUDY

The objective of this study is to determine the effects of display modality, level of interaction, and amount of information being presented on driving performance and ATIS task performance for commercial drivers. Introducing any level of interaction with an ATIS will probably result in some level of increased workload for the driver. However, it may be possible that the increase in workload will not result in dangerous driving behavior. A secondary objective of this study is to determine at what level of ATIS task demand driving performance begins to degrade to the point of lowering attention to the primary task of driving.

RESEARCH HYPOTHESES

The ATIS that was designed for this experiment is an example of the type of systems that may be used by commercial drivers in the future. It contains elements of information from in-vehicle routing and navigation systems (IRANS), in-vehicle signing and information systems (ISIS), in-vehicle motorist services information systems (IMSIS), and CVO systems. The information elements from the individual systems were integrated into a single prototype display. This study uses the integrated ATIS to determine the effects of varying display modality and ATIS task complexity on commercial driving performance. There are several hypotheses about how commercial drivers will perform while using the ATIS prototype. These hypotheses are as follows:

- Commercial drivers will experience a reduction in driving performance as the ATIS task demands are increased.

- Commercial drivers will experience less reduction in driving performance when using the ATIS prototype that uses a combination of auditory and visual displays as opposed to a system that uses visual displays only.

- Commercial drivers will experience a reduction in ATIS task performance as the ATIS task demands are increased.

- Commercial drivers will experience less mental workload while driving with a system that uses a combination of auditory and visual displays as opposed to a system that uses visual displays only.

CHAPTER 2: METHOD

A total of 20 subjects participated in this experiment. One-half of the subjects were long-haul truck drivers and the other half were taxi drivers. Two separate ATIS prototypes were developed for testing because the normal operating tasks are different for truck and taxi drivers. Each respective prototype contained information that might be useful while performing normal day-to-day operations as a truck or taxi driver.

All of the subjects who participated in this experiment were between 25 and 55 years of age. The mean age for the truck drivers was 34 and the mean age for the taxi drivers was 36. This age range was chosen because it is representative of the actual population of commercial drivers within each category.

Of the 10 truck drivers used in this experiment, 9 were male and 1 was female. Typically, attempts are made to balance the subjects by gender; however, in the case of truck drivers, the majority of active truck drivers are men, and recruiting limitations dictated that we use a male-biased population of subjects. The taxi drivers were more closely balanced but still contained a slight male gender bias -- six of the subjects were male and four were female.

DESCRIPTION OF ATIS PROTOTYPES

The commercial vehicle ATIS prototypes developed for this experiment consist of a base display of information that was always presented to the driver, in addition to an underlying menu structure that allows the driver to perform more complex information retrieval functions. The base ATIS displays for both taxi and truck drivers were identical, while the underlying menu structures were different for the two categories of drivers.

Base Display

The base ATIS display consisted of several elements, including a digital speedometer, navigation information, and road sign information. A diagram of the display contents is shown in figure 1. The speedometer is shown in the lower left portion of the display and is presented at all times. There are two positions at the right of the display space to display road sign information. Road sign information was typically displayed as an iconic representation of the standard sign as defined by the Manual of Uniform Traffic Control Devices. The current speed limit was displayed continuously in the lower right hand corner of the display. Other types of signs, such as “No Passing Zone,” were presented while the information was valid in the upper right hand corner of the display.

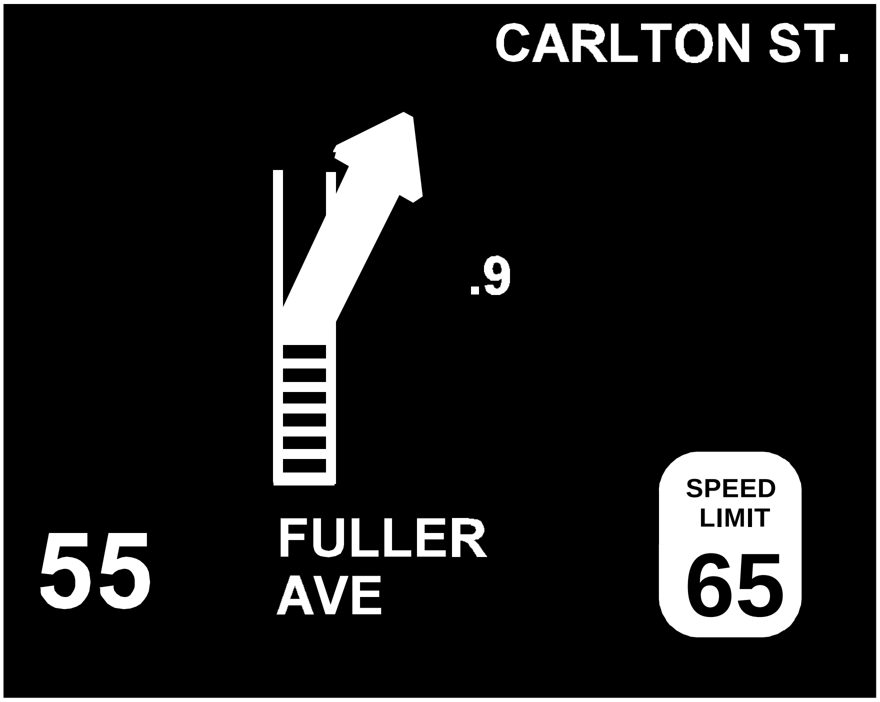

Figure 1. Base ATIS prototype display.

The center portion of the display was used to present navigation information. The navigation information consisted of a typical turn-by-turn instruction, including the name of the current street, the name of the next street on which to turn, an iconic representation of the intersection, an arrow indicating the direction of turn, and a digital counter of the distance to the turn in miles. It should be noted that subjects were never required to program the device for any particular destination. The subjects were told that the system had already been programmed with the desired destination and they were to just follow the displayed instructions.

The base portion of the display was presented continuously as long as the subject was not using the underlying menu structure to query information from the system. Subjects were required to make use of the interactive menu system to answer periodic questions from the experimenter. The menu system portion of the display would become active as soon as any one of four buttons located on the steering wheel spokes was pressed. The display feedback associated with the menu structure would then supersede the base display of information. An example of a menu screen is shown in figure 2.

Figure 2. Example of an ATIS prototype menu screen.

Once the menuing system was activated, the driver could navigate from screen to screen by making a button press that coincided with the displayed options. The button layout on the steering wheel is shown in figure 3. In this system, the options were displayed in the four corners of the display. To make a menu selection, the subject would press the appropriate button that coincided with the corner of the display where the option was located. Through successive button presses, the subject was able to navigate to a desired piece of information, report it to the experimenter, then return back to the base display again. The menu structures that were developed for the truck and taxi drivers were different in terms of the types of information they contained, but were similar in depth, breadth, and complexity.

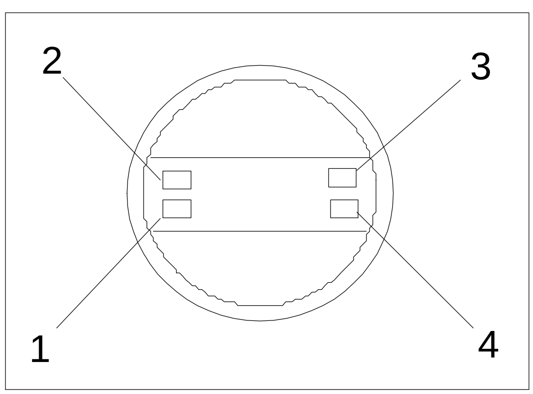

Figure 3. Steering wheel controls.

The Truck ATIS Menu System

The menu structure that was used for the truck drivers is shown in figures 4, 5, and 6. The menu system contained elements of information that are specific to the tasks that a truck driver must complete during day-to-day operations. These tasks include items such as monitoring the various vehicle equipment systems, communicating with dispatch, managing legal documentation (e.g., permits), and maintaining logbook records of driving activity.

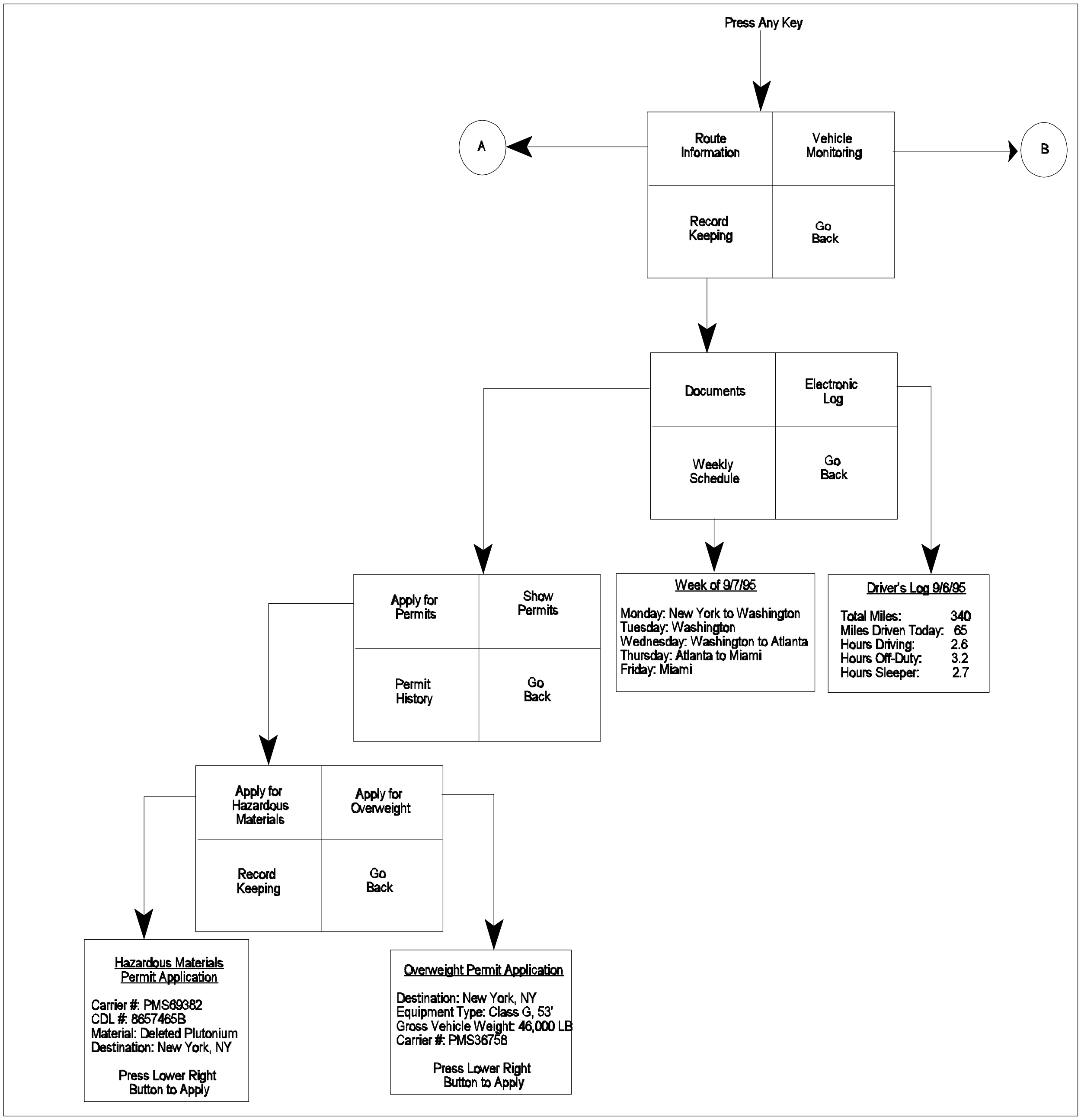

Figure 4. Schematic of ATIS prototype menu system for truck drivers.

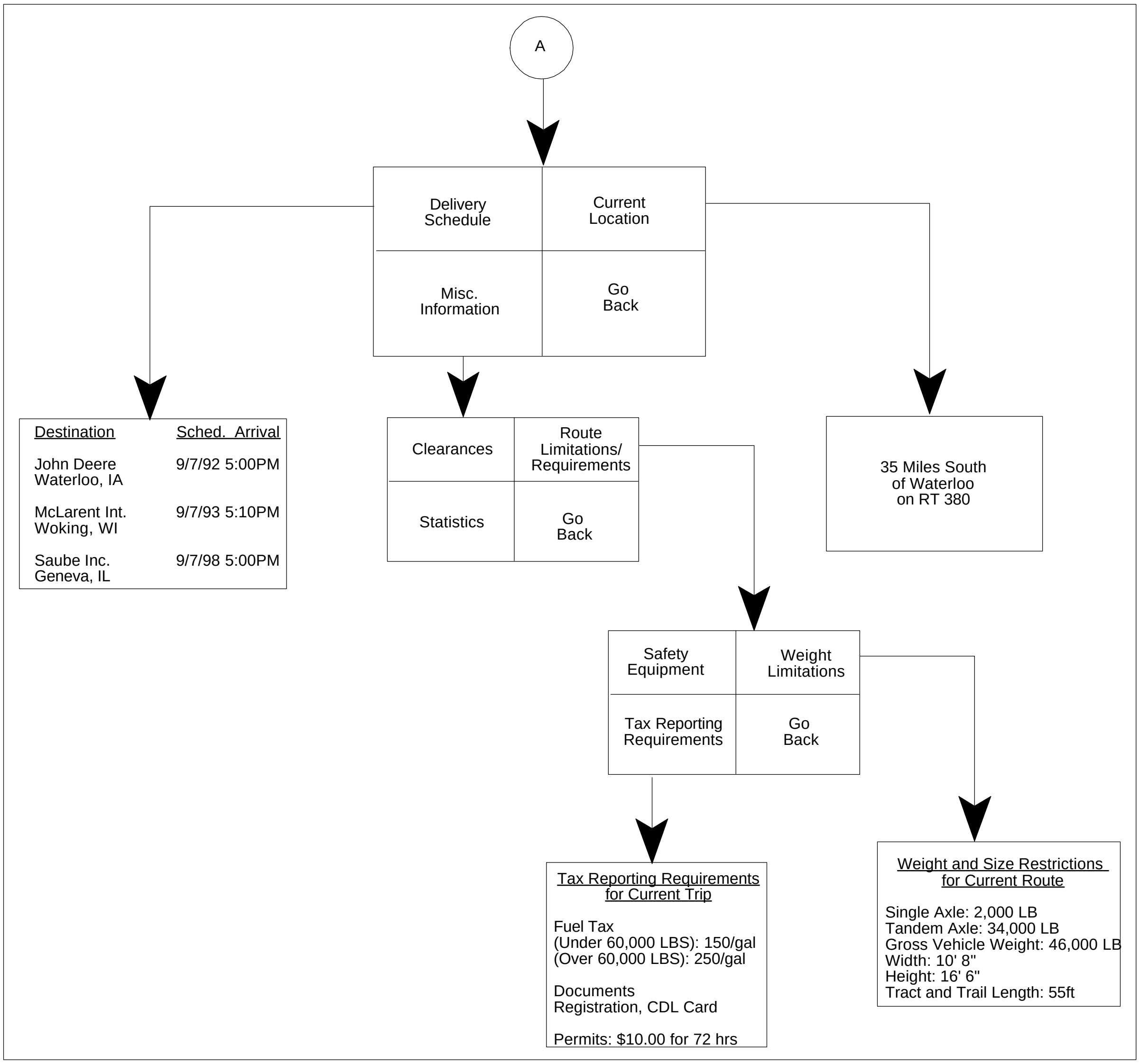

Figure 5. Schematic of ATIS prototype menu system for truck drivers (continued).

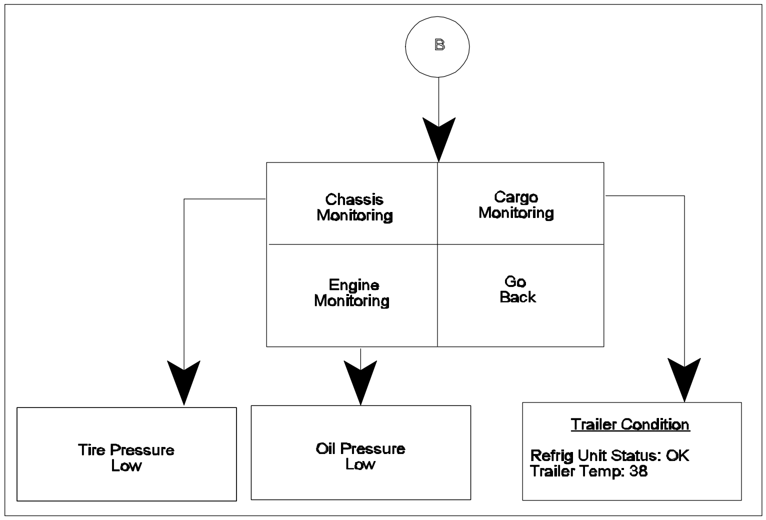

Figure 6. Schematic of ATIS prototype menu system for truck drivers (continued).

The Taxi ATIS Menu System

The menu structure that was used for the taxi drivers is shown in figures 7, 8, and 9. This menu system contains information pertaining to the day-to-day tasks that taxi drivers must perform. These tasks include communicating with dispatch, managing a cash flow, providing information about local attractions and services, and record keeping.

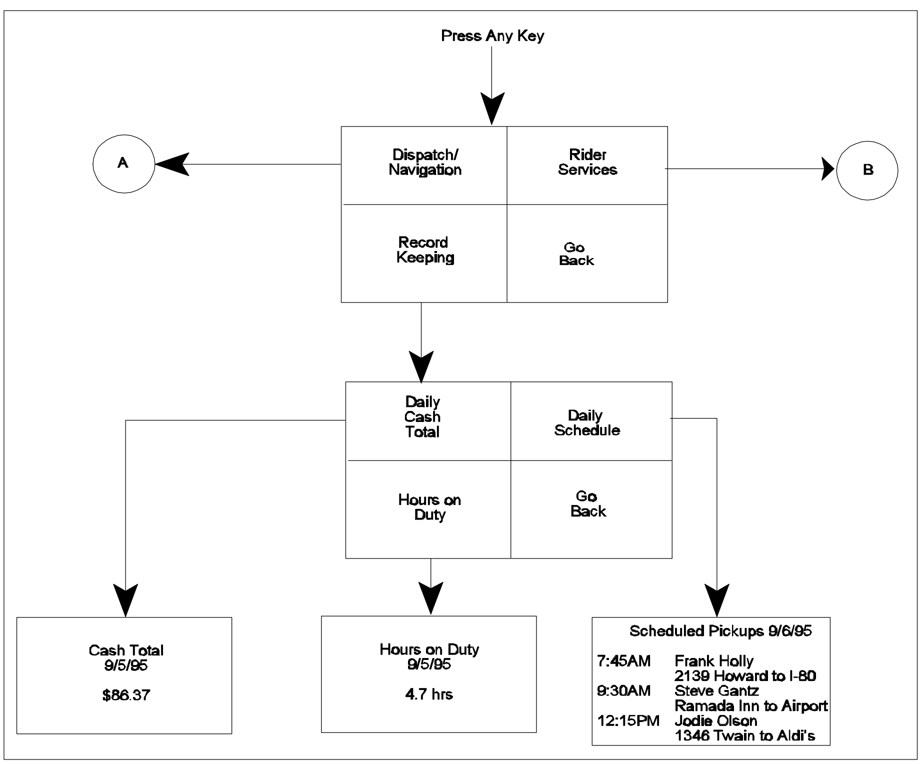

Figure 7. Schematic of ATIS prototype menu system for taxi drivers.

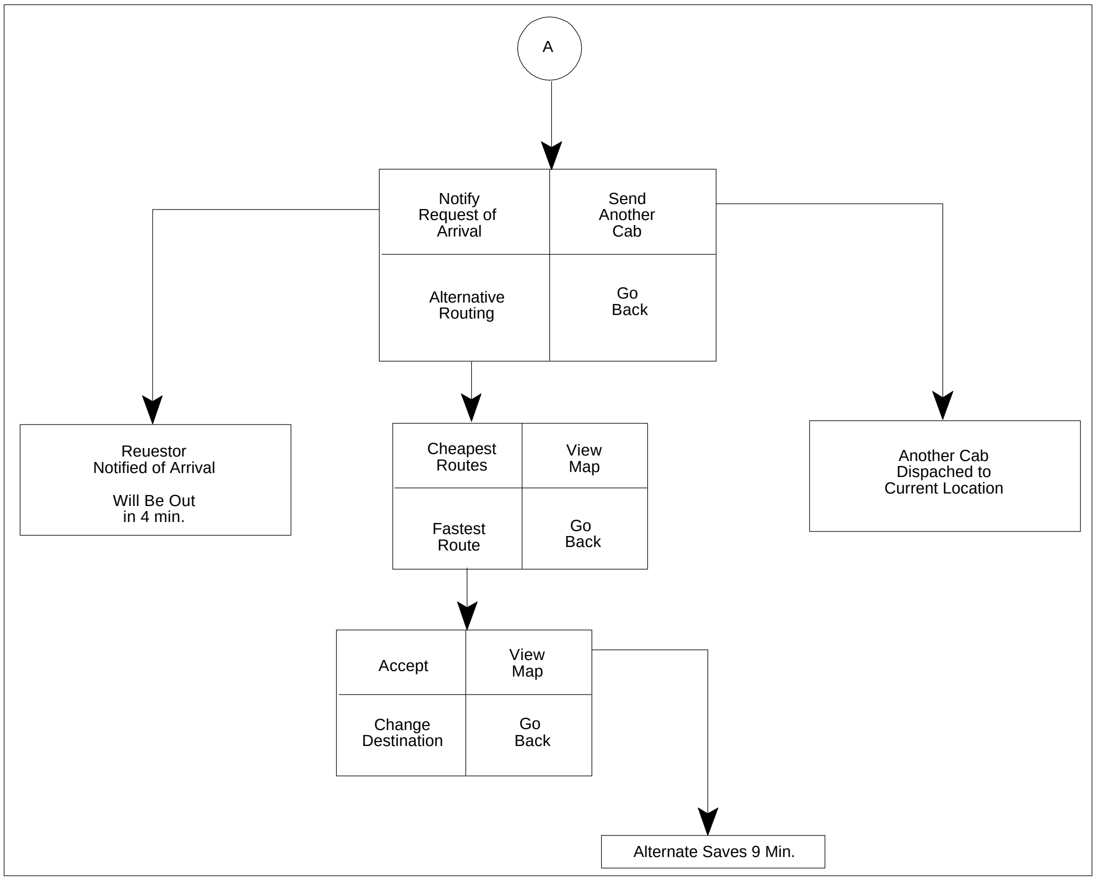

Figure 8. Schematic of ATIS prototype menu system for taxi drivers (continued).

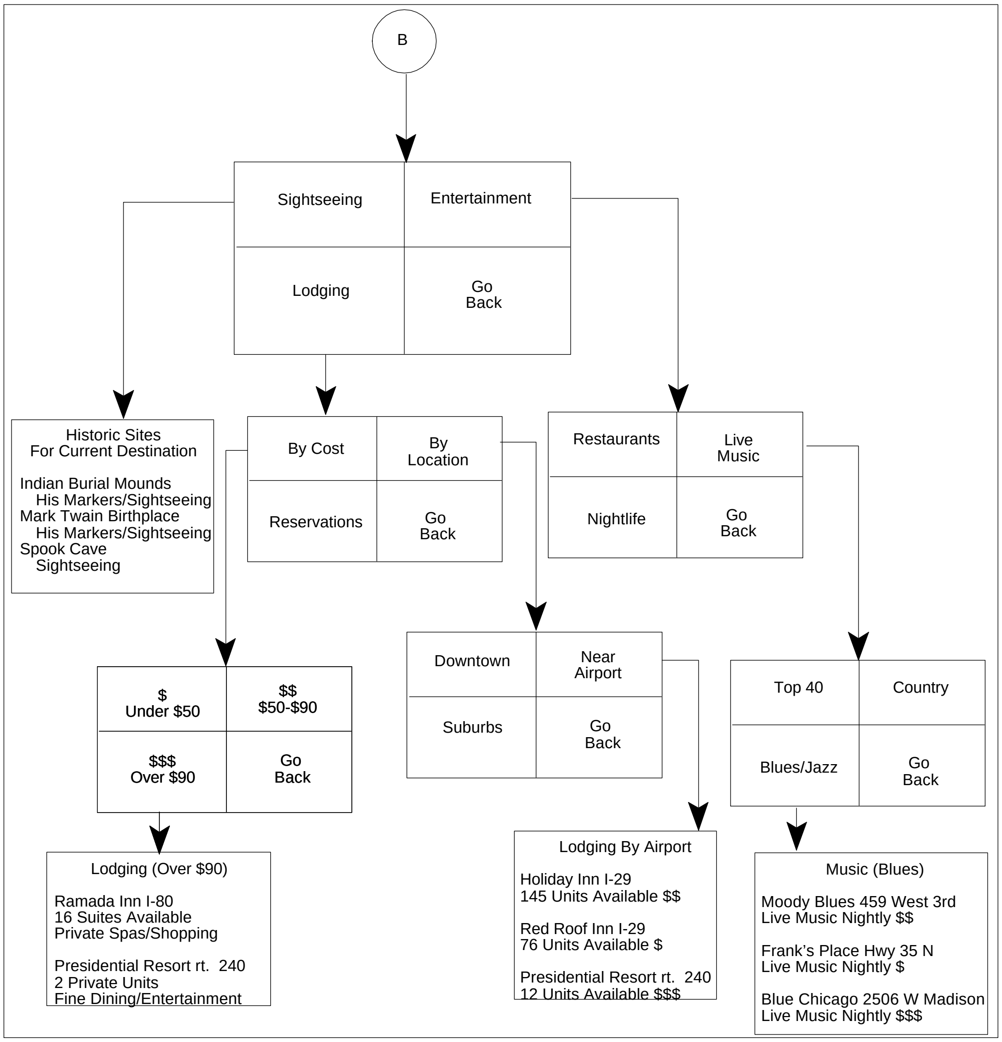

Figure 9. Schematic of ATIS prototype menu system for taxi drivers (continued).

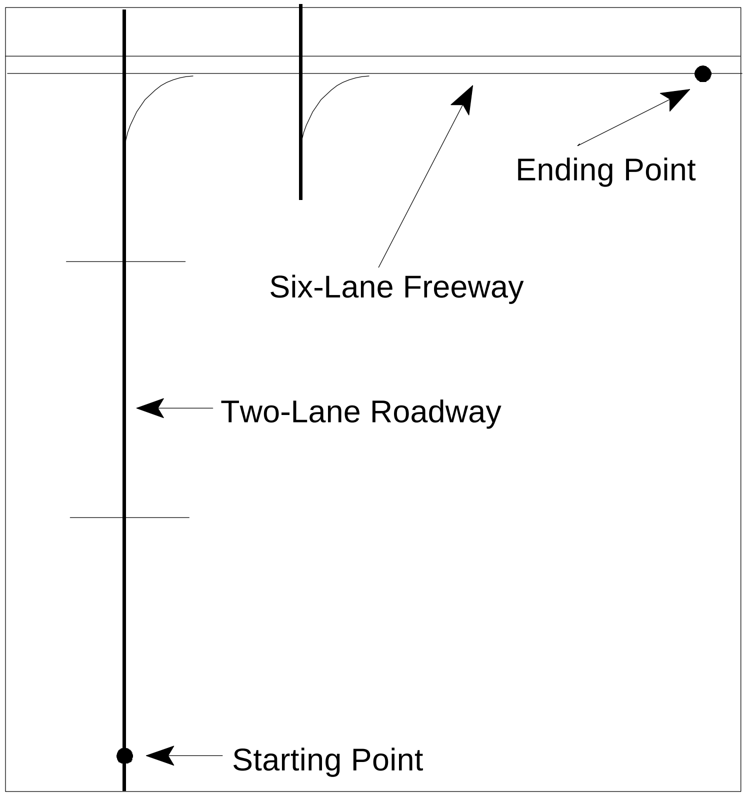

Figure 10. Simulated driving scenario.

DESCRIPTIONS OF DRIVING SCENARIOS

The driving scenario used for this experiment included two segments of straight roadway. The first segment of roadway consisted of approximately 10 miles of two-lane rural highway with random traffic that approached the subject in the opposite lane. The posted speed limit on the first segment of driving was 55 miles per hour.

The second segment of roadway consisted of approximately 15 miles of six-lane freeway with random traffic in all lanes that moved at or just above the posted speed limit of 65 miles per hour. The subject entered the freeway via an off-ramp that connected the two segments of roadway together. A diagram of the driving scenario is shown in figure 10. The traffic that was present was programmed to follow the rules of the road and not interfere with the subject's driving during the experiment.

The combined sections of roadway were divided into eight segments of equal length, four on the two-lane roadway and four on the six-lane freeway. The eight segments of equal length were used to define areas for task initiation and task completion. Subjects were asked to drive through the entire 25 miles of roadway twice during the experiment.

RESEARCH DESIGN

Two separate types of commercial vehicle drivers were used in this experiment to determine the effects of ATIS on workload. One group consisted of long-haul truck drivers and the other consisted of taxi drivers. The different types of activities that these two types of drivers perform during their day-to-day operations dictated that two unique systems would have to be developed for testing that would be specific to each driver type. In other words, the job descriptions were different enough that it would have made little sense to create one system that could be used to test both types of drivers. Therefore, even though the individual systems were developed under the same criteria for complexity, depth, and breadth, direct comparisons were not made between these groups. Furthermore, if it were possible to make direct comparisons between driver types, the knowledge gained from such comparisons could not be used to help create safer or more usable systems for commercial drivers.

The experimental design decisions described in the previous paragraph resulted in the study being conducted as if it were two separate experiments. All elements of the study, such as training, experimental design, driving scenario, and data collection, were identical between the experiments, but the ATIS that the subjects used was different. The data collected for each driver type is analyzed and reported separately in the "Results" section of this report.

The experimental design used to compare differences in workload between ATIS configurations in this study was a 2 x 4 completely within-subjects factorial design manipulating the sensory mode of display (visual only, combination visual and auditory) and ATIS task difficulty (low, medium, high, super high). Since there is no baseline condition that contains an auditory display element, it is impossible to make statistical comparisons across the sensory mode of display. Nonetheless, for some of the variables, such as driving performance variables, it made sense to compare the data collected while driving with the ATIS to that collected under baseline driving conditions. Therefore, the design used for these comparisons was a within-subjects design where ATIS task difficulty (baseline, low, medium, high, super high) was manipulated for each subject. In other words, if differences existed between the sensory mode of display (either a main effect or interaction), the data were partitioned by sensory mode of display and compared separately to the baseline data; however, if no differences existed due to sensory mode of display, the data were collapsed across the sensory mode of display and comparisons were made between baseline driving and driving under various levels of ATIS task difficulty. The importance of this comparison is to determine how much drivers are affected by the ATIS at each level of task difficulty as compared with normal driving.

The driving scenario was divided into eight segments of equal length. During the experiment, drivers were required to perform two ATIS tasks of the same difficulty level (two lows, two mediums, two highs, etc.) during each of the eight driving segments. The order of presentation was counterbalanced such that some subjects would perform low difficulty tasks first, some would perform medium tasks first, some would perform high tasks first, and so on. The order of presentation was varied to remove the possibility that practice effects might systematically affect the data collected under each ATIS task difficulty condition. The ATIS tasks were designed without reference to specific geographical features in the simulation so that they could be rearranged easily to create the different presentation orders. A sufficient number of unique tasks were created so that the subject would never encounter the same task twice during the experiment.

Subjects actually drove through the simulation scenario two separate times during the experiment. One of the drives would be with a visual-only ATIS display and the other with a combination auditory and visual ATIS display. Again, the order with which the subjects were presented with the individual sensory mode displays was counterbalanced such that half drove with the visual-only display first and the other half drove with the combination auditory and visual display first.

In between the two drives where subjects used the ATIS displays, they performed a 5-minute baseline drive. During the baseline drive, the ATIS display was powered down and the normal instrument panel was uncovered so that the standard analog dash instruments were available. Subjects were not required to perform any additional tasks beyond normal driving during the baseline drive.

Independent Variables

ATIS Task Difficulty

Subjects were periodically asked to use the ATIS to locate a specific piece of information that it contained. To accomplish this, the subject would have to manipulate the buttons on the steering wheel and navigate through the menu structure to locate the information. Once the information was found, it was to be verbally reported to the experimenter and then the subject would return to the normal driving display. Subjects would perform this task twice during each of the eight segments of the drive, for two complete drives. The menu structure is defined in detail in the "Description of ATIS Prototypes" section of this report.

The ATIS tasks were classified in terms of their difficulty as either low, medium, high, or super high (see table 1). A baseline task level was also included in the design to allow for comparisons among driving performances while using the ATIS prototype and normal driving. The classifications were based on two dimensions of interaction with the system. The first dimension was the amount of information to be presented on the display. A unit of information was defined as any portion of the display that had unique meaning. The displays were all designed as textual screens of information; therefore, a unit of information was a word or group of words that had a unique meaning. The amount of information was determined by the content of the screen containing the unique piece of information that the subject needed to report to complete the task. The second dimension with which tasks were classified involved the control inputs that were required to locate the information within the menu structure. This measure was a count of the number of button presses that were required to locate the desired information. This measure is directly related to the depth of the information in the menu structure. The following definitions contain the criteria that were used to classify the ATIS task difficulty:

Baseline. The baseline driving task was included in the experimental design to provide a benchmark of how the two groups of professional drivers controlled the vehicle under normal driving conditions. The subject was asked to drive the simulated vehicle down a straight roadway while maintaining the speed limit. Only the standard analog automobile instrumentation was available to the subjects while driving.

Low. A low difficulty task was defined as driving with the basic display of information from the ATIS display. In this case, the subject was not actually required to report any information from the display. Therefore, the low task required no control inputs, but did require that the subject monitor the ATIS display for correct speed, navigation information, and occasional road sign information.

Medium. A medium difficulty task was defined as requiring one or two control activations to locate the information screen. The appropriate screen of information would then contain three or fewer units of information. Typically, the piece of information the subject was looking for would be the only item displayed.

High. A high difficulty task was defined as requiring one or two control activations to locate the information screen. The appropriate screen of information would then contain seven or more units of information. The piece of information the subject was searching for would typically be found among several of the other pieces of information.

Super high. A super high task was defined as requiring four or five control activations to locate the information screen. The appropriate screen of information would contain seven or more units of information. The piece of information the subject was looking for would be displayed among the other pieces of information on the screen.

Table 1. ATIS task classification.

Task Level	Amount of Information	Control Inputs
Baseline	0	0
Low	2-3	0
Medium	2-3	1-2
High	7-8	1-2
Super High	7-8	4-5

<u>Sensory Mode of Information Display</u>

In this experiment, the ATIS display used either a visual-only display or a combination of auditory and visual information. The visual-only display was self-explanatory in that it contained only visual information. All the information in the menu portion of the system was textual in format.

The combination auditory and visual displays incorporated the displays from the visual-only condition with auditory feedback about both the menu choices that had been selected and the contents of the information screens. When a menu choice was made by pressing a button, a digitized voice recording would enunciate the selection. This feedback confirmed that the subject had in fact made the intended selection. A digitized voice also enunciated the important content within the information screens when they were encountered. It is important to note that subjects would not have to visually search the information screens for a particular item of interest because it would be presented verbally in this condition.

Dependent Variables

Driving Performance Measures

Variability in steering wheel position. Research has shown that changes in driver steering behavior occur when the driver's attention changes. For example, Wierwille and Gutman (1978) report that in normal, low attention circumstances, drivers make continuous, small steering corrections to make up for roadway variance and driving conditions. 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 then required to correct the position. Since small corrections decrease and large corrections increase, an increase in the standard deviation of steering wheel position indicates high attention or workload requirements and a reduction in driving performance.

Variability in vehicle velocity and mean vehicle velocity. Vehicle speed, like lane position, can be considered a vehicle state which, at some level, has to be held constant in most circumstances. Therefore, for the same reasons described above for steering wheel position, variations in velocity were used to evaluate performance; that is, drivers were required to make continuous adjustments in pedal displacement to maintain the correct speed. Monty (1984) found velocity maintenance to be a sensitive measure to changes in the amount of attention demanded by secondary driving tasks. In addition, average vehicle speed is also a valid measure of task demand. Antin, Dingus, Hulse, and Wierwille (1990) have shown that drivers adapt to increased task demand by modifying their behavior and driving more "cautiously."

Variability in lane position. Lane position variability is a measure of how much the vehicle has deviated from its mean lane position. Deviation scores were recorded in feet from the discrepancy between the vehicle position and the mean lane position. The deviation is recorded from the mean lane position rather than the center of the lane to remove any possibility of increased variability due to differences in driver perception of the location of lane center.

Number of lane deviations. A lane deviation was defined as any time any portion of the vehicle exceeded the lane boundary. The lanes of the roadway were 12 feet wide and the vehicle width was calculated to be 6 feet, leaving the subject the ability to deviate 3 feet in either direction from the center of the lane before a lane deviation was recorded.

Eye Glance Measures

Number of glances to the display per task. This is the mean number of glances made toward the display during the segment of data collection where the ATIS task was being performed. Safe driving requires constant scanning of the roadway and the driving environment. A reduction in the time spent scanning these locations can be construed as a decrease in driving performance.

The number of glances to the display is an indicator of the amount of attention that was required to complete the task. The eye glances were reduced to only two locations, either on or off the ATIS display.

Caution should be exercised when making comparisons of eye glance data collected in this experiment to data collected in a real-world driving environment, especially in the case of the truck driver subject group. The vehicle cab that was used for this experiment was a modified Saturn automobile. This cab contains fewer targets for glances than would be encountered had a truck cab been used. Truck cabs typically contain more gauges and controls than a standard automobile. In addition, truck drivers have often conditioned themselves to look in their mirrors more often to check trailer tracking and search for traffic. The eye glance measures may be used when making comparisons between conditions within this experiment but should not be extended toward making comparisons with data collected in a more realistic truck cab environment.

Mean duration of glances. This is a measure of how long the glances were toward the ATIS display. The durations that are being reported are individual glances rather than a combined total duration of multiple glances to complete the task. Even though a total duration of the glances to complete a task may seem high, a driver will often self-limit his/her glances away from the roadway to smaller durations. This switching between the display and the roadway will help improve the ability to maintain awareness of what is happening in the roadway environment.

ATIS Prototype Use Measures

Number of errors per required button press. This is a frequency count of the number of errors committed while using the system to find specific pieces of information to complete the ATIS tasks. When subjects were cued to find a piece of information, they would begin to push the steering wheel buttons to navigate through the menus. If the subject made a menu choice that would take him or her down the incorrect path, the ATIS would log an error and not allow the incorrect choice. The subject could then make another choice and navigate down the correct path. This measure is the number of errors that were recorded during a given task divided by the number of button presses that would be required to correctly navigate to the desired piece of information. This allows for the comparison of frequency of errors between tasks that may inherently require more decisions and subsequent button presses.

Subjective Workload Measures

Subjective workload. To assess the mental workload demand of the ATIS information retrieval tasks, a modified version of the Subjective Workload Assessment Technique (SWAT) was used (Reid, Eggemeier, and Nygren, 1982). Using this modified technique, subjective ratings were collected at the end of each of the eight data collection segments during the experimental drive. The subjective scale used required the subject to rate three dimensions of driving workload (visual effort, time stress, and psychological stress) as high, medium, or low.

Subjective workload measures were obtained by asking drivers to rate their level of effort in performing the ATIS task while driving the vehicle. In this context, effort refers to mental effort, not physical effort. Subjective measures of workload are used to express differences in effort at levels below which performance is reliably degraded. Thus, subjective workload measures may be sensitive to task differences that observable performance measures are not.

Subjects were asked to rate their workload on three dimensions: time stress, visual effort, and psychological stress. On each dimension, the ratings were expressed on a three-point scale: "low," "moderate," and "high." For data analysis, low, medium, and high were coded as 1, 2, or 3, respectively.

Time stress was defined in terms of the amount of time available for completion of driving and navigation tasks. Anchors for the low, moderate, and high ratings were provided during the pre-experiment briefing. A low rating was assigned if there was time to spare, such as for carrying on conversation or tuning the radio. A moderate rating was assigned if there was just enough time to accomplish the driving and navigation tasks. It was suggested that with moderate time stress, the driver would avoid distractions such as conversation. A high rating was assigned if there was insufficient time to fully attend to driving and navigating. For example, if the driver stopped scanning for the next road to turn on or ignored a system message indicating an upcoming turn, it was considered to be a high time stress situation.

Visual effort was defined in terms of the amount of visual scanning required. An example of low visual workload was feeling comfortable looking about, such as at objects in the simulation scenery. It was further suggested that under moderate visual effort, visual scanning necessary for driving and navigating could be accomplished comfortably, but that there was no spare visual capacity. Under high visual effort, it was suggested that the driver would have to delay looking at things necessary for driving or navigation. As an example, it was suggested that under high visual effort, the driver might have to ignore signs and concentrate solely on the forward roadway.

Psychological stress was defined in terms of feelings of confusion, frustration, danger, and anxiety. Low psychological stress was defined as feeling confident and secure. Moderate psychological stress was defined as mildly confused or frustrated, such as unsure of following the planned route or feeling anxious about finding the next turn. High psychological stress was defined as feeling extremely stressed, as one might feel after a near accident.

Subjective Questionnaire Measures

Questionnaire. A 45-item questionnaire was administered to the subjects after they completed all the driving for the experiment. The subjects were asked to provide their opinions about the value of these types of systems, the value of the individual information elements, which display configurations they liked the most, and how much they might be willing to pay for similar types of systems.

DESCRIPTION OF RESOURCES AND EQUIPMENT

The Iowa Driving Simulator

The IDS, located in the Center for Computer-Aided Design at the University of Iowa, was used for this study. The IDS utilizes recent technological advances in computational dynamics, parallel computing, and image generation to create a realistic ground–vehicle simulator.

A high fidelity, fixed-base (i.e., no motion) simulator was used for the simulation portion of the study. The fixed-base simulator uses a Harris NH4404 host computer and an Alliant FX2800 computing platform to execute the software required for the simulation. The capability exists to modify the channel configuration and field of view. This capability allows some degree of flexibility in the resolution and brightness of the projected visual scene. The simulator was configured to provide a visual scene of the roadway projected in front of the driver with a 60-degree horizontal by 20-degree vertical field of view (slightly larger than the view out of the front windscreen). This scene was rendered with an Evans and Sutherland ESIG 2000 image generator, three Sony multi-synch projectors, and a flat, unity gain screen. This configuration provided a resolution of less than 1.5 arc minutes of visual angle per pixel with 2.7 million pixels displayed.

The "vehicle" used in this study was a modified 1995 Saturn SL automobile that was converted to a simulator test platform. The modifications allow the test platform to fit into the physical confines of the simulator bay. The steering system provides control-loaded feedback during operation, and quadraphonic stereo imaging provides auditory cues while driving. All primary controls on the vehicle were functional and provided realistic feedback to the driver. The vehicle was positioned so the driver's eye point was approximately 9 feet from the screen.

The ATIS display was mounted on top of the instrument panel, directly in front of the driver. The display was located approximately 15 degrees below the driver's field of view, 28 inches from the driver's eye point. The display device used for the ATIS was a Sharp color LCD with a 720 x 240 pixel resolution. The usable display area was 87 mm x 114 mm (a 5.7-inch diagonal screen). The physical measurements of the entire unit were 149mm x 117mm x 23 mm. During conditions when the driver was to be using the ATIS display only, the standard dashboard instruments were covered so they could not be seen. During baseline driving conditions when the driver was to drive with the standard dashboard equipment, the ATIS display was turned off and the dashboard instruments were uncovered.

A customized ATIS prototype interaction program was developed for use during this experiment. The prototype allowed the experimenter to quickly define what was presented on the display. In addition, it allowed for the creation of multiple menu structures that could be navigated through the use of subject-manipulated steering wheel buttons. Data collection was also automated through the prototype software system.

The steering wheel was modified to include four push buttons that could be used to interact with a system that was displaying information on the ATIS display. The buttons were 1/2 inch square and raised 1/8 inch above the surface of the steering wheel spokes. Each button contained back lighting that allowed for easy visibility under any driving conditions. The buttons were arranged symmetrically on the steering wheel spokes so the drivers could operate them with their thumbs while holding the wheel with their hands in the nine and three o'clock positions. The buttons were connected to the serial port of a PC that controlled the ATIS display.

The simulator allows for the collection of a variety of performance measures in real time at a rate of 10 Hz. The simulated vehicle is electronically instrumented so that measures may be collected directly from the source of input (such as the gas pedal) as well as the resulting vehicle dynamic output (such as acceleration and speed). The measures are all collected simultaneously and stored into a single data file for subsequent analysis.

Videotaped Observation

Two small "lipstick case" video cameras were situated in the vehicle to give views of the subject's face and an over-the-shoulder view of the steering wheel buttons. These two views were combined with an external video line from the simulator scene and a close-up view of the ATIS display contents. The four views were combined in real time with a four-channel multiplexer into a single videotaped record of the experimental drives.

PROCEDURE

Subject Screening

All subjects were recruited from the local Iowa City/Cedar Rapids, Iowa area. Potential participants were required to pass a series of medical screening criteria (appendix A) to be eligible to complete the experiment.

Truck Drivers

The truck drivers were recruited from the Kirkwood Community College Commercial Driver Training program and several long-haul trucking firms in the local area. All subjects from the driver training program were instructors, rather than students. The eligibility requirements included possession of a current, valid commercial driver's license, logging more than 100,000 miles driven in a long-haul truck operation, and being between the ages of 25 and 55.

Taxi Drivers

The taxi drivers were recruited by posting flyers and contacting the local taxi companies. The eligibility requirements for taxi drivers included possession of a current, valid commercial driver's license, having more than 1 year of experience driving a taxi, and being between the ages of 25 and 55.

Information Summary and Informed Consent

As subjects arrived at the IDS, they were given an information summary that described what was going to take place during the experiment and a standard informed consent form. Copies of the information summary and informed consent form are given in appendices B and C, respectively.

Training

To familiarize the subjects with the experiment and the ATIS prototype, a video training tape was created. The video provided an overview of the experiment and showed pictures of what the system displays and controls would look like. The static elements of the ATIS prototype were all explained in detail, and the dynamic elements were demonstrated whenever possible. Once the videotape was complete, the subjects were allowed to ask questions or review any part of the training video.

The next portion of the training was the interactive segment where the subjects were actually able to manipulate controls and review the resulting display changes on a stand-alone PC that had been specially developed for training. Separate training materials were created for the two types of drivers. Four keys on the keyboard were set to perform the same actions as the steering wheel buttons on the simulator test vehicle. The subjects were allowed to explore the menu structure for a period of time, and a large diagram of the menu structure was provided on the wall to help the subjects create their mental model of the system. Once the subjects felt they were ready to move on, the experimenter asked each subject to use the system to find a number of information elements on the system in the same manner that would be used during the experiment. Training tasks identical to each of the experimental tasks were performed where the attendant would ask the subjects to use the system to find a specific piece of information and report it out loud. The subject was required to complete all training tasks flawlessly before continuing on to the driving portion of the experiment.

Once subjects were comfortable with using the computer and the menu system, they were given training on how to appropriately report their workload with the modified SWAT technique. The exact details of the training of subjects are given in the training scripts in appendix D. If the subject had no further questions, he or she was escorted to the simulator bay to begin the driving portion of the experiment.

Data Collection

After the subject arrived at the simulator bay, he or she was positioned in the vehicle and allowed to become comfortable by adjusting the seat or steering wheel as necessary. The operation of the controls was explained and any questions were answered. The experimenter then reiterated the process for reporting workload using the modified SWAT technique.

The first part of the driving portion of the experiment involved a practice session where the subject could familiarize him- or herself with the feel of the simulator, the operation of the display, and the proper reporting of workload levels. The practice drive was a 5-mile-long section of straight two-lane roadway, similar to that found in the actual experiment. As the simulation was beginning, the experimenter would point out and demonstrate the operation of the controls and displays of the ATI system. During the practice session, the subject was asked to locate several pieces of information and report them verbally to the experimenter, just as they would be required to do during the experiment. During the last portion of the practice drive, subjects were also asked to report their workload ratings verbally to the experimenter. At the end of the practice session, subjects were asked whether they would like any additional practice before moving on to the experiment. All subjects declined further practice.

After the practice session, the subject drove the first of two experimental drives using either the visual-only or the combination auditory and visual ATIS prototype system, whichever he or she was assigned to drive first. As the subject passed the beginning of each data collection segment, a digitized voice from the simulator would ask the subject to perform a task using the ATIS prototype. The subject would respond using the buttons located on the steering wheel to navigate through the menu system until the specific piece of information had been located. Once the subject found the information, the subject would report the answer verbally to the experimenter and exit the menu system. At the end of each of the eight data collection segments, the experimenter would ask the subject to report his or her workload ratings. This process continued until the end of the experimental drive had been reached.

Next, the subject would drive through a 5-minute baseline drive. The baseline drive consisted of simply driving down the road and maintaining the speed limit while using the standard dashboard instruments. The ATIS display was turned off and the dashboard instruments were uncovered just before the beginning of the drive.

After a short break, each subject completed the second experimental drive using the same procedures as the first drive. After completing all of the experimental drives, the subjects were given the questionnaire to be filled out (see Appendices E and F). Each subject was paid $25.00 per hour for their participation in the experiment.

CHAPTER 3: DATA ANALYSIS OVERVIEW

The dependent measures collected from this experiment were subjected to several types of statistical analyses, as appropriate, to determine the presence of differences among the experimental treatments. These analyses included both descriptive and inferential statistics.

DESCRIPTIVE STATISTICS

These statistics included measures of central tendency (mean) and measures of variability (variance), and various frequency distributions and graphs as appropriate.

INFERENTIAL STATISTICS

Inferential statistics included univariate analysis of variance (ANOVAs). ANOVAs were conducted utilizing the SAS General Linear Models procedure because cell sizes were rarely proportional. Multivariate ANOVAs (MANOVAs) were not performed. MANOVAs often exhibit an increase in type II error for repeated measures designs. Fortunately, the majority of the univariate ANOVAs had p values that were well below the $p<0.05$ criterion value for significance selected for this research. The reader is cautioned, however, against placing too much weight on a single ANOVA with a p value approaching $p=0.05$ due to the possibility of a type I error. The results described in this report should be interpreted by looking for supporting evidence across all of the performance measures collected.

For some measures, the analyses include a comparison to baseline driving performance. These measures were typically driving performance measures where data were available in the baseline condition. For other measures, such as the number of errors, no comparison was made with the baseline condition because there were no opportunities to make errors during the baseline drive. A brief explanation of the exact models and rationale for each analysis will be provided before the discussion of results for each measure.

CHAPTER 4: RESULTS

The following presentation of results has been divided between truck and taxi driver experiments. As mentioned in the "Experimental Design" section of this report, the two experiments were virtually identical except for the specific ATIS prototype that was used. Dividing the experiments into two sections allows for the clear presentation of results without having to continually state which driver type is being discussed. The results for each driver type will be presented and discussed in sections corresponding to the grouping of measures listed above.

RESULTS FOR THE TRUCK DRIVER EXPERIMENT

Driving Performance Results

The ultimate goal of this analysis was to assess the effects of differing task levels and sensory modes of information display on a variety of driving performance measures. It was expected that there would be some differences in driving performance as task demands were increased. The first step was to look for any differences in driving performance across the increasing levels of task demand that may be due to the sensory mode of information display. These differences were investigated without including the baseline driving condition because it was not possible to make comparisons with sensory mode. The resulting model for this analysis was a 2 x 4 repeated measures design, including the two sensory modes of display (visual only and combination auditory and visual) and task level (low, medium, high, and super high). If differences were found for the sensory mode of display, the data were partitioned by sensory mode and compared separately against the baseline data. If differences in sensory mode were not found, the data were collapsed across sensory mode of display and then compared with the baseline data. These analyses resulted in a one-way ANOVA repeated measures with one level of sensory mode of display (either partitioned across sensory mode for separate analyses or collapsed across sensory mode) and five levels of task demand (baseline, low, medium, high, and super high). The comparisons with the baseline data allowed assessment of the magnitude of driving performance differences and determination of how they compared with the baseline driving conditions.

The ANOVA performed using the 2 x 4 repeated measures design described above revealed that no sensory mode of display by task level interaction was significant, but differences did exist ($p<0.05$) for sensory mode of display for four of the five variables analyzed. Because of these differences, a decision was made to partition the data by sensory mode of display and analyze the data for each sensory mode separately, looking for differences between the ATIS task levels and the baseline condition. The results for each sensory mode analysis are presented separately in the following two sections, and discussed together later in the report.

Driving Performance Results for the Visual Sensory Mode of Display

The ANOVA results for the visual-only sensory mode of display are shown in appendix G, table 2. Standard deviation of steering wheel position, mean vehicle speed, standard deviation of vehicle speed, and standard deviation of lane position were all found significant at $p < 0.05$, while the standard deviation of accelerator pedal deflection was not.

A Student-Newman-Keuls post-hoc procedure was performed on the data for each of the variables found significant in the ANOVA. The means for the standard deviation in steering wheel position are shown in figure 11. The post-hoc test revealed that the super high task level resulted in standard deviations of steering wheel position that were greater than those for the remaining task levels. The low, medium, and high task levels were not found to be different from one another, but were all greater than the standard deviations from the baseline condition.

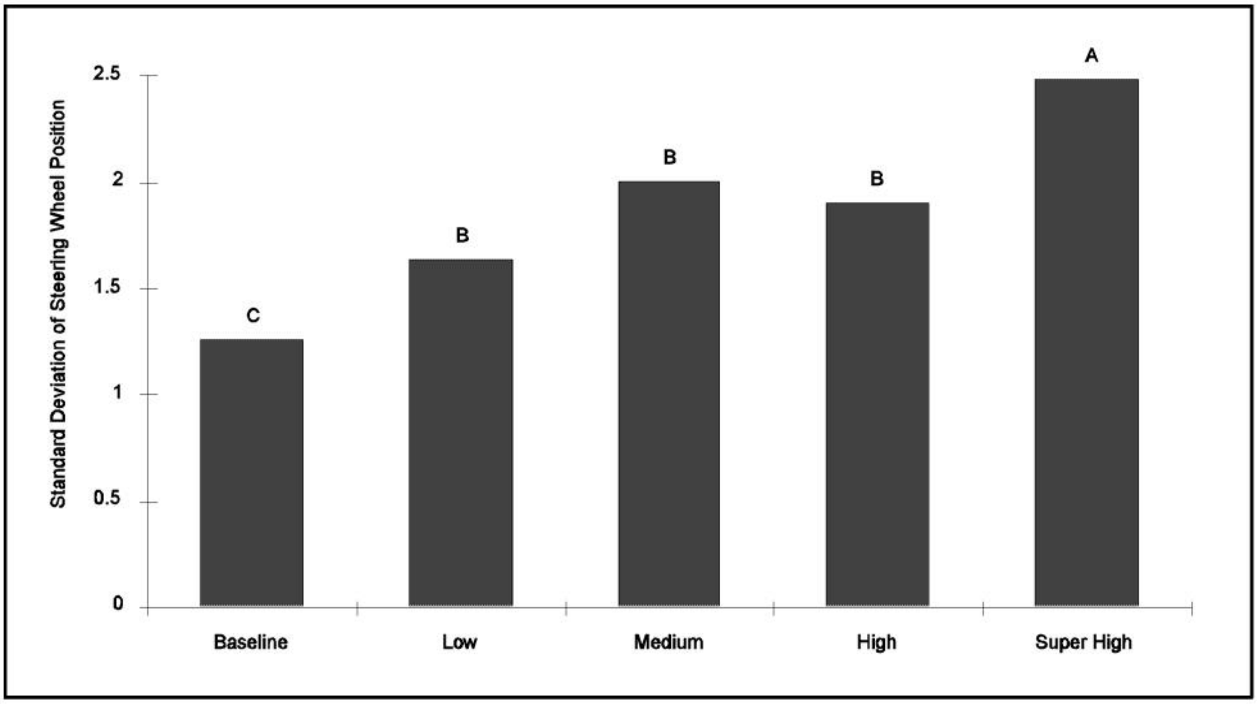

Figure 11. Standard deviation of steering wheel position by task level for visual-only sensory mode of display.

Steering wheel inputs can provide evidence of changes in workload that a driver is experiencing. As attention or workload demands increased, the frequency of steering corrections tended to decrease. Since the small centering corrections decreased, the vehicle tended to drift farther from the lane center, and a larger steering input was required to correct the position, resulting in larger standard deviations of steering input. The super high condition resulted in the largest standard deviations, suggesting that the task demands during those tasks were higher than for any of the other conditions. The low, medium, and high task levels indicated smaller levels of workload than the super high task, but were still greater than the baseline level.

The mean vehicle speed for each task level within the visual-only condition is shown in figure 12. The post-hoc test indicated that the baseline driving condition resulted in the fastest mean speed. The remaining task levels, which all required some level of interaction with the ATIS prototype, resulted in mean speeds that were slower than the baseline condition but were not different from each other. The slower vehicle speed seen in the ATIS task levels results from drivers slowing their speed while interacting with the ATIS prototype. The slowing of the vehicle under increased task demand may have been due to drivers adopting a more cautious driving strategy while interacting with the ATIS prototype system. Antin, Dingus, Hulse, and Wierwille (1990) have shown that drivers modify their behavior and drive more cautiously when adapting to increased secondary task demands while driving. This result helps support the hypothesis that drivers experience some level of increased workload while interacting with the ATIS.

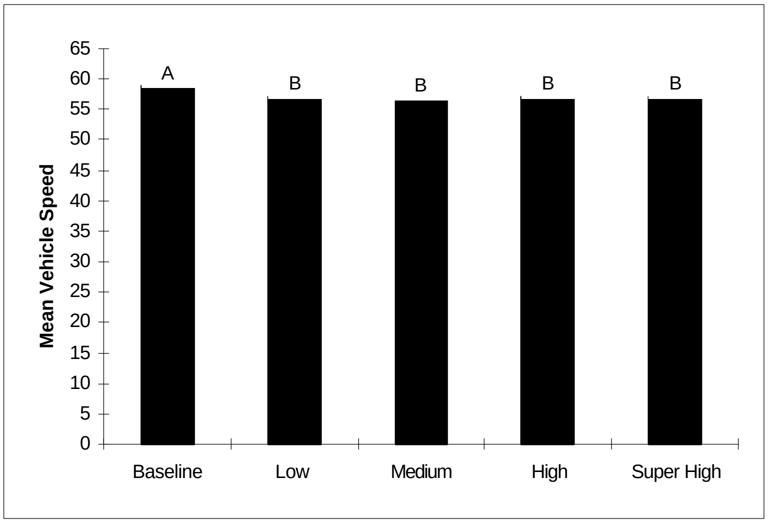

Figure 12. Mean vehicle speed by task level for the visual-only sensory mode of display.

The standard deviation of vehicle speed can also be an indicator of secondary task demand when driving (Monty, 1984). Figure 13 shows the mean standard deviation of vehicle velocity for each of the task levels. The post-hoc test indicates that there were no differences between the baseline, low, medium, and high task levels. The standard deviation for vehicle speed was found to be larger than all of the other task levels. This result would indicate that, at least for this measure of secondary task demand, subjects did not experience a change in driving performance from the baseline level to the low, medium, or high task levels. However, the super high task level did result in an increase in speed variability, suggesting an increase in the secondary task demand caused by the interaction with the ATIS prototype that was large enough to affect driving performance.

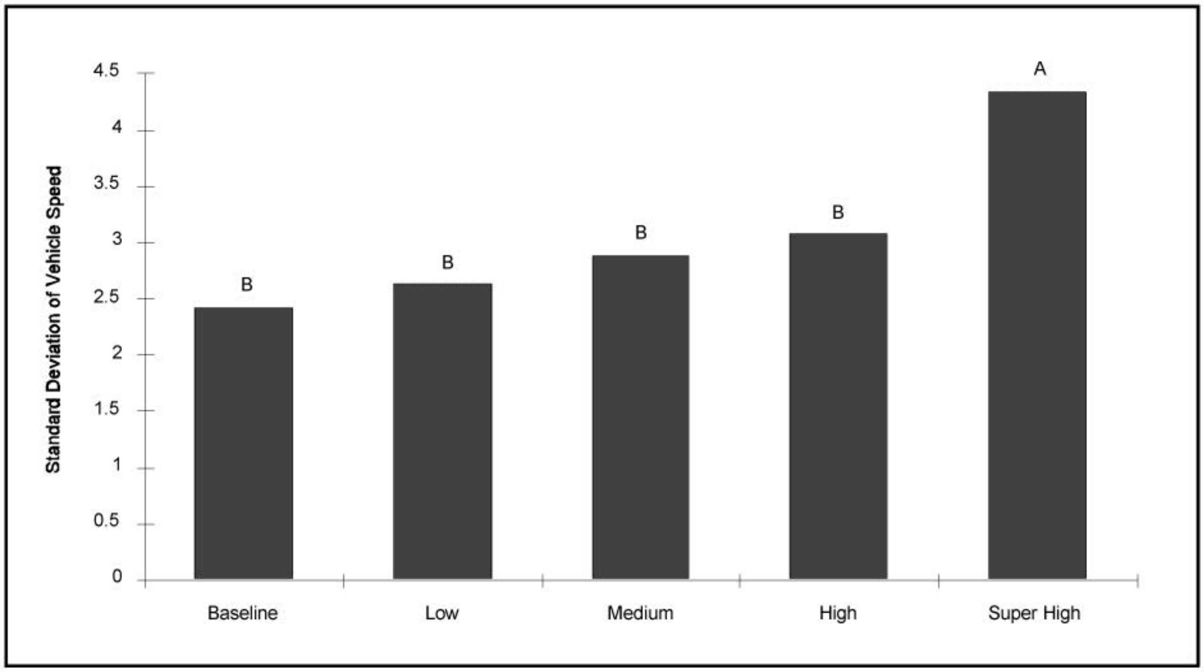

Figure 13. Standard deviations of vehicle speed by task level for visual-only sensory mode of display.

The standard deviation of lane position is a measure of the variability of the lateral position of the vehicle with respect to the center of the lane. An increase in the standard deviation of lane position is representative of increased workload for the driver. As workload increases, drivers have fewer spare visual resources to attend to the task of maintaining lane position. As the vehicle begins to stray more from the center of the lane, the value for standard deviation of lane position increases.

The mean values for standard deviation of lane position are shown in figure 14. The standard deviations for the super high task level were larger than for all other levels. The low, medium, and high levels were not significantly different from each other, but were greater than the baseline condition. Intuitively, these results are very similar to those found for the standard deviations of steering wheel position. The two measures are closely related and should be interpreted as such, rather than as completely independent measures of performance.

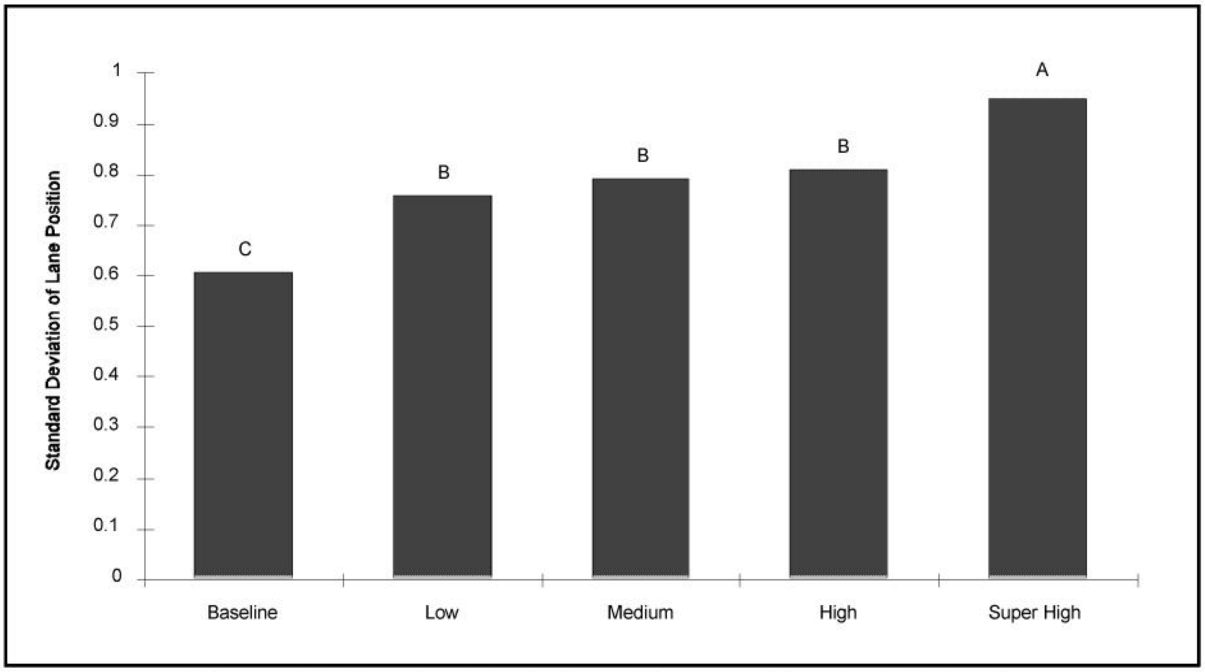

Figure 14. Standard deviation of lane position by task level for visual-only sensory mode of display.

The number of lane deviations was also included in the analysis of driving performance. The strategy for analyzing lane deviations was similar to the other measures in this section where the data were split between sensory mode of display and separate analyses were performed for each sensory mode. There were no lane deviations when driving in the baseline condition for either sensory mode, making all frequency counts for this measure zero. This result is not unexpected because drivers typically do not deviate from the lane when driving on straight two-lane roads. In fact, the absence of lane deviations under baseline conditions lends some evidence of validity to the data collected and the conditions under which they were collected.

The mean number of lane deviations per task is shown in figure 15. The post-hoc analysis determined that the number of lane deviations per task was statistically the same for the baseline, low, medium, and high task levels. The super high task level resulted in drivers making more lane deviations per task than with any other task level. These results suggest that for the visual-only sensory mode of display, even though the standard deviation of lane position increased from the baseline to all task levels that required interaction with the ATIS prototype, the number of actual lane deviations did not appear to increase until the task demands reached the super high level. Some caution should be exercised when interpreting these data. After the data were split into two sensory modes of display, there were 10 observations per task level. This results in a relatively low power test for this variable. While the larger differences between the task levels may be identified, the more subtle differences between task levels might be missed. It is also important not to lose sight of the meaning of the variable in this case. The baseline driving task resulted in no lane deviations. The low task level resulted in approximately one lane deviation every two times the task was completed. The medium and high task levels resulted in roughly one lane deviation every time the task was completed. The super high task level, which was found to be significantly greater than all other task levels, resulted in almost two and one-half lane deviations every time the task was completed. The magnitude of the number of lane deviations for the task levels seems to suggest that the drivers did experience a reduction in their ability to control the vehicle as the ATIS task demands increased to the super high level.

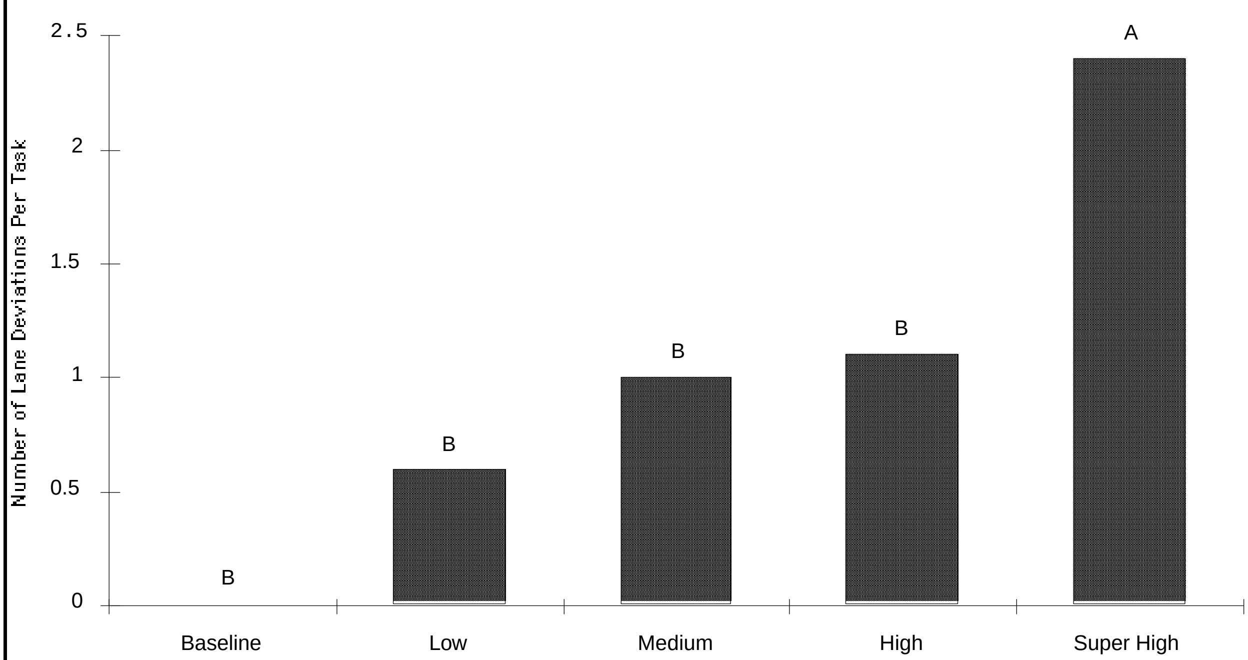

Figure 15. Number of lane deviations per task by task level for visual-only sensory mode of display.

Driving Performance Results for the Combination Auditory and Visual Sensory Mode of Display

The following results contain the data from the combination auditory and visual experimental trials that were partitioned from the visual-only data for analysis. The same types of analyses were performed on the combination auditory and visual data, and the results are presented in a similar manner. An ANOVA was performed on each of the variables that were used to assess driving performance. The results of the ANOVA are shown in appendix G, table 3. All variables included in the ANOVA were found to be statistically significant by task level at the $p<0.05$ level.

The means for the standard deviation of steering wheel position are shown in figure 16. The post-hoc test revealed that the super high task level resulted in steering wheel inputs that were larger than any of the other task levels. The mean for the high task level was larger than the low and baseline task levels, but was not different from the medium task level. The low and medium task levels resulted in means that were not statistically different from one another, but they were both found to be larger than the baseline task level. This graph demonstrates the effects of adding depth to the level of interaction required by the ATIS prototype on driver steering inputs. The mean for the baseline condition gives us an indication of the types of steering inputs that are required to drive the vehicle down a straight roadway while maintaining the speed limit using the standard dashboard instrumentation. The differences in means from the baseline to the low, medium, high, and super high task means show how drivers modified their steering behavior when the level of interaction with the ATIS prototype system increased. Recall that the depth of interaction was categorized based on the number of button presses required to retrieve information from the prototype system and the amount of information that was on the screen where the desired information could be found.

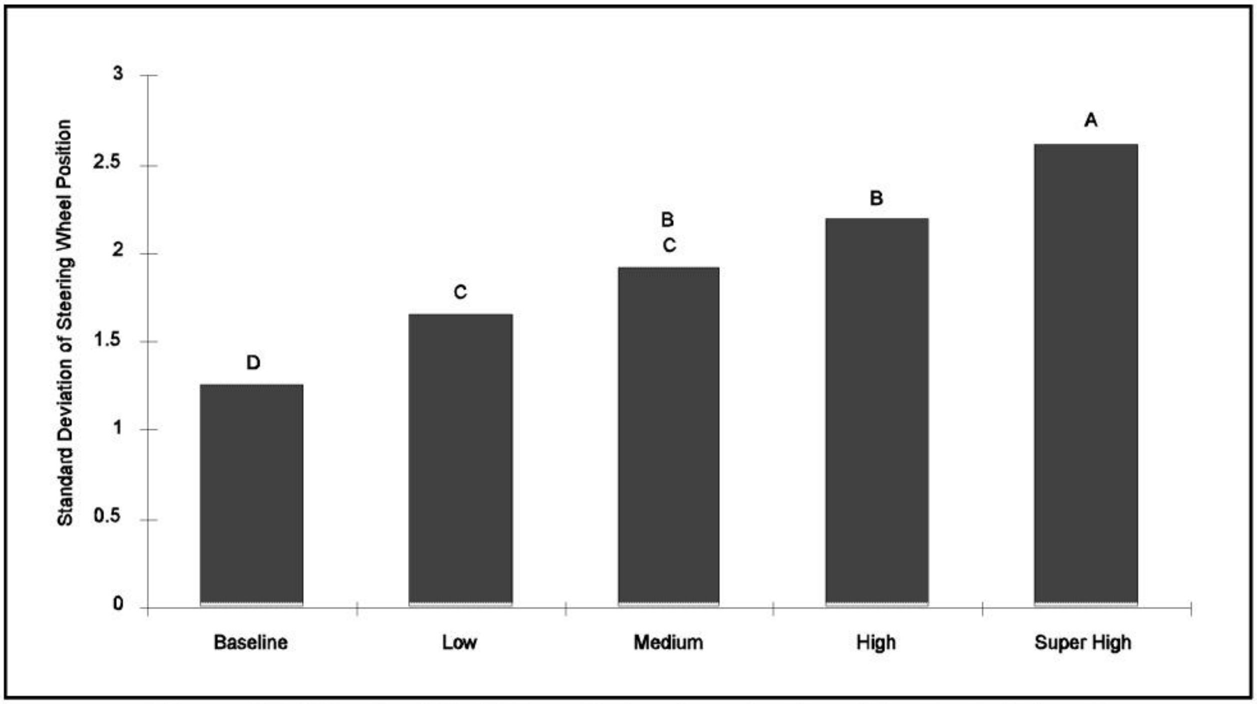

Figure 16. Standard deviation of steering wheel position by task level for combination auditory and visual sensory mode of display.

The mean vehicle speed for each task level is shown in figure 17. The post-hoc test indicated that the baseline task level resulted in higher mean speeds than any of the task levels that required interaction with the ATIS prototype. No differences were found between the low, medium, high, and super high task levels for this measure. Recall that drivers tended to adopt a cautious approach to driving that resulted in lower vehicle speeds when confronted with the addition of secondary task demands. In this case, it appears that the drivers tended to drive slower when required to interact with the ATIS prototype system than they did while driving the vehicle in the baseline condition. This result indicates that drivers experienced an increase in workload while driving and interacting with the ATIS prototype. However, one might have expected to find some differences between the mean speeds for the task levels due to the increase in depth of interaction.

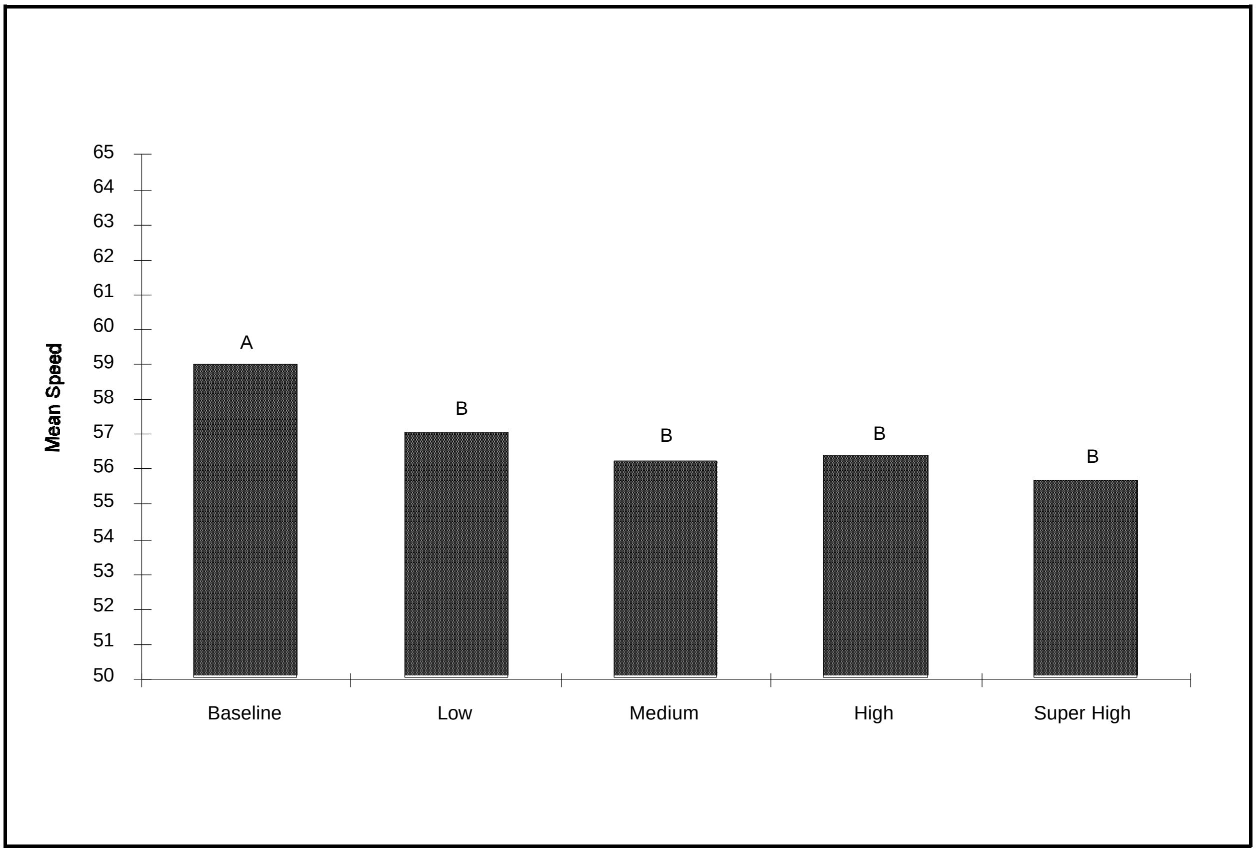

Figure 17. Mean vehicle speed by task level for the combination auditory and visual sensory mode of display.

The mean values for standard deviation of vehicle speed are shown in figure 18. The standard deviations for vehicle velocity were found to be higher for the super high task level than for all other levels. The baseline, low, medium, and high task levels were not statistically different from one another. From the preceding graph, we saw that the super high task resulted in a mean speed that was lower than the baseline condition. In this graph, we can see that the variability of speed was largest for the super high condition. Conversely, the baseline condition showed a lower amount of speed variability but resulted in the highest mean speed. These results indicate that the drivers were able to maintain a higher rate of speed with less variability in the baseline driving condition. In the super high task level, the drivers varied their speed more and actually drove slower. An explanation of this behavior is that, as the interaction task demands increased (especially to the super high level), the subjects tended to become engrossed in completing the task and would not pay as much attention to maintaining their speed. As the subjects completed the ATIS task, they would notice that they were no longer driving the correct speed and would begin to make corrections. These corrections are what caused the variability in speed to be greater in the super high task level. When subjects deviated from the target speed, it was typically in the direction of slowing down rather than exceeding the speed limit. This would help account for the slower mean speeds found in the super high task level.

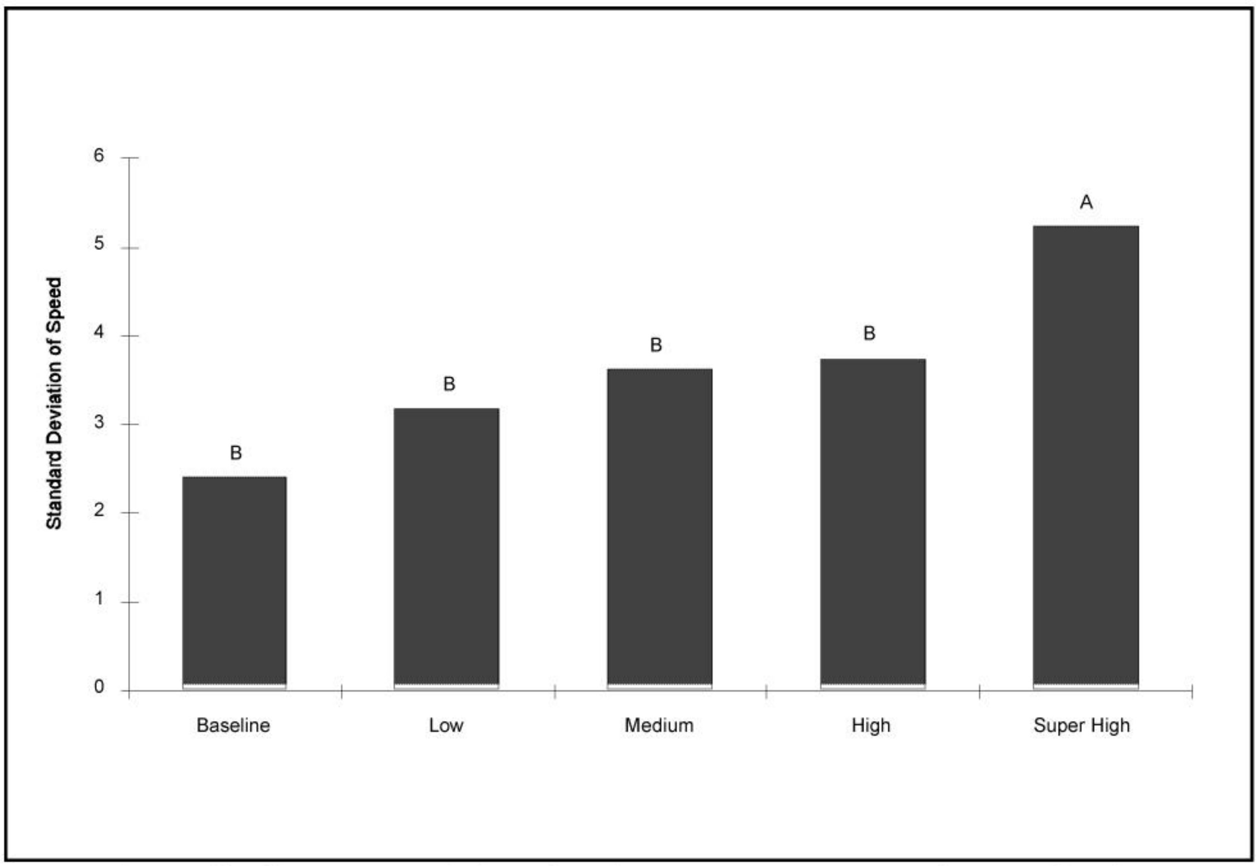

Figure 18. Standard deviation of vehicle speed by task level for combination visual and auditory sensory mode of display.

The means for the standard deviation of lane position are shown in figure 19. The super high task level resulted in the largest standard deviation of lane position, and the baseline task level resulted in the smallest. The low, medium, and high task levels were lower than the super high task level and greater than the baseline task level, but were not different from one another. An increase in the standard deviation of lane position is representative of increased workload for the driver. As workload increases, drivers have less spare visual resources to attend to the task of maintaining lane position. As the vehicle begins to stray more from the center of the lane, the value for standard deviation of lane position increases. The low, medium, and high task levels resulted in lane position variability that was greater than the baseline condition but was not different from one another. This would suggest that driving with the ATIS prototype caused some increase in the level of workload that the driver was experiencing as compared with normal driving.

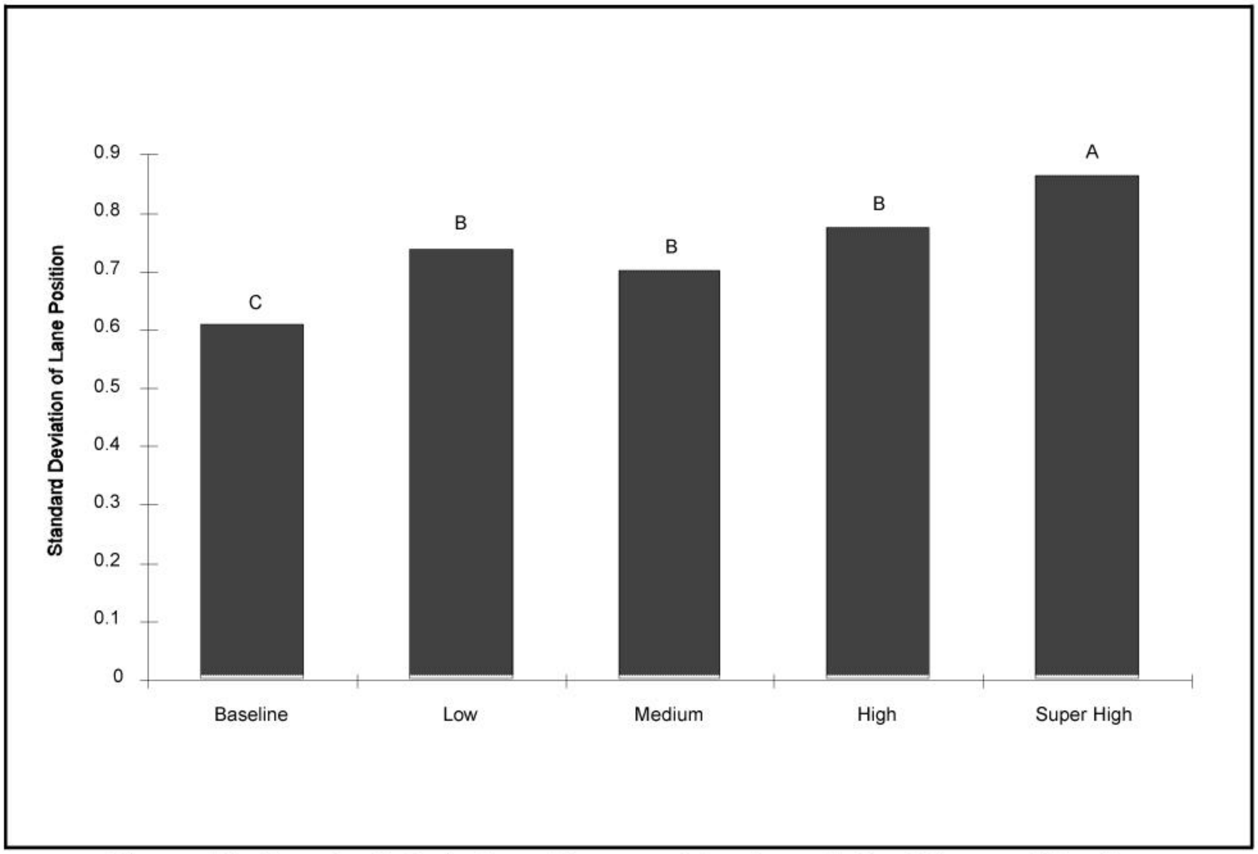

Figure 19. Standard deviation of lane position by task level for combination auditory and visual sensory mode of display.

The means for the number of lane deviations per task are shown in figure 20. As with the visual-only display, no lane deviations were committed while driving in the baseline task level. The number of deviations in the low task level was not statistically different from the baseline condition, but both were found to be lower than the super high task level. The medium and high task levels both showed an increase over the baseline task level. The super high task level had more deviations than the baseline and low task levels, but was not statistically larger than the medium and high task levels.

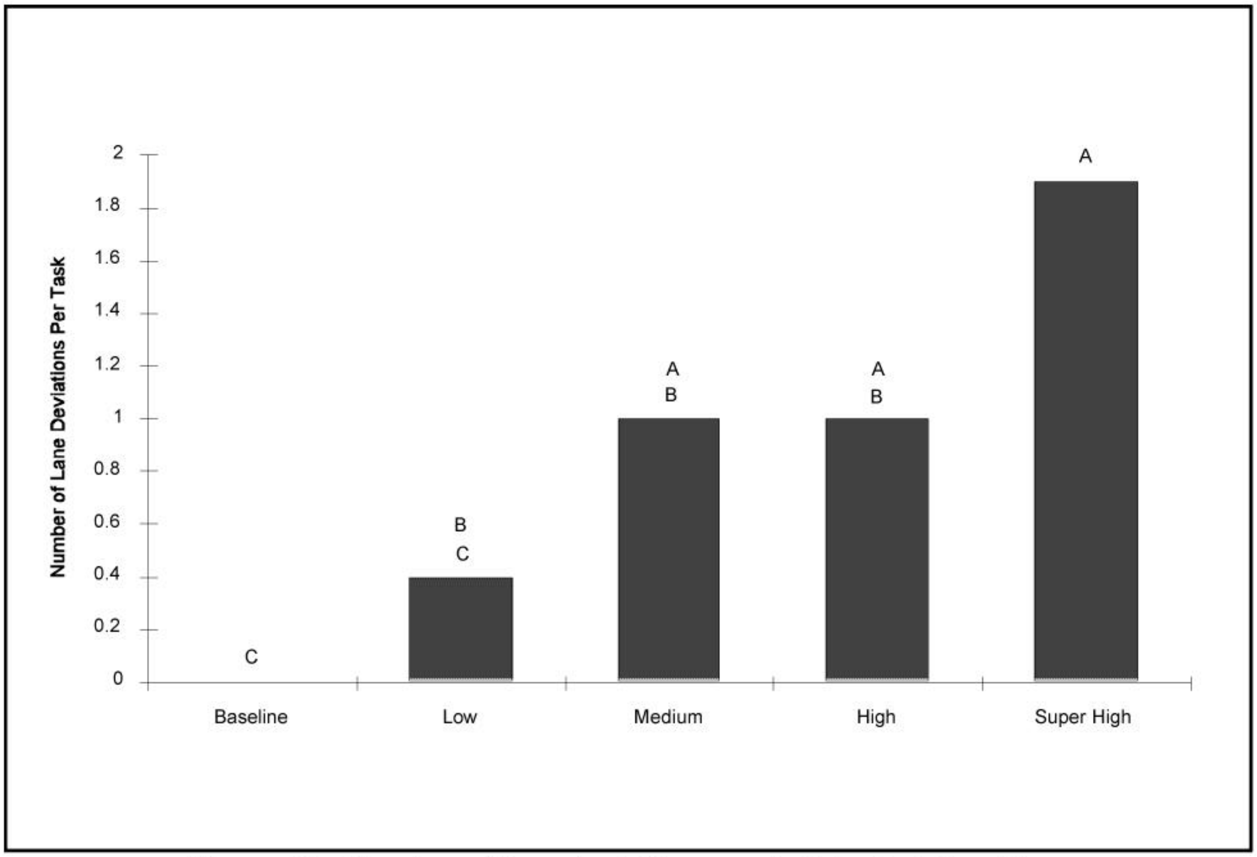

Figure 20. Number of lane deviations per task by task level for combination auditory and visual sensory mode of display.

Eye Glance Results

Driver eye glance behavior was analyzed by reviewing videotapes of drivers during their drives through the experiment. Through manual data reduction, it was possible to determine at each instant whether the driver's glance was to the display or to some other location. Typically, in this type of investigation, it would be desirable to classify the glances into a larger number of locations, including left and right mirrors, roadway, or specific instrumentation. These locations were all reduced to a simple measure of either on or off the display. The simulated vehicle that subjects were driving in this experiment was a 1995 Saturn SL, which is significantly different from the inside of a truck cab. In general, there were fewer target locations for the driver's glance in the simulator than there might be in an actual truck driving scenario; therefore, if efforts had been made to categorize data by more specific locations, the transformation of these additional locations to similar locations within a real truck cab would have been difficult. By looking at the data in this manner, it was easier to make judgments about the visual demand associated with the display of information. Both the number of glances and the duration of the glances were determined during the data reduction process.

The strategy for analyzing the eye glance data was similar to that used for the driving performance analysis in the previous section. An ANOVA was performed using a 2 x 4 (sensory mode of display by ATIS task level) within-subjects design. The analysis determined that there were no significant differences with sensory mode of display. The data were then collapsed across sensory mode of display and an ANOVA was performed on the data using a one-way within-subjects ANOVA that included baseline data as a benchmark task level. The results of the ANOVA are shown in appendix G, table 4. The number of glances per task variable was found to be statistically significant at $p<0.05$, while the duration of glance variable was not.

The means for the number of glances per task are shown in figure 21. The post-hoc tests revealed two stratifications for the frequency with which subjects glanced at the display while completing the experimental tasks. First, there were no differences found between the baseline, low, medium, and high task levels. Second, there were no differences found between the baseline, medium, high, and super high task levels. The only pair-wise difference found with this test was between the low and super high task levels, where the super high task level resulted in a higher number of glances to the display than the low task level.

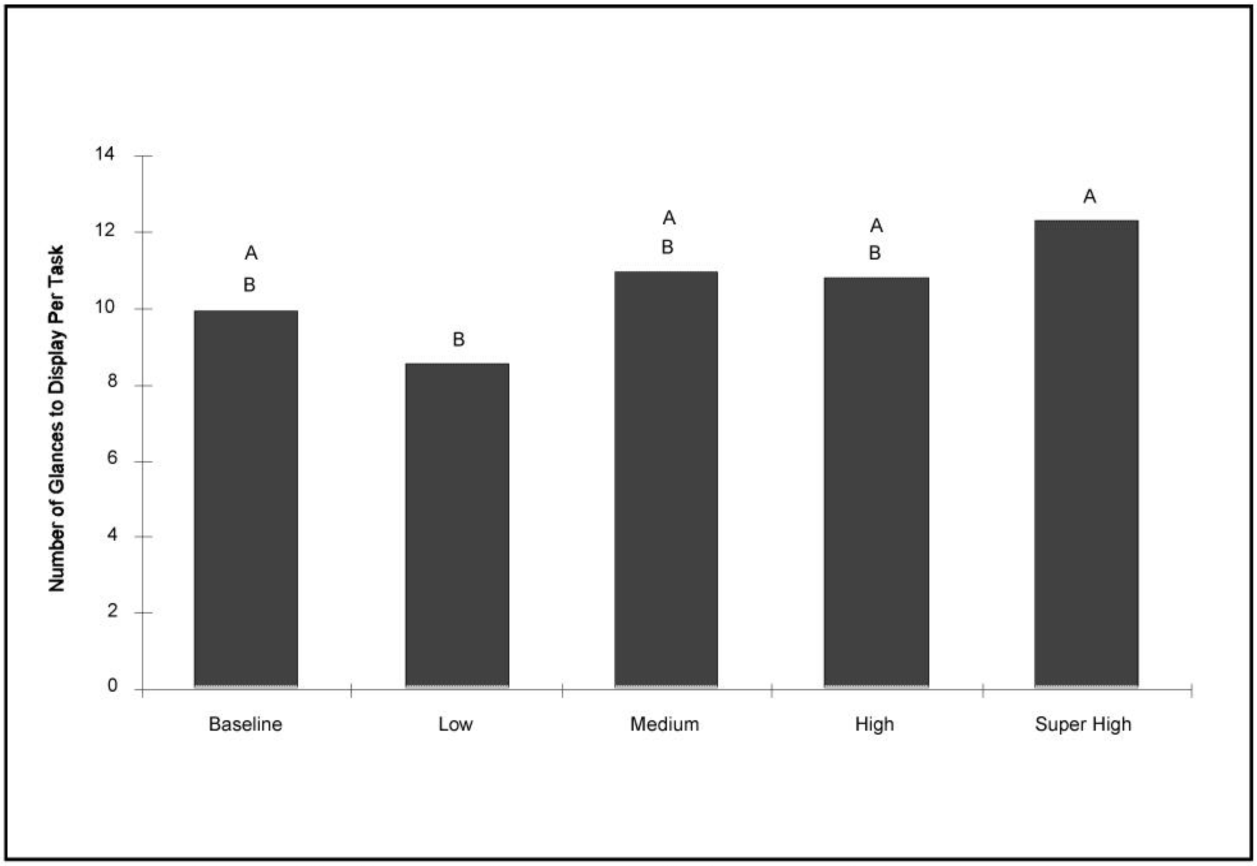

Figure 21. Number of glances to display per task by task level.

ATIS Prototype Use Results

Two measures were analyzed to make assessments of how subjects performed when using the ATIS prototype during the experiment. The two measures were the amount of time to complete the experimental tasks, and the number of errors committed per button press. Note that there were no occurrences of subjects missing a turn that was prescribed by the navigation information presented by the ATIS prototype. Only the medium, high, and super high task levels were included in this analysis because the low task level did not require any control manipulations while interacting with the system, and there was no system in the baseline task level.

For these measures, the data were analyzed as a 2 x 3 within-subjects factorial design, including the visual-only and combination auditory and visual sensory modes of display and the three task levels that required control manipulations. The results of the ANOVA for the time to complete task and number of errors per required button press are shown in appendix G, table 5. The main effect of task level was found to be significant for the time to complete task measure. The interaction between sensory mode of display and task level, and the main effect of task level, were significant for the number of errors per required button press measure. The means of the time to complete task measure are shown in figure 22.

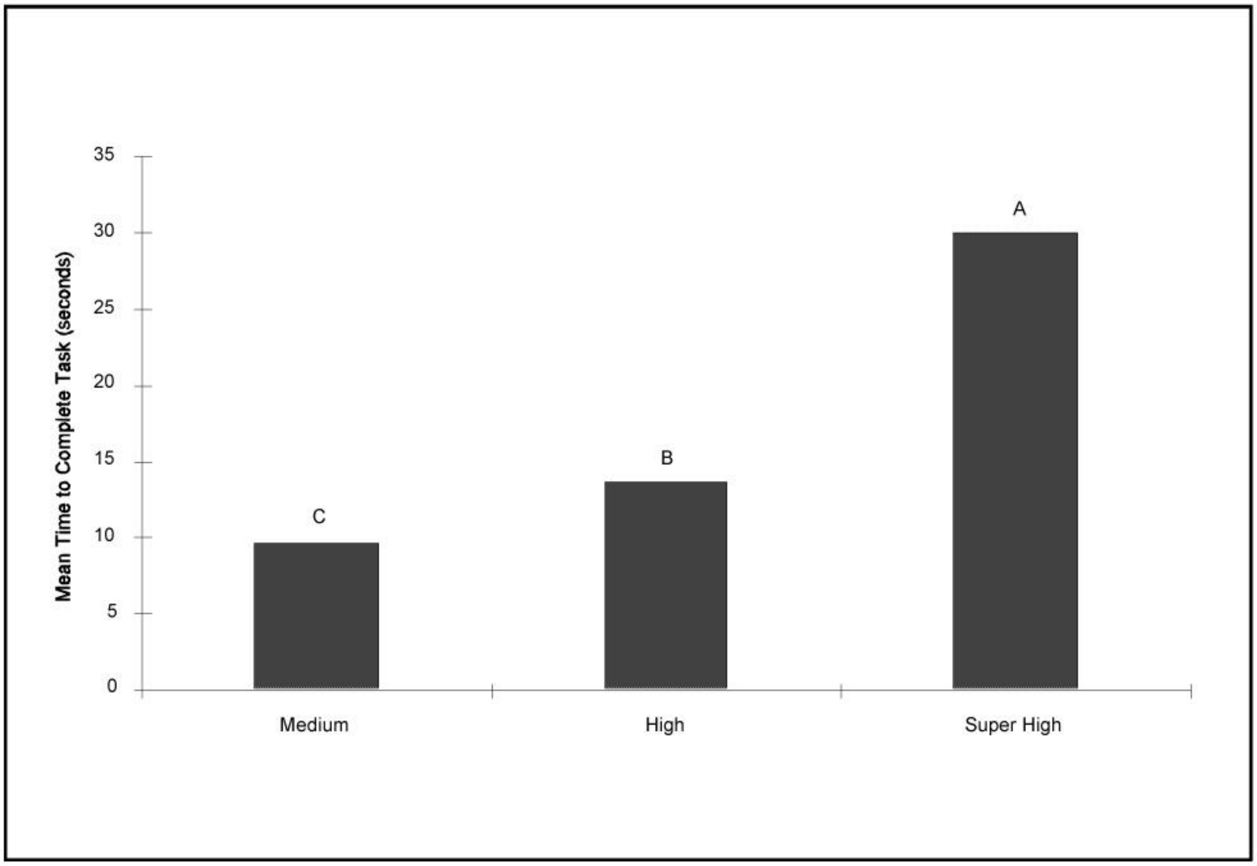

Figure 22. Mean time to complete task by task level.

The significant interaction between sensory mode of display and task level is shown in figure 23. The data were divided by sensory mode of display and a separate ANOVA was run on each individual set of data to analyze the simple effects and determine how the number of errors differed for each sensory mode. A statistically significant difference was found with the visual-only sensory mode, where the super high task resulted in more errors than the medium or high task levels. The medium and high task levels were not found to be statistically different from one another. No differences were found between task levels when comparing the task levels for the combination auditory and visual sensory mode of display. This result suggests that there is a difference in how subjects are able to cope with the increasing complexity of tasks based on whether supplemental auditory information was provided. When supplemental auditory information was added to the ATIS prototype, no differences were found in the number of errors committed based on the difficulty of the task. As figure 23 shows, in the absence of the auditory information, the subjects committed more errors when completing the super high tasks.

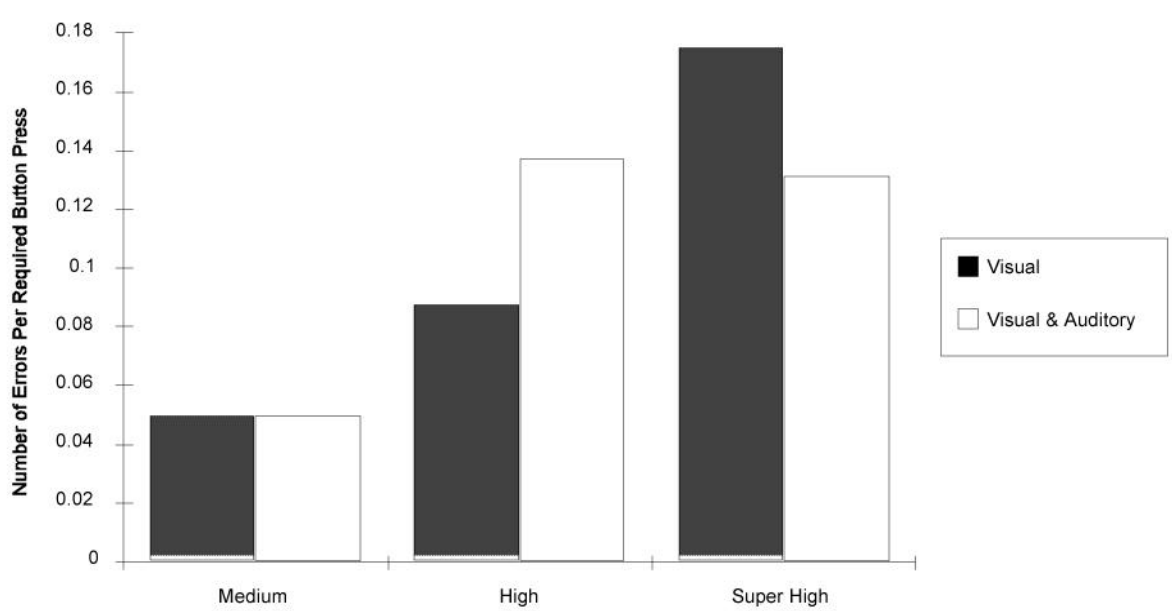

Figure 23. Number of errors per required button press by sensory mode of display.

Subjective Workload Results

To assess the mental workload demand of the ATIS information retrieval tasks, a modified version of the SWAT was used (Reid, Eggemeier, and Nygren, 1982). Using this modified technique, subjective ratings were collected at the end of each of the eight data collection segments during the experimental drive. This subjective scale required the driver to rate three dimensions of driving workload (visual effort, time stress, and psychological stress) as high, medium, or low. All three dimension scores for each of the segments were summed to produce a combined score. The data were coded such that a subjective rating of low was given a one, medium was given a two, and high was given a three.

An ANOVA was performed on the workload measures collected during the experiment. A 2 x 4 within-subjects factorial model was used with two levels of sensory mode of display and four task levels. The baseline condition was not included in any of the subjective workload analyses because data were not collected for this measure during the baseline run. The results of the ANOVA are shown in appendix G, table 6, for the individual dimensions of workload as well as the combined score. No statistically significant differences were found between any of the subject workload measures collected.

Questionnaire Results

After completing all experimental drives, truck drivers were asked to complete a 24-item questionnaire designed to determine differences in how they felt about the types of information that had been presented, the methods that were used to present it, and the effectiveness of these types of systems overall. Several of the questionnaire items were designed to determine the truck drivers' attitudes about how useful the information being presented would be when performing their jobs. On the questionnaire, these items were asked once for each type of information that was presented. The five types of information included navigation, vehicle condition monitoring, general communication, warning, and road sign information. The drivers were given clear examples of each and asked to rate how useful the information was on a scale from very useful to not useful at all (one to seven). A similar question format was used to determine how drivers felt about whether each of the five types of information would help them pay more attention to their driving and how much drivers would be willing to pay for each type of information. Each of the questions was asked one time if the information was presented with a visual-only display, and one time if the information was presented with a combined auditory and visual display. A 2 x 5 within-subjects factorial model was used with two levels of sensory mode of display and five levels of information type. An ANOVA was performed on the data from each question and the results are shown in appendix G, table 6.

No significant interactions between the sensory mode of display and information type were found for any of the questions analyzed. The information type main effect was found to be significant ($p < 0.05$) for the items pertaining to the usefulness of the information and the degree to which the information would help direct attention toward driving. Graphical representations of the mean questionnaire response for these questions are shown in figures 24 and 25.

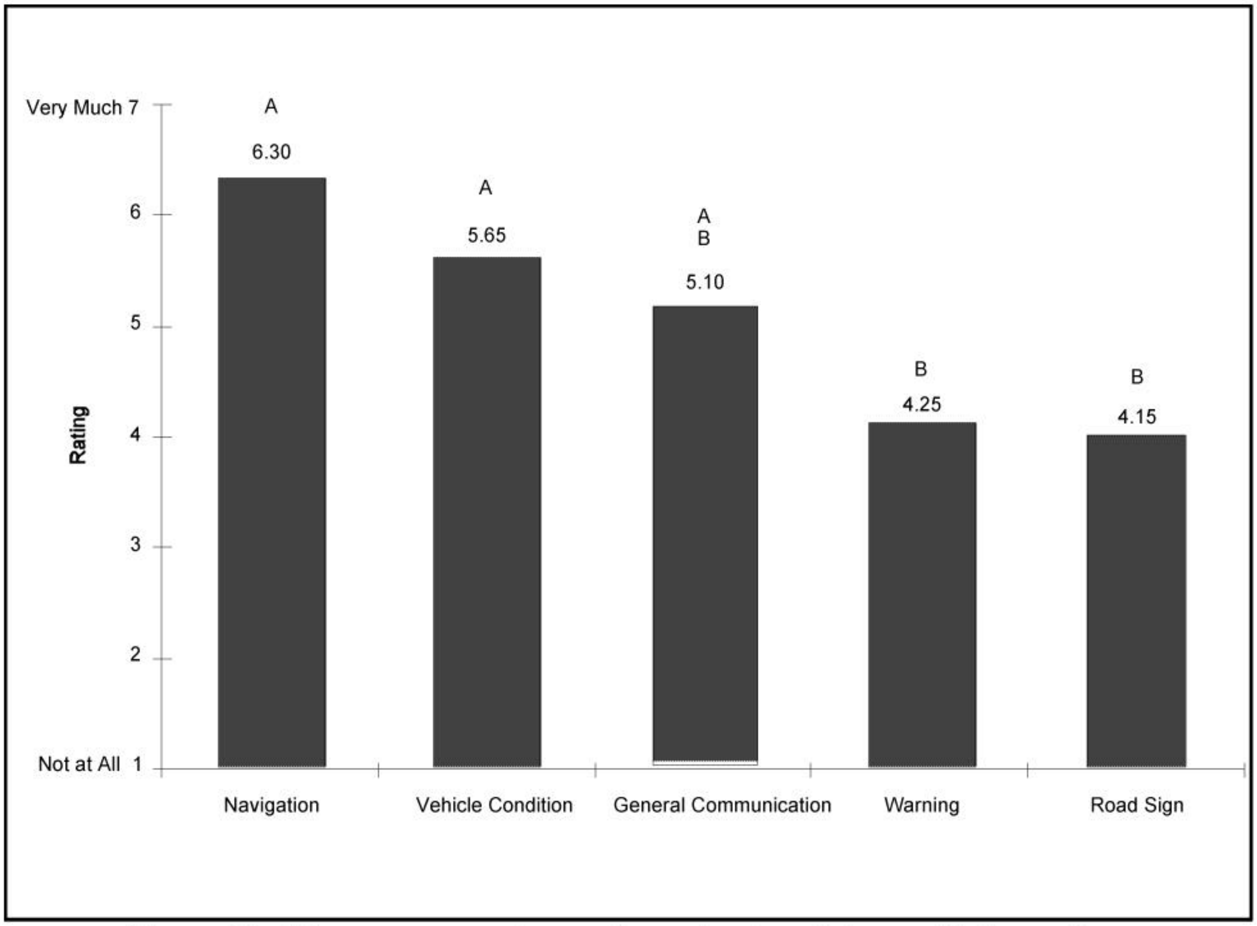

Figure 24. Mean responses to questions about usefulness of information.

The graph shows the results of the post-hoc analysis, which reveals that the truck drivers found the navigation and vehicle condition information more useful than the warning or road sign information. The general communication information was not rated more or less useful than any of the other information types.

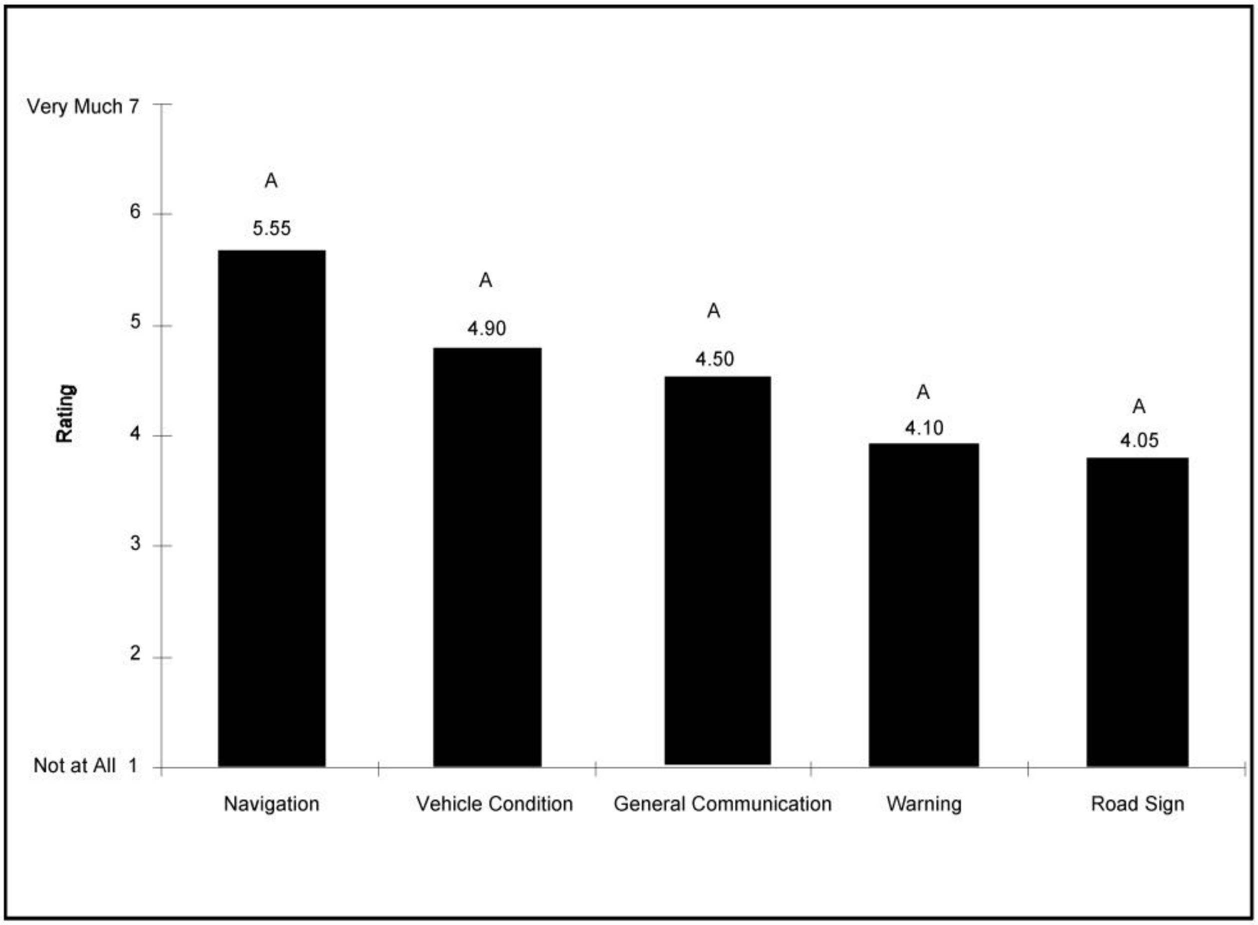

Figure 25. Mean responses to questions about how much the information would help the driver pay attention to driving.

When asked to rate how much each of the types of information helped drivers pay more attention to driving, trends developed that were very similar to those from the question pertaining to how useful the information was. The significance level for this effect (p=0.0446) was very close to the acceptable significance level chosen a priori for this analysis. **As** a result, the Student-Newman-Keuls post-hoc analysis of the significant main effect failed to find any differences between the mean responses for the information types. The critical difference between mean values (5) required to find significance under this test was 1.534. The largest pair-wise difference actually found between any of the means was 1.500, between navigation and warning information. Driver attention was aided more by the navigation information as compared with the warning information.

A complete listing of results for all questionnaire items is given in appendix E. In general, the truck drivers responded positively toward the system concept and the information it was able to provide. For example, when indicating how much they liked using the display, participants responded with a mean rating of 5.47 on a scale from one to seven, where a one was "did not like it at all" and a seven was "liked it very much." They also seemed especially accepting of the navigation information and how helpful it might be when navigating in unfamiliar surroundings, giving it a rating of 5.85 on a scale of one to seven, where a one was "not helpful at all" and a seven was "very helpful."

The truck drivers were also asked a series of questions about the system when it used the visual-only display and when it used a combination auditory and visual display. A pair-wise t-test was performed on each pair of questions, but no differences were found between the sensory modes of display. Note that there was a significant amount of variance for each of the questionnaire answers. This, combined with the low number of subjects, probably eroded the power of these tests to a minimal level.

RESULTS FOR THE TAXI DRIVER EXPERIMENT

Driving Performance Results

The goal of this analysis was to determine how taxi driver performance was affected by the use of an ATIS prototype system. There are several aspects of these types of systems that may have an impact on driver workload, including the sensory mode of display and the level of task difficulty. The ATIS prototype that taxi drivers used during this experiment was very similar to the system used by the truck drivers in the previously described truck driver experiment. The task levels of baseline, low, medium, high, and super high were also operationally defined the same.

It was expected that differences would exist in driving performance as task demands were increased. The first step in our analysis was to look for any differences in driving performance across the increasing levels of task demand that may be due to the sensory mode of information display. These differences were investigated without including the baseline driving condition because there was no system with which to make valid comparisons. The resulting model for this analysis was a 2 x 4 repeated measures design including the two sensory modes of display (visual-only and combination auditory and visual) and task level (low, medium, high, and super high). If differences were found for the sensory mode of display, the data were partitioned by sensory mode and compared separately against the baseline data. If differences in sensory mode were not realized, the data would be collapsed across the sensory mode of display and then compared with the baseline data.

The 2 x 4 analysis was run and no interaction or main effect differences were found for the sensory mode of display, except for the number of lane deviations per task variable. The analysis for the number of lane deviations per task included the 2 x 4 factorial repeated measures analysis to determine the effects of sensory mode of presentation on performance. In addition, a one-way ANOVA repeated measures analysis was conducted for the two groups of data partitioned by sensory mode of display (this included the baseline data). For all other measures, the data were collapsed across sensory mode of display and compared with data from the baseline drive, resulting in a one-way ANOVA with five levels of task demand (baseline, low, medium, high, and super high). The comparisons with the baseline data allow an assessment of the magnitude of driving performance differences and a determination of how they compared with the baseline driving conditions.

Several measures were collected to help make assessments of how using the ATIS prototype affected driving performance. These measures included standard deviation in steering wheel position, mean vehicle speed, standard deviation of vehicle speed, standard deviation of lane position, and number of lane deviations per task. The results of the one-way ANOVA comparing measures with the baseline condition are shown in appendix G, table 8. The standard deviation in steering wheel position, mean vehicle speed, standard deviation in lane position, and number of lane deviations per task were all found to be statistically significant at the $p<0.05$ level. The results of the 2 x 4 ANOVA for number of lane deviations per task are shown in appendix G, table 9. Since the interaction between task level and sensory mode of display was found to be significant, the simple effects were analyzed by partitioning the data across the sensory mode of display and performing a one-way ANOVA on each group, including the baseline task level data. The results of these ANOVAs are shown in appendix G, table 10.

The means for standard deviation in steering wheel position are shown in figure 26. No difference was found between the low and baseline task levels. In addition, no differences were found between the medium, high, and super high task levels, but they all resulted in larger steering variability than the low and baseline task levels. Recall that steering wheel variability can provide evidence of changes in workload that a driver is experiencing. As secondary task demands increased, the frequency of steering corrections tended to decrease. Since the small centering corrections decreased, the vehicle tended to drift farther from the lane center, and a larger steering input was required to correct the position, resulting in larger standard deviations of steering input. Therefore, these results might indicate that drivers were experiencing higher levels of workload in the medium, high, and super high task levels. The characteristic difference between the task levels in the higher and lower grouping was that the low and baseline task levels did not require the subject to manipulate any controls while driving. The medium, high, and super high task levels did require control manipulation and therefore resulted in higher steering variability.

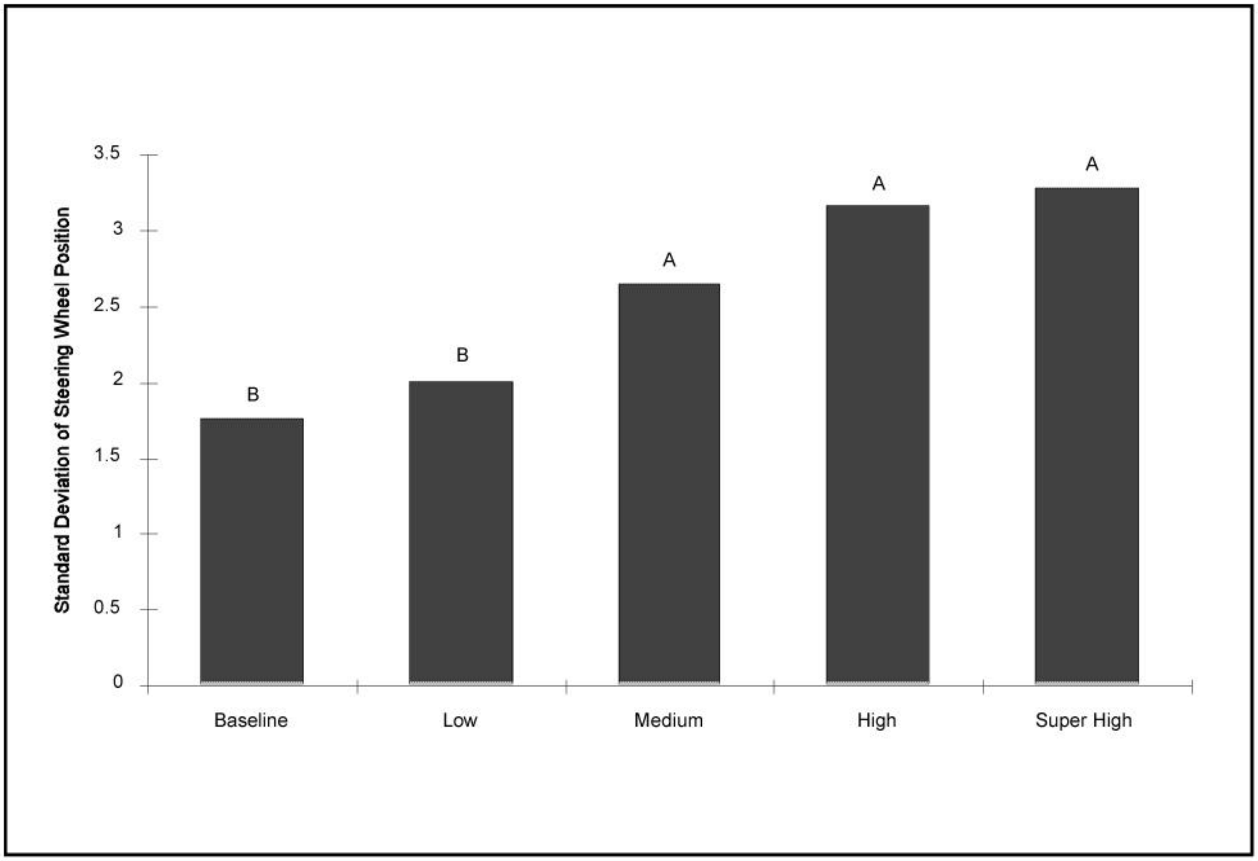

Figure 26. Standard deviation of steering wheel position by task level.

The mean vehicle speeds for each task level are shown in figure 27. The baseline task level resulted in the highest mean speed. The mean speeds for the remaining task levels were all lower than the baseline condition but were not different from each other. Mean vehicle speed has been shown by Monty (1984) to be a good indicator of secondary task demand. When drivers become involved with performing the secondary task—interacting with the ATIS prototype in this example—they tend to shift their attention away from maintaining the appropriate vehicle speed. This shift in attention eventually causes the vehicle speed to deviate from the target speed and will typically deviate in the direction of slower speeds because the driver will adopt a more cautious driving strategy (Antin, Dingus, Hulse, and Wierwille, 1990). In this case, all of the task levels that required interaction with the ATIS prototype resulted in a speed reduction when compared with driving without the system. Given the range of secondary task demands that are posed by the different task levels, one might have expected differences to exist between the lower and higher task levels. These data indicate that subjects did experience an increase in workload when using the ATIS prototype, but the differences in the workload between ATIS task levels either did not exist or were too slight to be detected under these testing conditions.

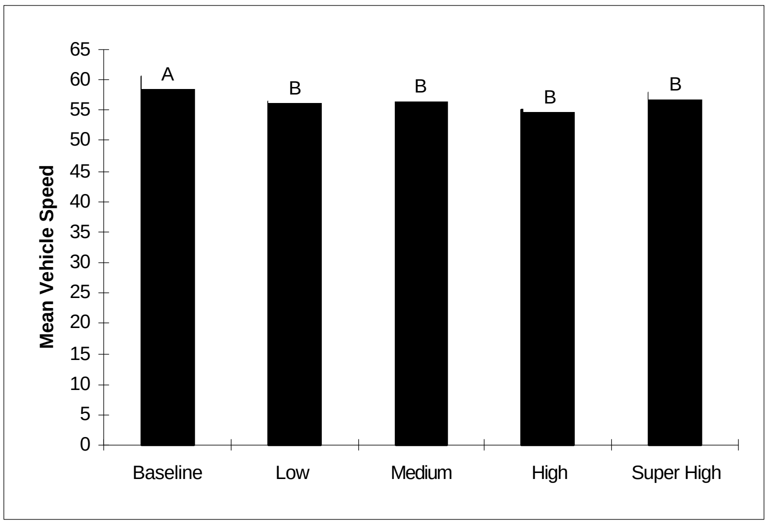

Figure 27. Mean vehicle speed by task level.

The means for standard deviation in lane position are shown in figure 28. The lane position variability was found to be lower in the baseline and low task levels than for the super high task level. The medium and high task levels were not found to be statistically different from the baseline, low, or super high task levels. Variation in lane position is an indication of how much the vehicle has strayed from the center of the lane during the drive. A potential reason that the vehicle might stray from the center of the lane would be due to the secondary task demands that result from interacting with the ATIS prototype system. The data for this measure indicated that the low, medium, and high task levels were not different from the baseline task; however, the super high task level did result in lane position variation that was greater than the baseline and low task levels. This difference is likely due to the extra attention necessary to make the higher number of control inputs that the super high task level required.

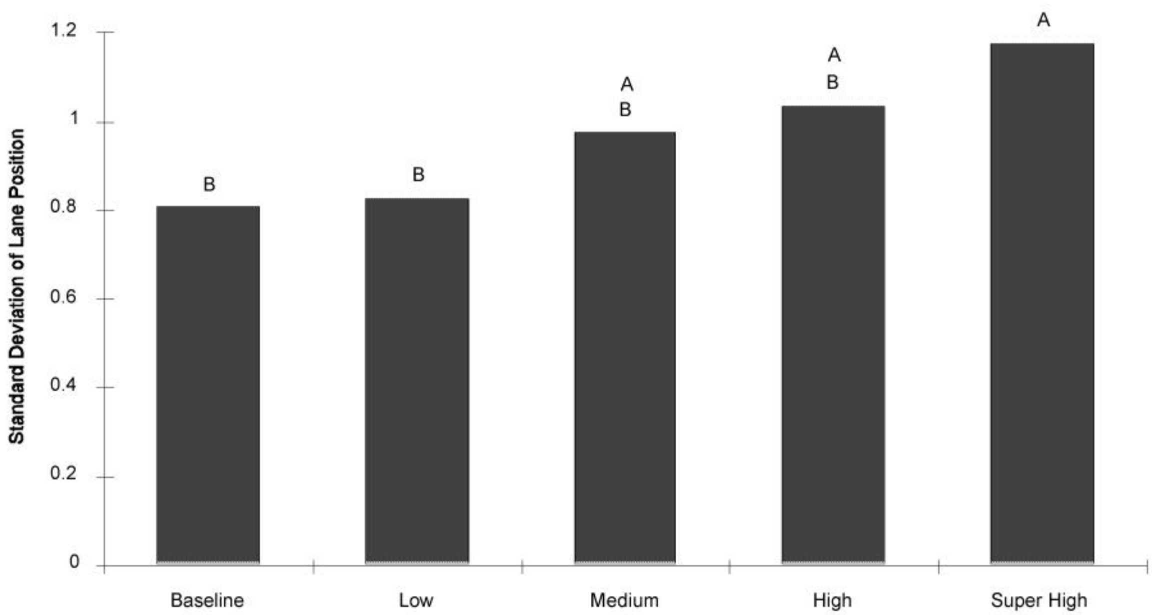

Figure 28. Standard deviation in lane position.

The interaction between sensory mode of display and task level for number of lane deviations per task is shown in figure 29. At first glance, it appears that the number of lane deviations per task is larger in the visual-only sensory mode of display for the low, medium, and high task levels. This effect also seems to be reversed for the combination visual and auditory sensory mode of display. Lane deviations are a face-valid measure of the workload incurred by subjects performing a secondary task, such as interacting with the ATIS prototype. An increase in this measure suggests that the subjects are diverting their attention away from the task of maintaining their lane position toward their interaction with the system. This result would indicate that the visual-only sensory mode of display caused a reduction in driving performance for the low, medium, and high task levels, but not in the super high task level. A possible explanation for this effect is that the addition of the auditory element of the display helped subjects interact with the system and maintain their lane position at increasing levels of task demand until the super high task level was reached. At the super high task level, it is possible that subjects were so overloaded that the addition of the auditory element caused a further reduction in lane-keeping performance. The information on the visual-only display could be sampled at the driver's convenience, allowing the driver to better manage his or her distribution of resources between controlling the vehicle and interacting with the system. The auditory information had to be sampled when it was presented, so the driver had no way of controlling when he or she wanted to pay attention to the information. Therefore, in the highest condition of workload, the addition of the auditory information served to further distract the subject and caused him or her to commit a higher number of lane deviations.

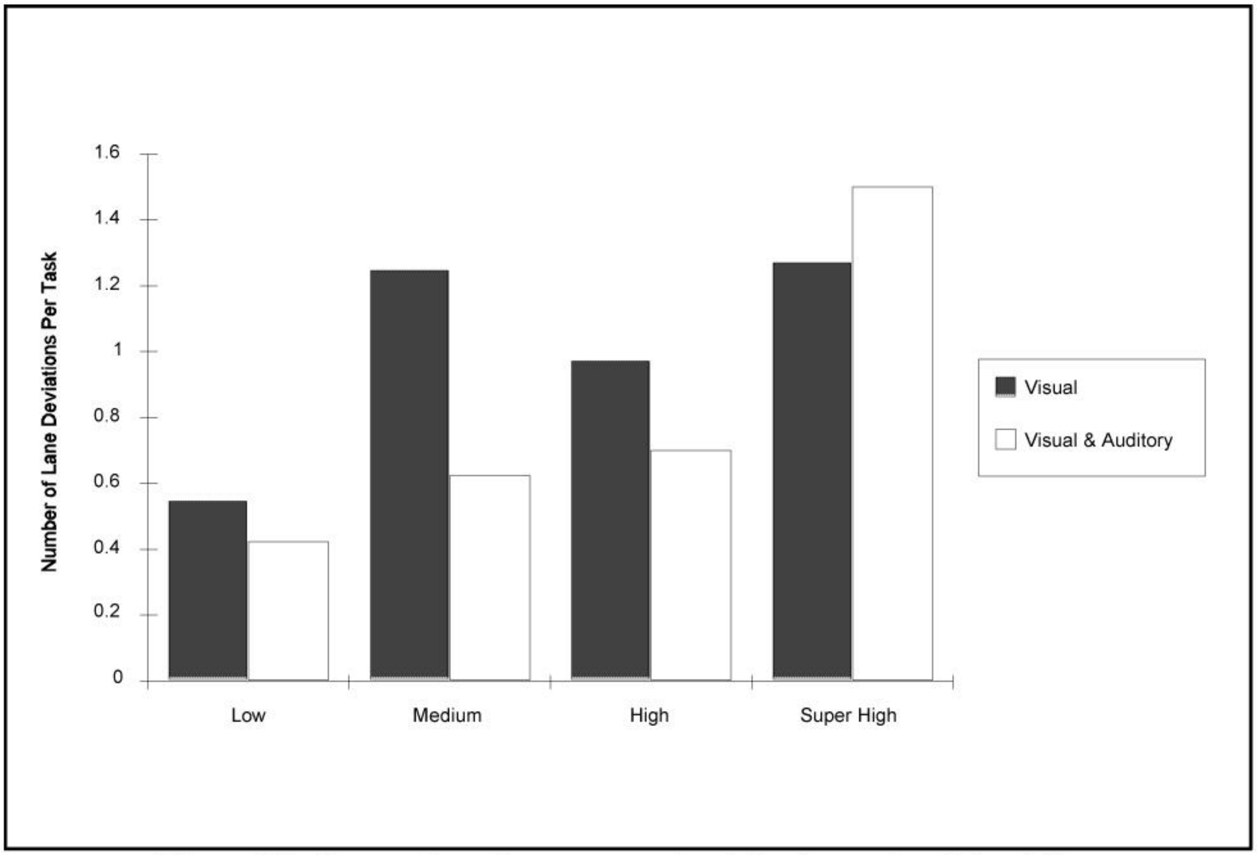

Figure 29. Interaction of sensory mode of display and task level for number of lane deviations per task.

The simple effects for each sensory mode of display were analyzed separately by partitioning the data by sensory mode and performing separate ANOVAs independently on each group with the baseline data included. The data for the visual-only and combination auditory and visual sensory modes of display are shown in figures 30 and 31, respectively. When comparing the ATIS task levels with the baseline data, an increase in the number of lane deviations over baseline may be seen in the medium, high, and super high task levels. Again, as in the truck driver experiment, there were no lane deviations during the baseline drives. When the information was presented in a visual-only format, relatively small increases in task demand, such as one or two button presses for the medium task, caused an increase in lane deviations. An increase in lane deviations for the combination auditory and visual sensory mode of display over the baseline task level did not occur until the task demands had been increased to the super high level, where four or five button presses were required and a high amount of information was presented on the display.

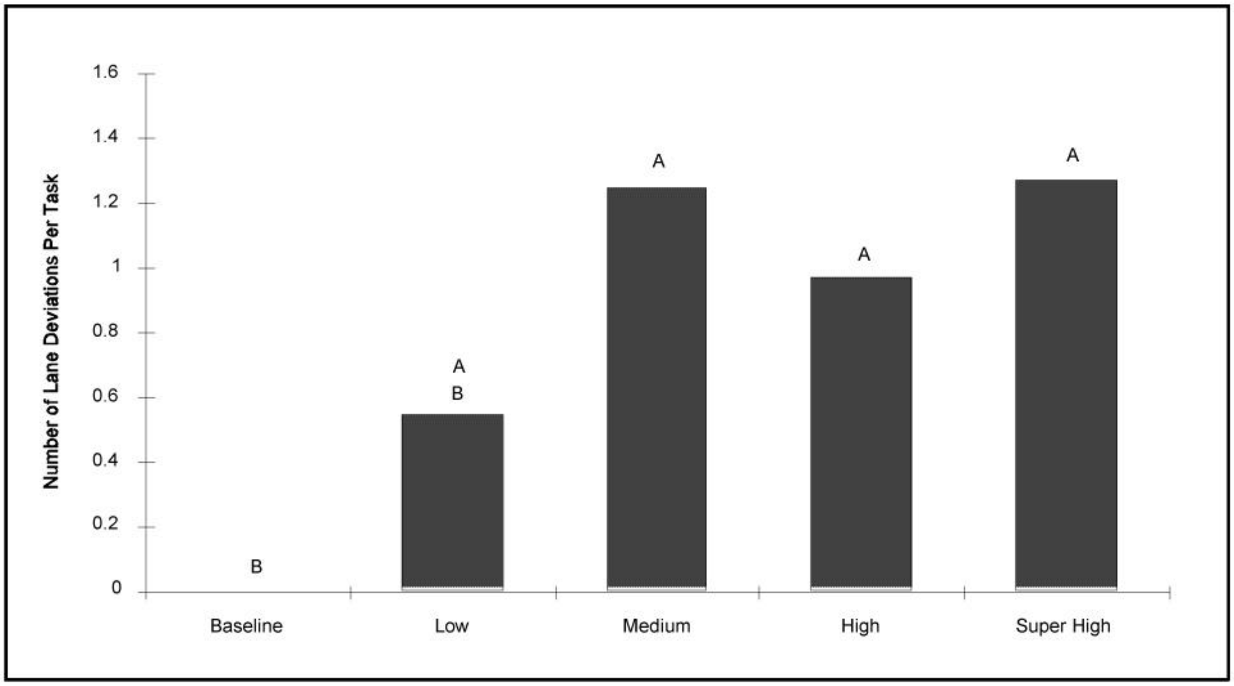

Figure 30. Number of lane deviations per task by task level for visual-only sensory mode of display.

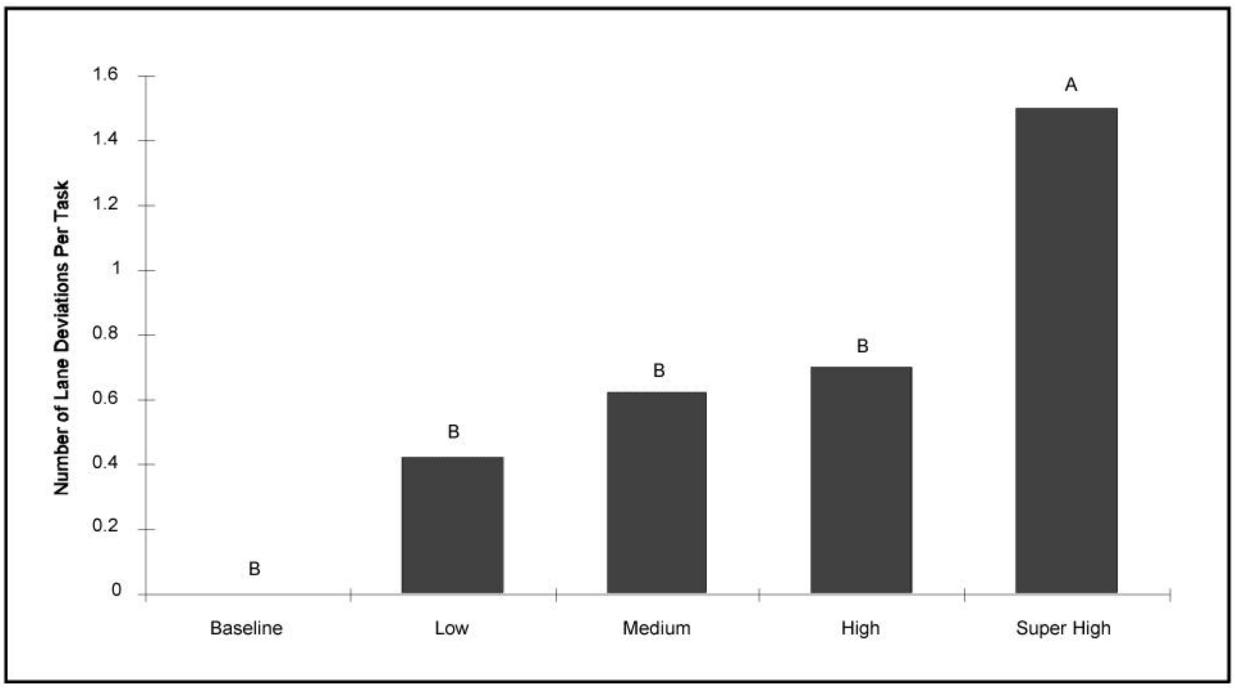

Figure 31. Number of lane deviations per task for combination auditory and visual sensory mode of display.

Eye Glance Results

The strategy for analyzing the eye glance data was similar to that used for the driving performance analysis in the previous section. The two eye glance measures analyzed for this experiment were duration of glances and number of glances per task. An ANOVA was performed on the data using a 2 x 4 (sensory mode of display by ATIS task level) within-subjects design. The analysis determined that there were no significant differences found by sensory mode of display. The data were then collapsed across the sensory mode of display and a one-way ANOVA was performed on the data using a within-subjects design that included baseline task level data. The results of the ANOVA are shown in appendix G, table 11. The number of glances per task variable was found to be statistically significant at $p < 0.05$, while the duration of glance variable was not. The mean values for the number of glances per task are shown in figure 32. The post-hoc test revealed that the number of glances to the display per task for the low task level was not different from the baseline task level. The medium, high, and super high task levels were not different from one another, but were higher than the low and baseline task levels.

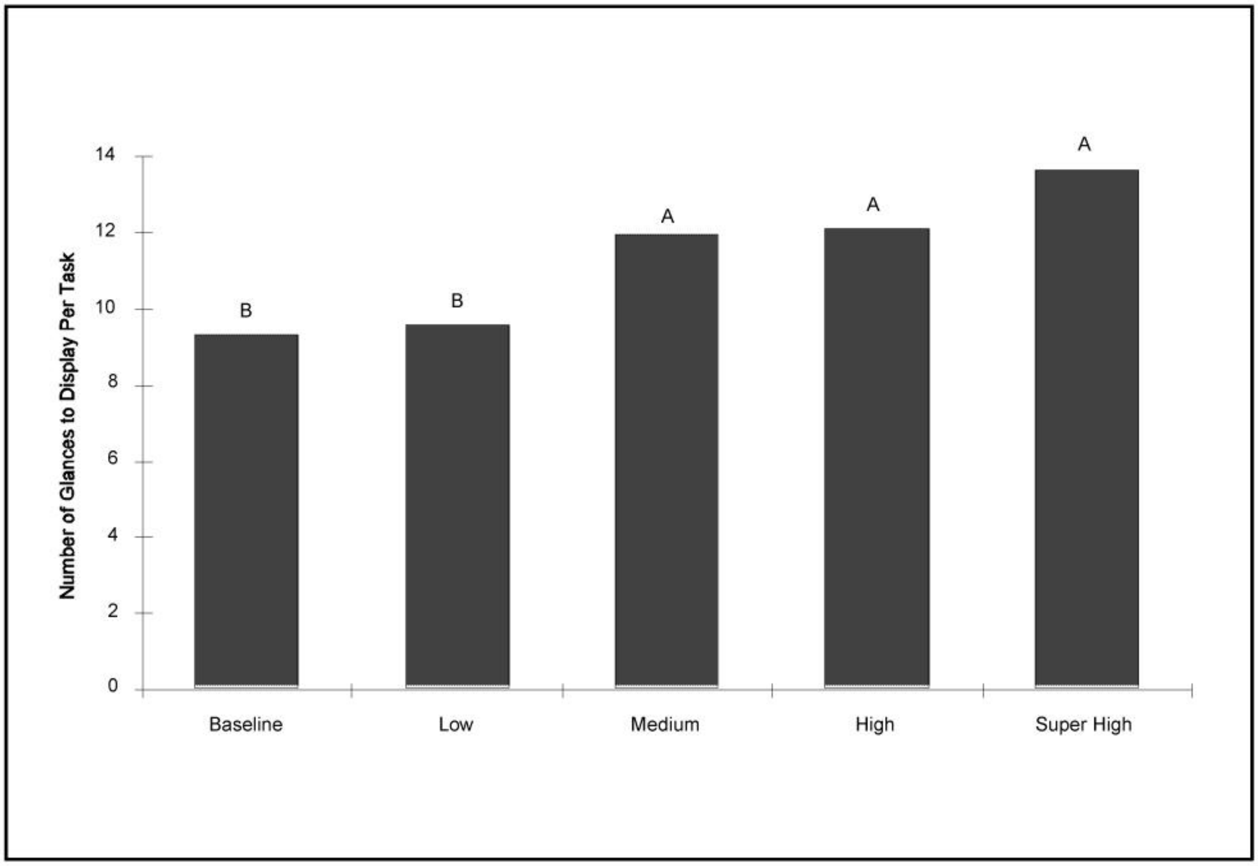

Figure 32. Number of glances per task by task level.

ATIS Prototype Use Results

Two measures were analyzed to make assessments of how subjects performed when using the ATIS prototype during the experiment. The two measures were the amount of time to complete the experimental tasks, and the number of errors committed per required button press. It is also worth noting that there were no occurrences of subjects missing a turn that was prescribed by the navigation information presented by the ATIS prototype. Only the medium, high, and super high task levels were included in this analysis because the low task level did not require any control manipulations while interacting with the system, and there was no system in the baseline task level.

For these measures, the data were analyzed as a 2 x 3 within-subjects factorial design including the visual-only and combination auditory and visual sensory modes of display, and the three task levels that required control manipulations. The results of the ANOVA for the time to complete task and number of errors per required button press are shown in appendix G, table 12. Only the main effect of task level was found significant for the time to complete task measure. The mean values for the time to complete task measure are shown in figure 33. The super high task level resulted in task completion times that were greater than both the medium and high task levels. The medium and high task levels were not different from one another.

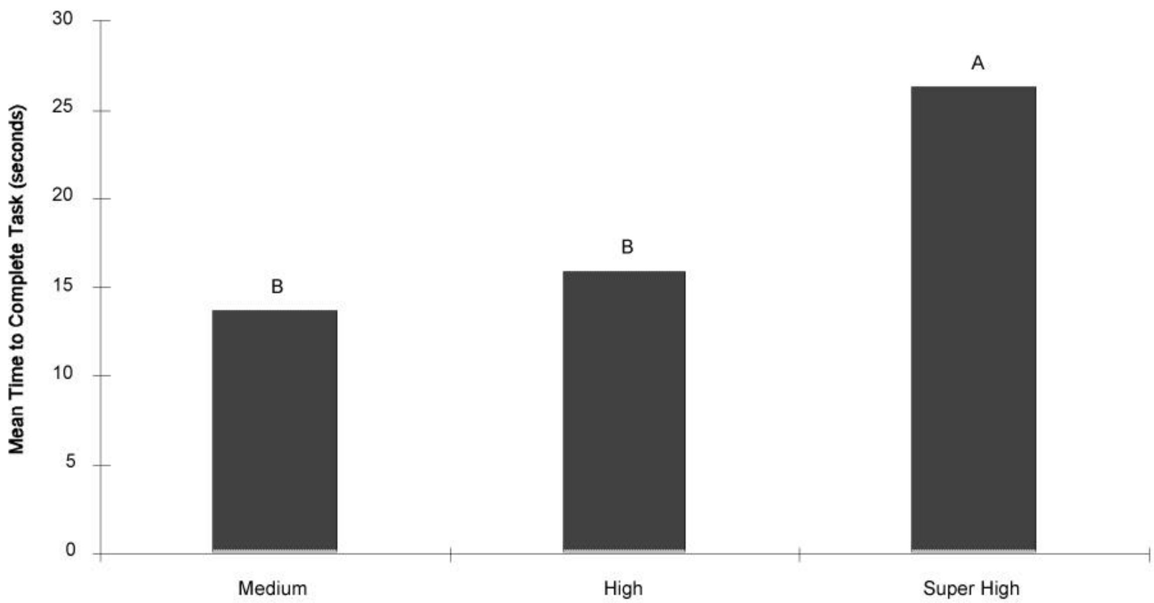

Figure 33. Mean time to complete task by task level.

Subjective Workload Results

A modified version of the SWAT (Reid, Eggemeier, and Nygren, 1982) was used to determine subjective workload differences. Subjective ratings were collected at the end of each of the eight data collection segments during the experimental drive. Drivers provided subjective ratings on three dimensions of mental workload (visual effort, time stress, and psychological stress) as high, medium, or low. All three dimension scores for each of the segments were then summed to produce a combined score. The data were coded such that a subjective rating of low was given a one, medium was given a two, and high was given a three.

An ANOVA was performed on the workload measures collected during the experiment. A 2 x 4 within-subjects factorial model was used with two levels of sensory mode of display and the four task levels. The baseline condition was not included in any of the subjective workload analyses because data were not collected for this measure during the baseline run. The results of the ANOVA are shown in appendix G, table 13, for the individual dimensions of workload as well as the combined score. No statistically significant differences were found between any of the subject workload measures collected for this experiment.

Questionnaire Results

After completing all experimental drives, the taxi drivers were asked to complete a 24-item questionnaire that was designed to determine differences in how they felt about the types of information that had been presented, the methods that were used to present it, and the effectiveness of these types of systems overall.

The questionnaire was designed to determine the taxi drivers' attitudes about how the information would affect how they perform their job. One of the items addressed how useful these drivers felt the information was. The question was asked in separate items, once for each type of information that was presented. The five types of information included navigation, vehicle condition monitoring, general communication, warning, and road sign information. The drivers were given clear examples of each and were asked to rate how useful the information was on a scale from very useful to not useful at all (one to seven). A similar question format was used to determine how drivers felt about whether each of the five types of information would help them pay more attention to their driving, and how much drivers would be willing to pay for each type of information. Each of the questions was asked once for the information presented with a visual-only display, and once for the combined auditory and visual display. A 2 x 5 within-subjects factorial model was used with two levels of sensory mode of display and five levels of information type. An ANOVA was performed on the data from each question and the results are shown in appendix G, table 14.

No significant interactions were found for any of the questions that were analyzed. The main effect of information type was found to be significant for questions pertaining to how useful the information was and how much the drivers would be willing to pay for each type of information. The mean ratings of how useful the information was to the taxi drivers are shown in figure 34. A Student-Newman-Keuls post-hoc analysis was performed on the main effect data to determine pair-wise differences between the different information types. The analysis revealed that the taxi drivers rated the navigation information more useful when performing their jobs than the vehicle condition and road sign information. The mean ratings of usefulness for general communications and warning information were not found to be different from any of the other types of information.

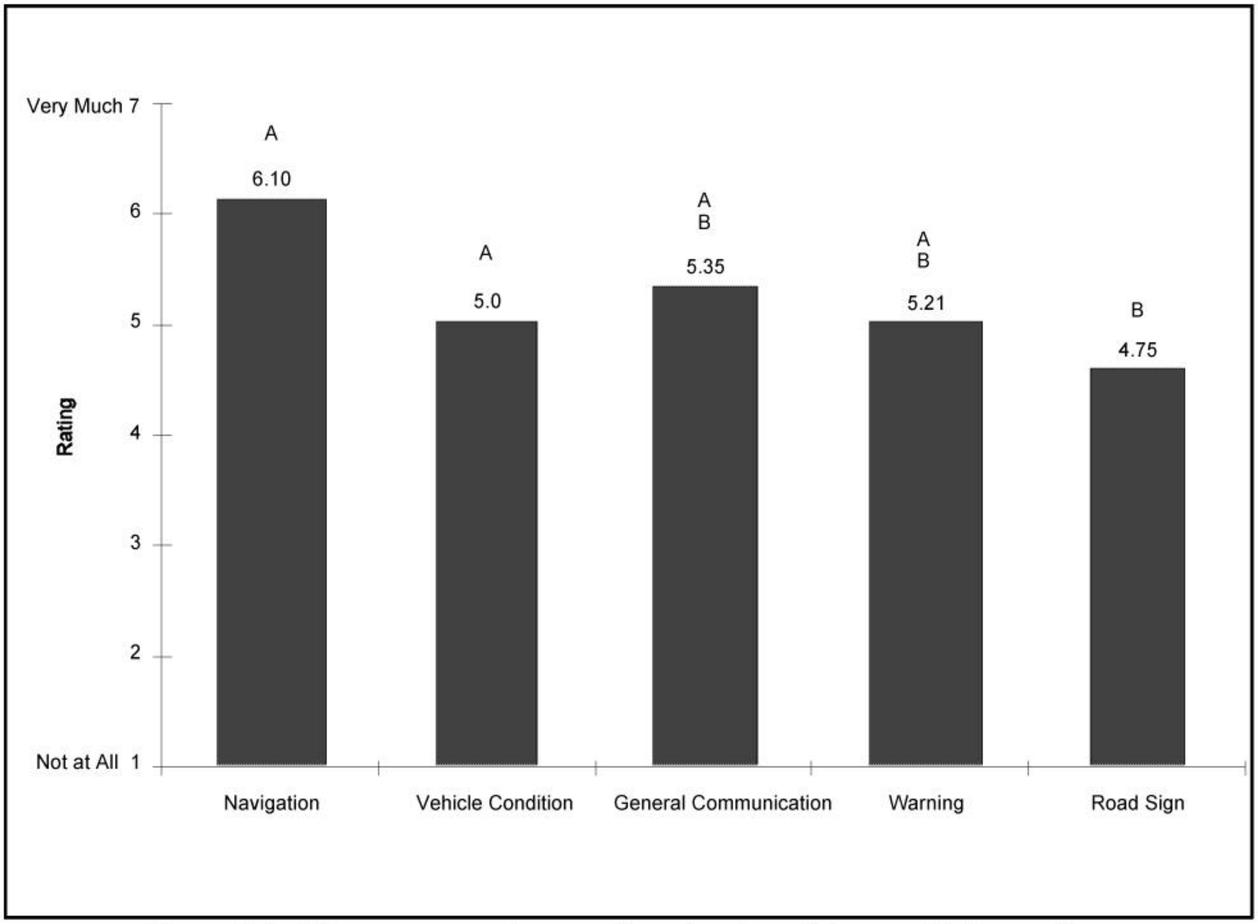

Figure 34. Mean response to question about usefulness of information.

The mean responses for how much the taxi drivers would be willing to pay for the different types of information are shown in figure 35. The taxi drivers indicated that they would be willing to pay more for the navigation and general communications information than the road sign information. Their willingness to pay for the warning and vehicle condition information was not different from any of the other types of information. Almost certainly, the navigation and general communication information was rated more valuable by the taxi drivers because they were able to see a direct application of the information in how they currently perform their jobs.

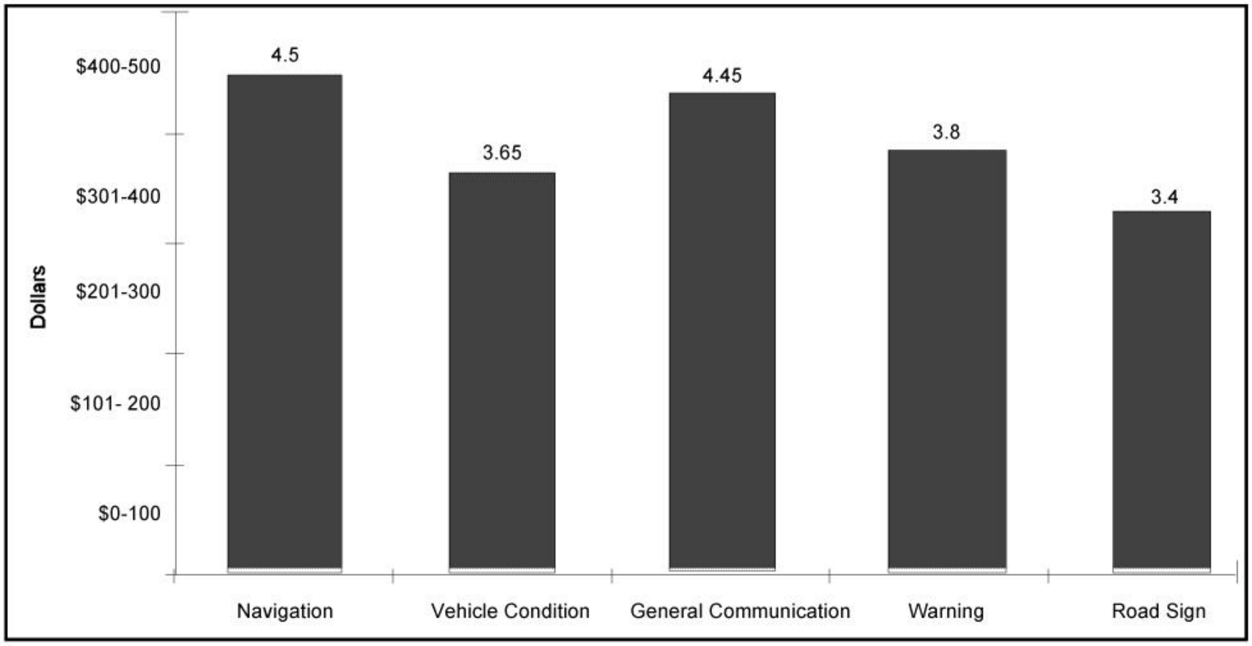

Figure 35. Amount of money taxi drivers would be willing to spend for a system that includes the categories of information.

A complete listing of questionnaire results is given in appendix F. Overall, the taxi drivers responded positively toward using the system to help them complete their jobs. They were especially positive when asked how helpful the navigation information would be in finding an unfamiliar destination. The mean response was 5.8 on a scale from one to seven, where a one was "not helpful at all" and a seven was "very helpful."

Each of the questions was asked about the system when it used the visual-only display and when it used a combination auditory and visual display. A pair-wise t-test was performed on each pair of questions, but no differences were found between the sensory modes of display. Note that there was a significant amount of variance for each of the questionnaire answers. This, combined with the low number of subjects, probably eroded the power of these tests.

CHAPTER 5: DISCUSSION AND CONCLUSIONS

TRUCK DRIVER EXPERIMENT

Commercial truck drivers are typically more experienced, and in some cases are more trained, than the average driver on the road. It has been hypothesized that because of this additional experience and training, commercial drivers will be better able to cope with the additional workload that may be present while interacting with ATIS. To help define the impacts of increasing workload on commercial drivers, it was necessary to evaluate their driving and ATIS task performance across varying levels of interaction.

The objective of this study was to determine the effects of display modality, level of interaction, and amount of information being presented on driving performance and ATIS task performance for truck drivers. The introduction of any level of interaction with an ATIS will probably result in some level of increased workload for the driver when compared with normal driving. However, it may be possible that the increase in workload would not result in dangerous driving behavior. A secondary objective of this study was to determine at what level of ATIS task demand driving performance might begin to degrade to the point of becoming dangerous.

Driving Performance

Driving performance, as it was examined in this experiment, consists of several measures of vehicle control that can be used to make assessments of the workload a driver has experienced. A goal of this experiment was to determine the effects of various levels of ATIS task difficulty on the amount of workload a truck driver experiences while driving. A baseline task level has also been included to provide a benchmark reference of how drivers perform during conventional driving. By comparing the direction and magnitude of differences between the baseline task level and each of the ATIS task levels, we can begin to make judgments about how the truck driving population might be affected by the inclusion of ATIS into their driving environment.

A second goal of this research was to determine the effects of sensory mode of information displayed on driver workload. The data analysis revealed that a difference did exist for the variable of standard deviation of speed. Therefore, the data were partitioned by sensory mode of display, and the remaining comparisons to the baseline task level were performed independently for all variables. The differences that did exist seemed to be subtle, often only showing up as minor differences in some of the pair-wise comparison groupings between the ATIS task levels as determined by the post-hoc tests. All of the trends between task levels for the remaining variables were consistent across the sensory mode of display.

The lack of strong differences between the sensory modes of display is somewhat surprising. The auditory component of the display provided feedback about the menu selections chosen and the content associated with the screens of information. It was hypothesized that the addition of the auditory information would make the ATIS system easier for the truck drivers to use, reducing overall workload. The original hypothesis that this would help reduce workload was based on the idea that if the drivers were able to listen to the information without having to shift their visual attention to the display, it could reduce visual attention demand.

There are two possible explanations for the lack of benefits seen as a result of the addition of the auditory component of the display. First, the additional information provided through the auditory channel gave mostly feedback information about menu selections and important information that was also presented on the display. In other words, the auditory information was redundant and did not assist the driver in making correct decisions or choices with the system. Instead, it provided feedback and assurance about what selection had been made or what the important information was on a given screen. Probably the most difficult task to undertake while interacting with the system was to decide which menu selections to make to find the appropriate information. These tasks might have a relatively high potential to increase driver workload because they require attentional resources to review the potential options, decide which option to choose, and then make the appropriate control activation associated with the option. If the use of the auditory information would have been used to somehow present the menu options, thus reducing the amount of visual attention required, there might have been more of an opportunity to reduce driver workload. This kind of use of auditory information presentation was considered during the development of the prototype but was ultimately disregarded due to the large number of information choices required to be remembered and the high potential for it to annoy the driver over repeated use.

The second possible explanation for the lack of auditory presentation benefit has to do with the location of the ATIS display. The display was located directly in front of the driver above the steering wheel at about 15 degrees below the driver's line of sight. This position made it very easy to glance at the display while driving. In fact, it is possible that the display attracted the driver's attention in some cases because of the natural tendency to want to look at the display after the visual content had been updated. If the display was attracting the driver's attention regardless of whether the redundant auditory cues were presented, the potential benefits of the auditory display (i.e., eliminating visual attention demands) were probably not completely realized.

After the data were partitioned by sensory mode, the analysis concentrated on determining the differences caused by varying the secondary task load as a result of interacting with the ATIS prototype. Recall from previous explanations that the difference between task levels was stratified by the amount of information being presented on the display and the number of control interactions required to retrieve information from the ATIS prototype. The low task consisted of the display of a low amount of information on the ATIS prototype display. No interaction other than visually monitoring the display was required for the low task level. The medium task level also had a low amount of information (three or fewer units) presented on the display but required the driver to make one or two button presses to navigate through the menu system to get to the desired information. The high task level also required one or two button presses, and the desired information was located on a screen that contained a high amount of information (greater than seven units). The super high task level required four or five button presses, and the desired information was on a screen that contained a high amount of information.

Across all measures collected to analyze driving performance, the baseline task level resulted in values indicating that driver workload was always less than or equal to that collected for the ATIS task levels. Since we expect to see an increase in driver workload as the task complexity is increased, the question then becomes, at what task level does the workload increase significantly beyond the baseline level? Another important issue in this analysis is the question of how driver performance varies between the ATIS task levels, and what the characteristic differences are between the task levels that would seem to have the greatest impact on driving performance.

The standard deviation of steering wheel position, standard deviation of lane position, and number of lane deviations may be considered indicators of lateral vehicle control. Increases in these variables reflect an increase in driver workload. When comparing performance between the baseline and low task levels, the truck drivers exhibited an increase in standard deviation of steering wheel position and standard deviation of lane position (related measures), but not an increase in number of lane deviations. This result suggests that the different presentation of information and amount of information in the low task level caused drivers to make more steering adjustments to maintain lateral control of the vehicle. This increase did not, however, result in a larger number of lane deviations, which might have implicated the potential for increased incidents of unsafe driving behavior.

For these same lateral control measures, the only one that showed any differences between the low, medium, and high task levels was the standard deviation in steering wheel position. The difference was only noted for the combination auditory and visual condition where the high task level resulted in a higher level of steering variability than the low condition. The super-high task level resulted in values for each of the lateral control measures that were always higher than the baseline task level, and were also always higher than the low, medium, and high task levels. This result shows that there was some characteristic of the super high task level that resulted in a significant decrease in driver performance—the number of control activations required to complete the task. Recall that the design differences between the medium, high, and super high task levels were the amount of information on the screen and the number of control activations required to complete the task; furthermore, the difference between the medium and high task levels was the amount of information presented on the display. This difference did not result in many statistical differences between the lateral control measures. There was, however, a large difference between the high and super high task levels. The characteristic difference between the high and super high task levels was the number of control activations required to complete the task where the high task required up to two button presses and the super high task required up to five button presses.

The standard deviation of vehicle speed and mean vehicle speed can be considered measures of longitudinal control. Increases in the standard deviation of vehicle speed and decreases in mean vehicle speed are indications of increased driver workload. When compared with the values collected during the baseline condition, mean speed was found to be different from all ATIS task levels in the direction that would suggest that drivers were experiencing greater levels of workload. The data for this variable did show that interacting with the ATIS prototype did have an impact on driving performance where all ATIS task levels were worse than baseline, but not different from one another. The standard deviation of vehicle speed showed a different result where there were no differences between the baseline, low, medium, and high task levels, but a greater speed variability did exist with the super high task level.

Across nearly all of the driving performance variables collected, the trend that surfaced was that there were few differences between the low, medium, and high task levels. This lack of difference seems to suggest that the characteristic differences between the low, medium, and high task levels did not result in differences in driving performance. This means that, for the truck drivers that participated in this experiment, an increase in the amount of information being displayed did not cause a change in performance, while an increase in the number of button presses required to complete the task did cause a change in performance.

Eye Glance

The most interesting result with respect to the eye glance data collected during these experimental trials is actually the lack of differences found between the task levels. It was expected that, as the visual demands of interacting with the system were increased, the number of glances to the display would also increase. These data indicate that there were no statistical differences found between the visual glancing behavior between the baseline task level (normal driving) and the task levels that required interaction with the ATIS prototype. This result, along with the finding that subjects did not increase the duration of glances based on task level, would suggest that the truck drivers sampled from the display regularly and for fairly short periods of time. Since this effect also occurs in the baseline condition, it could be hypothesized that the truck drivers have learned this glance behavior from their everyday truck driving tasks and were also able to apply it to the task of interacting with the ATIS prototype.

The difference found between the low and super high task levels was probably caused by this increase in driver-system interaction. The super high task required subjects to make five button presses to navigate through a menu system and then locate a desired item on a screen that contained more than seven units of information. The low task simply required the subject to monitor the speedometer and road sign information that was being presented on the display.

ATIS Prototype Use

It was not surprising that time to complete the task became longer as the complexity of the display and the level of interaction required to complete the task became greater. Of interest is the difference in magnitude between the times to complete each task level. The difference between the medium and high task level was just over 3 seconds, whereas the mean time to complete the high tasks was 13.6 seconds. The characteristic difference between the medium and high tasks was the amount of information presented on the screen that the subject would have to search through to find the desired piece of information. The screen contained less than three units of information for the medium tasks and more than seven units of information for the high tasks. Either one or two button presses were required to complete both the medium and high task levels.

The difference between the mean time to complete the super high task was more than twice that of the high task level, requiring just over 30 seconds per task. The characteristic difference between the high and super high tasks was the number of button presses required to complete the task. The amount of information presented on the screen during the tasks was the same. The super high task required four or five button presses, whereas the high task level required only one or two presses. This result seems to indicate that a much larger increase in time to complete the task resulted from an increase in the number of control manipulations required as compared with the increase in the amount of information presented on the screen.

Subjective Workload

No statistically significant differences were found between any of the subject workload measures collected for this experiment. It is surprising that no differences were found in this experiment, especially for the task level variable. As task demands were increased, it was expected that the subjects would become aware of an increase in their workload and give higher reported responses to the workload questions. A possible explanation for this is that the subjects were not recognizing the increases in workload and therefore did not report them appropriately. Another possible explanation for this is that truck drivers are actually better able to manage increases in mental workload caused by increases in secondary task demand. It might be that truck drivers frequently encounter situations that can cause an increase in mental workload and as a result they have developed strategies to cope with it. Prior to their experimental drive, drivers were reminded about the meaning of the workload ratings. It is still possible, however, that they were unable to accurately recognize the differences as they arose.

Questionnaire

The navigation information was rated more useful than several other information types. This may be because it is information that can be more difficult to retrieve from conventional sources such as maps or lists of directions from a dispatcher. The navigation information, as presented in the prototype system, gave truck drivers exact information about where they should make their turn, reducing the amount of visual scanning and mental processing required to find a destination. The truck drivers also rated vehicle condition information more useful. This result is not surprising because of the high costs associated with operating equipment that might be unsafe for driving or could result in damaged cargo. The general communications information was also rated somewhat useful to the truck drivers. It is plausible that this type of information was rated higher because the truck drivers are somewhat conscientious of always being accessible to a dispatcher. There were no questions directed toward determining this; however, many of the drivers mentioned that it would be nice if they could call in at any time, but they didn’t necessarily want to be reached at the dispatcher’s convenience.

The warning and road sign information was probably rated less useful because this was usually redundant information, often duplicating what was presented in some other manner, such as on road signs. The conditions of the simulated driving environment were clear weather and good forward visibility. It is possible that this information might have been deemed more useful under conditions of reduced visibility or poor weather where an in-vehicle display could provide the most benefit.

When asked to rate the degree to which each of the types of information helped drivers pay more attention to driving, trends developed in the results that were very similar to those from the question pertaining to the usefulness of the information. The navigation information was considered to help the drivers pay more attention to their driving than the warning information. In general, the truck drivers responded positively toward the system concept and the information it provided.

Sensory Mode of Display

The sensory mode of display was varied between visual-only and a combination of visual and auditory displays. An auditory-only condition was not included because it was felt that any feasible system will have some element of visual display, especially when considering the diversity and complexity of information that might be presented. Overall in this experiment, there were few performance differences shown between the visual-only and combination auditory and visual systems.

The lack of benefits shown by adding the auditory information to the display could be due to a genuine lack of a real performance advantage that auditory information can provide with this driver population, the conditions in the testing environment, or how the auditory information was incorporated into the ATIS prototype design. There have been a variety of studies performed in the past that have demonstrated driving performance benefits from the addition or use of auditory information (Dingus, McGehee, Hulse, Jahns, Manakkal, Mollenhauer, and Fleischman, 1994; Walker, Alicandri, Sedney, and Roberts, 1990; Labiale, 1990). Because these previous research efforts have shown driving performance benefits by adding auditory information, it is necessary to scrutinize the testing conditions and the use of auditory information in this experiment.

In terms of how the auditory information was incorporated into the prototype system, the auditory information was redundant and did not independently assist the driver in making correct decisions or choices with the system. Instead, it was used to provide feedback and assurance about what selection had been made or what the important information was on a given screen. The auditory display was not used to present menu choices due to the high potential for annoying the driver. In general, spoken option lists must be relatively short to be acceptable and usable. If the supplemental auditory information could have been used in a non-intrusive or non-annoying way to assist drivers with making menu choices, it might have been able to help reduce workload in tasks that required greater interaction. In terms of system operation and, in particular, the number of errors committed, the addition of the auditory information actually caused a slight increase in errors at the high task level but also reduced the number of errors in the super high task level. This helps support the idea that the auditory information is most effective when included in situations where it is not just redundant information, but rather can help the driver cope with the demands of increased task complexity.

Another plausible explanation for the lack of auditory presentation benefit relates to the location of the ATIS display during this experiment. The display was located directly in front of the driver above the steering wheel at about 15 degrees below the driver’s line of sight. This positioning made it very easy to glance at the display while driving. In fact, it is possible that the display actually attracted the driver's attention as it was updated. The addition of the auditory information should have, theoretically, resulted in a display that required less visual attention than the visual-only display. However, there were no differences found between the number or duration of glances to the display by sensory mode of display. If the display was attracting the driver's attention, whether or not the redundant auditory cues were presented, the potential benefits of providing supplemental auditory information (i.e., eliminating visual attention demands) were not realized. Again, this was evident in the lack of differences seen in driver performance, eye glance behavior, and subjective workload assessments.

In summary, it would appear that in terms of the potential for such systems to be used by truck drivers in the future, it is possible to allow truck drivers to interact with a relatively complex ATIS while driving without necessarily compromising driving safety. The results of this experiment indicate that the number of control activations (menu selections) has a greater impact on overall driver performance than the amount of information that was presented on the display. Some implications for systems design are that when the driver must use a system to complete a function while driving, it would be beneficial to design the system so that the number of interactions required to complete the task is minimized. The point at which the number of interactions begins to make the task unsafe for completion while driving is not exactly known at this time. Additional research using experimental methods and equipment that are able to provide more ecological validity is recommended before a quantification of the impacts of ATIS on truck driving safety may be determined.

One positive aspect of the results found in this experiment is that the truck drivers appear to be relatively good at self-regulation when it comes to dividing their attention between obtaining information from the system and controlling the vehicle. The lack of differences in the performance measures that were collected, especially eye glance behavior, between the medium and high task levels provides evidence of this effect. The amount of information on the display was effectively doubled between these conditions, yet no differences were shown between the frequency or duration of glances between these or any other performance measures collected in this experiment.

TAXI DRIVER EXPERIMENT

The goal of this research was to determine the impacts of varying the sensory mode of display and the amount of interaction required by an ATIS prototype on taxi driver workload. Emerging ATIS technologies will soon be available to aid taxi drivers in their day-to-day operations. Some of the tasks they will be performing with the ATIS will have to be performed while driving. To ensure that these systems do not increase driver workload to a level where driving safety is compromised, it is necessary to determine the best methods for displaying information and what levels of interaction can be considered safe. The taxi driver participants of this experiment drove a simulated vehicle while operating an ATIS prototype that incorporated different sensory modes of display and varying levels of task complexity. Data were collected for each participant's drive and were analyzed to help make assessments of the impacts of operating an ATIS on driving safety.

Driving Performance

A number of measures were collected in this experiment to help determine the effect of interacting with an ATIS on taxi driver performance. These measures included the standard deviation in steering wheel position, mean vehicle speed, standard deviation of vehicle speed, standard deviation of accelerator pedal position, standard deviation of lane position, and the number of lane deviations per task. The measures were collected while the taxi drivers performed tasks of low, medium, high, and super high difficulty. A baseline task level has also been included to provide a benchmark reference of how drivers perform during conventional driving. By comparing the direction and magnitude of differences between the baseline task level and each of the ATIS task levels, we can begin to make judgments about how the taxi-driving population might be affected by the emergence of ATIS technologies into their working environment.

The standard deviation of steering wheel position, standard deviation of lane position, and mean vehicle speed all showed statistically significant differences by task level. Again, we expect to see some differences in these variables as the task demands are increased. Of interest is determining where these increases occur. For standard deviation in steering wheel position, there was no difference between the baseline and low task levels, but the remaining medium, high, and super high task levels did result in greater steering variability. For the standard deviation in lane position, which is related to steering variability, the baseline and low task levels resulted in the least lane position variability, and the super high task level showed the most. So, for these measures of lateral vehicle control, there seems to be a division in performance where the baseline and low tasks resulted in the lowest amount of variability. This makes sense since the low task level displays provided close to the same amount of information, just in a different format and location. The remaining task levels all required some level of interaction, which is probably why some differences were shown between them and the baseline and low task levels. One explanation for this decrease in performance is that taxi drivers may not be accustomed to operating many additional controls while driving the vehicle. They typically do have to operate some type of communications device and a meter but probably do not have much additional equipment.

Longitudinal or performance measures included the standard deviation in speed, mean vehicle speed, and standard deviation of accelerator pedal position. Of these three variables, only the mean vehicle speed showed a significant difference between task levels. The mean speed was found to be higher in the baseline task level than for any of the other task levels. There were no statistically significant differences between the remaining ATIS task levels. The higher mean speed in the baseline condition is probably due to drivers being much more comfortable in operating the vehicle when they know they will not have to interact with the system. The baseline driving did not require the driver to perform any secondary tasks that might have caused an increase in driver workload. The lower speeds seen for the ATIS task levels might have been caused by drivers taking a more cautious approach to driving when they knew they would have to interact with the system. Mean vehicle speed has been shown by Monty (1984) to be a good indicator of secondary task demand and will often vary in the direction of being more cautious as task load increases (Antin, Dingus, Hulse, and Wierwille, 1990).

In the case of the taxi drivers, the results found across all driving performance variables were not in complete agreement as to the effects of driving with the ATIS prototype. In the case of the truck driver experiment discussed previously, there was a greater consensus among driver performance variables, showing a clearer picture of where the changes in performance occurred across task levels. In this case, several of the lateral vehicle control measures and one of the longitudinal control measures showed differences by task level. The clear differences between task levels were that the super high task level was consistently greater than the baseline and low task levels for the measures of lateral vehicle control that were significant, and the medium, high, and super high task levels were never found to be different from one another. In the previously described truck driver experiment, few differences were found between the medium and high task levels, but they typically indicated a lower level of workload than that shown by the super high task level. For the taxi drivers, there were no differences found in driving performance measures between the medium, high, and super high task levels.

It was also the goal of this research to determine what effects varying the sensory mode of information display would have on driver workload. The first part of the statistical analysis was performed to specifically determine whether there were any differences in performance due to the sensory mode of display. The analysis revealed that differences by sensory mode only existed for the number of lane deviations per task measure.

The number of lane deviations per task is a content-valid measure of vehicle control. Obviously, an increase in the number of lane deviations per task is an indication of increased driver workload. The significant interaction between task level and sensory mode of display suggests that the taxi driver's performance varied at the different task levels based on the sensory mode of display. When looking at simple effects with the data partitioned by sensory mode and in comparison with the baseline data, several interesting findings appear. For the combination auditory and visual sensory mode, the baseline, low, medium, and high task levels did not result in differences, but the super high task level did result in an increase. The increase was more than twice that of the high task level, which was the next highest.

For the visual-only sensory mode, the baseline and low task levels were not different from one another, but the medium, high, and super high task levels were all higher than baseline. Thus, it appears that the number of lane deviations per task did increase as the task demands became more difficult, but the increase occurred at a lower ATIS task demand with the visual-only sensory mode. The addition of the auditory component may have helped to keep driver workload lower in the low, medium, and high task levels, but not in the super high condition.

Eye Glance

The number of glances to the display per task for the low task level was not different from the baseline task level. The medium, high, and super high task levels were not different from one another, but were higher than the low and baseline task levels. The number of glances per task is a good indicator of the amount of visual resources that are required to interact with the system. The medium, high, and super high task levels required more visual attention since the subject had to look at the choices that were available each time a selection was made using the system. No statistical differences were found between the medium, high, and super high levels even though the number of button presses (menu selections) and the amount of information being presented on the screen varied among them.

ATIS Prototype Use

Regarding ATIS prototype use, the super high task level resulted in task completion times that were greater than both the medium and high task levels. The medium and high task levels were not different from one another. The reason that this result is interesting stems from the characteristic differences between the tasks levels. The increase in the amount of information on the display did not result in an increase in task completion times between the medium and high task levels. A difference was found between the high and super high task level where the number of button presses required to complete the task was doubled. This result would seem to suggest that the number of menu selections (including choice and control activations) has more of an impact on the task completion time than the amount of information presented on the screen. It was expected that the mean time to complete the task would be greater for the super high task level, but not as large a difference as the data show. The time to complete the super high task was nearly twice as long as the medium and high task levels.

It was hypothesized that there might be changes in driver performance measures that indicate an increase in driver workload as task difficulty was increased. What was not known was the point at which the ATIS task levels become statistically different from the baseline task level. There was a trend that seemed to exist among many of the performance variables collected for this experiment. There seems to be a natural division in performance between the low and medium task levels. The baseline and low task levels resulted in values that would indicate that the driver was experiencing less workload than those found for the medium, high, and super high task levels. This was true of several variables found significant, including standard deviations of steering wheel position and lane position, and the number of glances per task. The exception to this was the mean vehicle speed, for which there were no differences between the ATIS task levels, but the baseline task level did result in taxi drivers maintaining a higher speed, which would indicate that they were incurring less workload.

The characteristic differences between the task levels resulting in performance differences was manual interaction with the system to obtain the desired data from the system. Recall that in the low task level, the driver only had to monitor the information being presented on the screen. In the medium, high, and super high task levels, the driver was required to make menu choices by pushing buttons on the steering wheel to obtain the desired information from the system. There were no differences in the amount of information being presented on the display between the low and medium task levels. Therefore, it appears that the interaction with the system, rather than the amount of information on the display, had the greatest effect on the driving performance variables.

Another interesting result of this study was the lack of differences found between the medium, high, and super high task levels. There were no differences between the data collected for these task levels for any of the variables collected except for the mean time to complete the ATIS task. However, it was somewhat expected that this variable would increase with increased task complexity. So in this case, the added difficulty of the super high task level caused the subjects to require more time (approximately 10 seconds more) to complete the tasks, but did not result in any other performance decrements that could be detected in this experiment. It is also worth noting that there were no differences in the number of errors committed per required button press across any independent variable.

The previously discussed results would seem to indicate that the taxi drivers who participated in this experiment did not really exhibit any behavior that would suggest an increase in workload over normal driving conditions when they were performing the low ATIS task level. They did, however, show performance decrements when they were required to interact with the system. Still, this decrease did not seem to depend on the number of interactions or button presses required, as supported by the lack of differences between the medium, high, and super high task levels. What needs to be determined is whether the increase in workload that was seen between the low and medium task levels is enough of an increase to affect driving safety.

Subjective Workload

No statistically significant differences were found between any of the subject workload measures collected for this experiment. It is surprising that no differences were found in this experiment, especially for the task level variable. As task demands were increased, it was expected that the subjects would become aware of an increase in their workload and give higher reported responses to the workload questions. A possible explanation for this is that the subjects were not appropriately recognizing the increases in workload and therefore did not report them appropriately. Several iterations of training about the meaning of the different ratings were given to each subject prior to his or her experimental drives. It is still possible, however, that the drivers were unable to accurately recognize the differences as they arose.

Questionnaire

The questionnaire analysis revealed that the taxi drivers rated the navigation information more useful when performing their jobs than the vehicle condition and road sign information. The higher ratings of usefulness given to the navigation information were not surprising given that a significant portion of the taxi drivers' job requires them to find destinations that they may or may not be familiar with. The lower ratings given to the vehicle condition information probably represent a lack of perceived need for the information. The taxi drivers who participated in this experiment all drove vehicles that were company-owned and maintained. It is possible that because these drivers did not own or maintain their vehicles, they may perceive less value in information that would help them with that process. It also may represent less need for vehicle condition information due to the lower complexity of the vehicles that are normally used for taxi service.

The taxi drivers indicated that they would be willing to pay more for the navigation and general communications information than the road sign information. Almost certainly, the navigation and general communication information was rated more valuable by the taxi drivers because they were able to see a direct application of the information in how they currently perform their jobs. All of the taxi drivers who participated in this experiment were familiar with making regular two-way voice communications with a dispatcher and trying to find destinations in unfamiliar areas. The lower value placed on the road sign information might be due to the driving conditions under which the subjects used the system. The simulation consisted of daytime driving conditions with good weather and overall visibility. If the system had been used in conditions where visibility was poor, the subjects may have seen how the supplemental road sign information could be more beneficial.

Sensory Mode of Display

In terms of driver performance measures, or the ability of the driver to control the vehicle, the differences between the sensory modes of display did not result in widespread differences in driver behavior. It was hypothesized a priori that the addition of auditory information would provide benefits by reducing driver workload and visual attention requirements. Statistical differences were found between the sensory modes of display for the driver's ability to keep the vehicle in the lane where the addition of the auditory component resulted in fewer lane deviations for the low, medium, and high task levels. The number of lane deviations is a good, content-valid measure of vehicle control and probably indicates some level of benefit of an auditory system for this population.

GUIDELINES FOR COMMERCIAL VEHICLE OPERATORS

Based upon the results of this research, guidelines have been developed to aid in the design of ATIS. The following guidelines have been developed for ATIS that will be operated specifically by commercial truck drivers:

- It is possible to overload truck drivers as they interact with the system while driving. Minimize the level of interaction required by the system while driving by keeping the number of control manipulations to a minimum (less than four). The number of control activations has a greater effect on driver performance than the amount of information presented on the display (e.g., figure 15, figure 18)..

- If the number of control activations is kept to a minimum (i.e., less than four, as with the medium and high task loads), there are no apparent benefits with the addition of a redundant auditory cue providing confirmation of option selection (figure 23).

- For truck drivers, navigation and vehicle condition information is considered more useful than warning and road sign information presented by an ATIS while driving (figure 24).

The following set of guidelines has been developed for ATIS that will be operated specifically by taxi drivers:

- For taxi drivers and other drivers with minimal training, minimize the amount of interaction required by an ATIS if the interaction is time-dependent. Drivers in this experiment were more comfortable delaying control activations until they felt it was safe to do so (figure 33).

- The ATIS should be designed to supply navigation and general communication information first. The taxi drivers who participated in this experiment rated the navigation and general communication information more useful and were also willing to pay more money for it (figure 34, figure 35).

APPENDIX A. MEDICAL SCREENING CRITERIA

Before this list of questions is administered, please communicate the following:

Because of pre-existing health conditions, some people are not eligible for participation in this study. I need to ask you several health-related questions before you can be scheduled for a study session. Your response is voluntary and all responses are confidential. This means that you can refuse to answer any question that you choose and that we will not keep any record of your response. Please answer yes or no to the following questions:

Questions to be asked prior to scheduling:

1) Do you suffer from a heart condition such as disturbance of the heart rhythm or the experience of a heart attack? If yes, please describe.
[Exclude if there has been a heart attack within the past 6 months, or if there is a history of ventricular flutter or fibrillation, or systole requiring cardioversion. Potential participants with atrial fibrillation may be acceptable, given that their heart rhythm is now stable following medical treatment or pacemaker implants.]

2) Have you ever suffered brain damage from a stroke, tumor, head injury, or infection? If yes, what are the resulting effects? Do you have visual loss, blurring, or double vision; weakness, numbness, or funny feelings in the arms, legs, or face; trouble swallowing; slurred speech; incoordination or loss of control; trouble walking; trouble thinking, remembering, talking, or understanding?
[Exclude if there has been a stroke within the past 3 months, there is an active tumor, or if there are lingering effects.]

3) Have you been diagnosed with a serious or terminal illness? If yes, is the condition still active? Are there any lingering effects? If yes, do you care to describe?
[Exclude if there is any current serious condition.]

4) Have you ever been diagnosed with seizures or epilepsy? If yes, how frequently and what type?
[Exclude if there has been a seizure within the past 2 months.]

5) Do you suffer from a respiratory disorder such as asthma or chronic bronchitis? If yes, please describe.
[Exclude if disorder results in obvious or continuous shortness of breath or if the subject requires chronic medical therapy such as theophylline, inhalers, steroid medications, and especially oxygen therapy.]

6) Do you ever suffer from motion sickness? If yes, on what mode of transportation and what were the conditions (e.g., rough sea, back seat, etc.)? What symptoms did you experience? How old were you when this occurred?
[Exclude if sickness occurs often, occurs in mild to moderate conditions, or results in severe symptoms (i.e., vomiting).]

7) Do you suffer from inner ear, dizziness, vertigo, or balance problems? If yes, please describe. Do you have Meniere's disease?
[Exclude if there is any recent history of inner ear, dizziness, vertigo, or balance problem.]

8) Have you ever been diagnosed with a mood problem or a psychiatric disorder? If yes, are you taking medication? Please describe.
[Exclude if there is any diagnosed psychiatric disorder. This includes schizophrenia, depression, mania, personality disorder, dependency or abuse of psychoactive or illicit drugs or alcohol, chronic fatigue syndrome, agoraphobia, hyperventilation, or anxiety attacks.]

9) Do you have diabetes? Have you been diagnosed with hypoglycemia? If yes, do you take insulin or any other medication for blood sugar?
[Exclude if insulin is taken for this condition.]

10) Do you have migraine or tension headaches? If yes, what is the nature of this pain? How often and when was the last headache? Are you currently taking medication for these headaches? If so, what are you taking?
[Exclude if headaches occur greater than 2 times a month, if there has been a headache in the past 48 hours, or if the subject takes chronic daily or narcotic medications.]

11) Are you currently taking any medications? If yes, what is the medication and what is it for?
[Exclude if medication if for motion sickness, psychiatric disorder, or any of the conditions mentioned above that indicates a problem mentioned above that may have been incorrectly denied previously.]

12) Are you, or is there a possibility that you are, pregnant?
[Exclude if there is any possibility of pregnancy.]

APPENDIX B. INFORMATION SUMMARY FORM

Project Title: Battelle Experiment 11: Advanced Vehicle Information Systems

Investigators: Tom Dingus and Mike Mollenhauer

Thank you for coming in today. The purpose of the study is to evaluate different advanced vehicle information systems being considered for use in future vehicles. We will be gathering information and input to discover if these systems would be beneficial to drivers.

If you agree to take part in this study, you will be asked to watch a short training video, participate in an interactive training activity, drive the simulator for approximately 1 hour and 15 minutes, and complete a questionnaire that describes your reactions to the systems you will have used while driving. Your participation should take approximately 2 - 2 ½ hours. For your participation, you will receive $15 an hour.

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 which lasts only 10-15 minutes. If you feel uncomfortable, you may ask to quit at any time. Most people enjoy driving the simulator and do not experience any discomfort.

All information gathered in this study will be kept confidential. Your participation is voluntary. You may discontinue participation at any time without penalty or loss of benefits to which you are entitled. You should understand that you have the right to ask questions at any time and that you can contact Tom Dingus at (319) 335-5936 for information about the study and your rights.

You should understand that in the event of physical injury resulting directly from the research procedures, no compensation will be available in the absence of negligence by a state employee. However, medical treatment is available at the University Hospitals and Clinics, but you will be responsible for making arrangements for payment of the expenses of such treatment. Further information may be obtained from Dorothy M. Maher, Division of Sponsored Programs, Office of the Vice-President for Research, (319) 335-2123.

A record of your responses and driving performance will be maintained for future use. This record will be kept confidential and will be stored without reference to your personal identity.

Again, thank you.

I have discussed the above points, including the information required by the Iowa Fair Information Practices Act, with the subject or the legally authorized representative, using a translator when necessary. It is my opinion that the subject understands the risks, benefits, and obligations involved in participation in this project.

______________________	_______	______________________	_______
Investigator	Date	Witness	Date

APPENDIX C. INFORMED CONSENT FORM

Project Title: Battelle Experiment 11: Advanced Vehicle Information Systems

Investigators: Tom Dingus and Mike Mollenhauer

I certify that I have been informed about the study in which I am about to participate. I have been told the procedures to be followed and how much time and compensation is involved. I have also been told that all records which may identify me will be kept confidential. I understand the possible risks and the possible benefits to me and the others from the research.

I have been given adequate time to read the attached summary. I understand that I have the right to ask questions at any time and that I can contact Tom Dingus at (319) 335-5936 for information about the research and my rights.

I understand that my participation is voluntary and that I may refuse to participate or withdraw my consent and stop taking part at any time without penalty or loss of benefits to which I may be entitled. I hereby consent to take part in this project.

______________________________ __________

Signature of the Participant Date

APPENDIX D. TRAINING SCRIPTS

- Greet Participant.
- Obtain Parking Permit. Walk down with participant to place placard on vehicle (lock building doors, etc.).
- Verify that Medical Screening questions were administered. If not, use normal screening questions.
- Provide the participant with Information Summary Form. Answer any questions asked. If unknown, ask Mike.
- Administer Informed Consent Form. Ensure form is signed.
- Read the following Instructions and show the subject the Training Video.

.

Today we are going to have you drive a simulator while reading and using an information system that is mounted in a car. The system that you will use is representative of the types of systems that might be used in commercial vehicles in the near future. It is not intended to be a fully functional system, but rather, it will help us determine how commercial drivers can use devices such as these to improve their efficiency, comfort, and safety. The purpose of the testing today is to determine how to best design these systems and whether such systems will be useful in the future.

The video that I am about to show you will be used to give you an idea how a portion of the system will operate. Specifically, you will use the navigation and road sign display portions of the video today while you drive. If you have any questions, you may ask me or the experimenter at any time.

Stop video early; I'll give the counter number to stop at.

(Answer questions if necessary, refer to experimenter if you don't know the answer)

When you begin your drive, a destination will have already been entered into the navigation system. Part of your task will be to follow the system's directions to this destination.

On the way to your destination, you will be presented with a series of signs, similar to what is found on a normal roadway. Another part of your task will be to respond to signs which provide road condition information. An example of this would be slippery when wet. You will respond to this taxi-specific information by simply reading the information to the experimenter as soon as you see it.

In addition to the navigation and sign-reading tasks, you will occasionally be asked to perform tasks that represent functions and features that future systems will likely have available. For these tasks, you will be able to access different information by pressing several buttons available on the steering wheel of the vehicle. It is important for you to drive as you normally would while performing these tasks by obeying the rules of the road.

! Perform Menu System Training by reading the following instructions and letting them practice with the menu system. Encourage participants to practice until they are very proficient at operating the menus without error.

We will now show you the information system and let you practice using it. It is important that you practice with the system until you feel very comfortable with its use. Even though you practice, however, you may still make mistakes while driving. This is not a reflection of your abilities, but is instead due to the newness of these types of systems.

As you will see in a moment, you can use this system to look up a variety of information that might be used by commercial drivers while performing their job. The types of information include messages from the dispatcher, navigation information, daily and weekly record keeping, and listings of rider services. The information is displayed on the screen just like the navigation and signing information that you saw in the training video. In order to get the information you desire, you have to make some selections based on the information on the screen. You will make your selections by pressing one of four buttons that are mounted on the steering wheel, like a horn or cruise controls.

(Show the participant the training computer, tell them that the 1, 2, 3, and 4 buttons on the key board are like the four buttons on the steering wheel. Point out that unlike the computer keyboard, however, on the actual steering wheel the button location corresponds to the location of the function to be activated on the menu system. That is, if you want to access the information category on the lower right of the screen, you will press the lower right button. This will make the system in the car easier to use. For practice, the 1 is like the lower left button, the 2 is like the upper left, the 3 is like the upper right, and the 4 is like the lower right. They will then practice with the training computer.)

(Explain how to enter the menuing system, i.e., push any button.)

(Explain that to back out of the menu system, you always press the lower right button.)

(Demonstrate how the screens change on the training computer.)

(Allow participant to play with it a little, and guide them at the beginning.)

(Show subject the map of the menus and point out how the information is grouped.)

We will now practice using the system as you will be asked to do in the car. As you are driving, you will be asked to use the system to go and find a piece of info and report it out loud to the experimenter. Most times, you will need to enter the menuing system to get the information. However, sometimes a screen will pop up and you will just have to read what is on the screen out loud to the experimenter.

(Ask the subject to do the following activities with the system:)

(These should be one of each of the types of tasks they will do during the experiment. Ask them to respond verbally; help them if they make errors or have questions.)

- Check the daily cash total.
- Check to see the names of the hotels located near the airport.
- Check what types of historical sites are located at your current destination.
- View the map for the fastest alternate route.
- Notify the requestor of your arrival.
- Check the list of establishments that play blues music at your current destination.
- Check the number of hours on duty.
- Check the daily schedule for pickups.
- Notify dispatch that another cab is needed.
- Check the list of hotels available for over $90 per night.
- Acknowledge a message sent by dispatch.

(Explain that they will be doing these same types of tasks while driving the simulator. The system will not allow them to make a mistake by pressing a wrong menu choice. So, if they hit a button and it doesn't go anywhere, they should try some other button because the correct path is available.)

- Repeat practice tasks until subject is performing consistently error free.
- Perform Workload Training by reading the following:

After you perform the information system tasks, and occasionally while you are navigating, we will be interested in knowing how easy or difficult you think it is to perform the tasks while driving. To do this, the experimenter will ask you to rate the ease or difficulty based only on the task that you just completed. We would like you to provide your ratings as "low," "medium," or "high" for each of the following scales: 1) time stress, 2) visual effort, and 3) psychological stress.

Time stress is the amount of time available for completion of driving and performing the other tasks, if any. We would like you to use a low rating only if there was time to spare while doing the task, such as for carrying on conversation or tuning the radio. Please use a medium rating for time stress if there was just enough time to accomplish the assigned tasks. During a period of moderate time stress, you would tend to avoid additional distractions to your driving such as conversation or changing a heat setting. Please use a high rating for time stress if you have insufficient time to fully attend to driving and the assigned tasks.

Visual effort is the amount of time that your eyes are required to be off the road to perform the task. Please use a low visual effort rating only if you feel comfortable looking about, such as at objects in the simulation scenery. Please say that visual effort is medium if the visual scanning necessary for the assigned tasks can be accomplished comfortably, but you couldn't really look at anything else comfortably. Please use a high visual effort rating if you feel that you have to delay looking at information to maintain safe driving performance. An example would be if someone asked you to look at some scenery, but you decide to delay looking until after a curve or traffic situation is over.

Psychological stress refers to any feeling of confusion, frustration, danger, and anxiety that you experience during an assigned task. Please try to give this rating based on how you would feel in the real world under the same circumstances. That is, although you may not feel in danger in the simulator, how would you feel given the same situation in an actual taxi on the highway. Low psychological stress should only be used when you feel confident and secure. Please use a rating of medium if you feel mildly confused or frustrated, such as not being sure you are on your planned route, or not being able to perform the tasks very well while driving. Please use a rating of high psychological stress when you feel a high level of stress or frustration, such as one might feel after a near accident or when totally lost and confused as to how to get to a destination.

! Ask for and answer any Final Questions.
! Bring to simulator with appropriate videotape and paperwork.

APPENDIX E. TRUCK DRIVER QUESTIONNAIRE RESULTS

Standard
Question Mean Deviation

1. How much did you like using the VISUAL-ONLY display? 5.31.4944341
(not at all) 1___2___3___4___5___6___7 (very much)

2. Overall, how useful was the VISUAL-ONLY display for your driving? 5.21.3984118
(not useful at all) 1___2___3___4___5___6___7 (very useful)

3. How understandable was the VISUAL-ONLY display? 5.41.1737878
(not at all)1___2___3___4___5___6___7(very understandable)

4. How much did the VISUAL-ONLY display help you pay attention to your driving? 4.81.5491933
(not at all) 1___2___3___4___5___6___7 (very much)

5. How easy was the VISUAL-ONLY display to learn? 5.11.1972190
(not easy at all) 1___2___3___4___5___6___7 (very easy)

6. How much did the VISUAL-ONLY display interfere with your driving? 3.91.5238839
(not at all) 1___2___3___4___5___6___7 (very much)

7. How difficult was the VISUAL-ONLY display information for you to follow? 3.11.1005049
(very easy)1___2___3___4___5___6___7 (very difficult)

8. How much did the VISUAL-ONLY display distract you while driving? 3.81.5491933
(not at all) 1___2___3___4___5___6___7 (very much)

9. If you had a VISUAL-ONLY display installed in your vehicle, how much would this display help you navigate to unfamiliar destinations? 5.81.3984118
(not at all) 1___2___3___4___5___6___7 (very much)

10. If you had a VISUAL-ONLY display system in your vehicle similar to the one in this experiment, how much of the following information would be useful?
(not at all) 1___2___3___4___5___6___7 (very much)

    - Navigation Information (i.e., Distance and Direction of turn) 6.40.9660918
    - Vehicle Condition Information (i.e, Engine Temperature) 5.91.6633300
    - Road Sign Information (i.e., Stop, Slow) 4.51.6499158
    - Warning Information (i.e., Children Crossing) 4.71.7029386
    - General Communicating Information (i.e., Dispatch Message) 5.41.6465452

11. If you had a VISUAL-ONLY display system in your vehicle similar to the one in this experiment, how much would the following information help you pay attention to your driving?
(not at all) 1___2___3___4___5___6___7 (very much)

    - Navigation Information (i.e, Distance and Direction of turn) 5.61.4298407
    - Vehicle Condition Information (i.e, Engine Temperature) 5.01.6996732
    - Road Sign Information (i.e., Stop, Slow) 4.31.8287822
    - Warning Information (i.e., Children Crossing) 4.31.7029386
    - General Communicating Information (i.e., Dispatch Message) 4.72.0575066

12. If you had a VISUAL-ONLY display system in your vehicle similar to the one in this experiment, how much would you be willing to pay for the following information?
$0-100 (1)
$101-200 (2)
$201-300 (3)
$301-400 (4)
$401-500 (5)
I am unsure at the moment (6)

- Navigation Information (i.e, Distance and Direction of turn) 4.21.7511901
- Vehicle Condition Information (i.e, Engine Temperature) 3.82.3475756
- Road Sign Information (i.e., Stop, Slow) 3.52.6352314
- Warning Information (i.e., Children Crossing) 2.72.4381231
- General Communicating Information (i.e., Dispatch Message) 3.882.3154073

13. How much did you like using the COMBINED (V+A) display? 5.551.2360331
(not at all) 1___2___3___4___5___6___7 (very much)

14. Overall, how useful was the COMBINED (V+A) display for your driving? 4.771.9220938
(not useful at all) 1___2___3___4___5___6___7 (very useful)

15. How understandable was the COMBINED (V+A) display? 6.01.1180340
(not at all)1___2___3___4___5___6___7 (very understandable)

16. How much did the COMBINED (V+A) display help you pay attention to your driving? 4.91.5238839
(not at all) 1___2___3___4___5___6___7 (very much)

17. How easy was the COMBINED (V+A) display to learn? 5.61.1737878
(not easy at all)1___2___3___4___5___6___7(very easy)

18. How much did the COMBINED (V+A) display interfere with your driving? 3.61.6465452
(not at all) 1___2___3___4___5___6___7 (very much)

19. How difficult was the COMBINED (V+A) display information for you to follow? 2.71.2516656
(very easy) 1___2___3___4___5___6___7 (very difficult)

20. How much did the COMBINED (V+A) display distract you while driving? 3.21.3984118
(not at all) 1___2___3___4___5___6___7 (very much)

21. If you had a COMBINED (V+A) display installed in your vehicle, how much would this display help you navigate to unfamiliar destinations? 5.91.4491377
(not at all) 1___2___3___4___5___6___7 (very much)

22. If you had a COMBINED (V+A) display system in your vehicle similar to the one in this experiment, how much of the following information would be useful?
(not at all) 1___2___3___4___5___6___7 (very much)

- Navigation Information (i.e, Distance and Direction of turn) 6.21.0327956
- Vehicle Condition Information (i.e, Engine Temperature) 5.41.5055453
- Road Sign Information (i.e., Stop, Slow) 3.81.9888579
- Warning Information (i.e., Children Crossing) 3.82.0439613

- General Communicating Information (i.e., Dispatch Message) 4.81.8737959

23. If you had a VISUAL-ONLY display system in your vehicle similar to the one in this experiment, how much would the following information help you pay attention to your driving?
(not at all) 1___2___3___4___5___6___7 (very much)

- Navigation Information (i.e, Distance and Direction of turn) 5.51.7159384
- Vehicle Condition Information (i.e, Engine Temperature) 4.82.0439613
- Road Sign Information (i.e., Stop, Slow) 3.92.0789955
- Warning Information (i.e., Children Crossing) 3.82.0976177
- General Communicating Information (i.e., Dispatch Message) 4.31.8885621

24. If you had a VISUAL-ONLY display system in your vehicle similar to the one in this experiment, how much would you be willing to pay for the following information?
$0-100 (1)
$101-200 (2)
$201-300 (3)
$301-400 (4)
$401-500 (5)
I am unsure at the moment (6)

- Navigation Information (i.e, Distance and Direction of turn) 4.41.5055453
- Vehicle Condition Information (i.e, Engine Temperature) 3.82.3475756
- Road Sign Information (i.e., Stop, Slow) 3.62.5473298
- Warning Information (i.e., Children Crossing) 3.62.5473298
- General Communicating Information (i.e., Dispatch Message) 4.12.2827858

APPENDIX F. TAXI DRIVER QUESTIONNAIRE RESULTS

Standard
Question Mean Deviation

1. How much did you like using the VISUAL-ONLY Display? 4.61.2649111
(not at all) 1___2___3___4___5___6___7 (very much)

2. Overall, how useful was the VISUAL-ONLY display for your driving? 5.01.4142136
(not useful at all) 1___2___3___4___5___6___7 (very useful)

3. How understandable was the VISUAL-ONLY display? 5.61.3498971
(not at all)1___2___3___4___5___6___7 (very understandable)

4. How much did the VISUAL-ONLY display help you pay attention to your driving? 3.81.4757296
(not at all) 1___2___3___4___5___6___7 (very much)

5. How easy was the VISUAL-ONLY display to learn? 5.31.4944341
(not easy at all) 1___2___3___4___5___6___7 (very easy)

6. How much did the VISUAL-ONLY display interfere with your driving? 4.01.4907120
(not at all) 1___2___3___4___5___6___7 (very much)

7. How difficult was the VISUAL-ONLY display information for you to follow? 2.10.9944289
(very easy)1___2___3___4___5___6___7 (very difficult)

8. How much did the VISUAL-ONLY display distract you while driving? 3.81.5491933
(not at all) 1___2___3___4___5___6___7 (very much)

9. If you had a VISUAL-ONLY display installed in your vehicle, how much would this display help you navigate to unfamiliar destinations? 5.51.4337209
(not at all) 1___2___3___4___5___6___7 (very much)

10. If you had a VISUAL-ONLY display system in your vehicle similar to the one in this experiment, how much of the following information would be useful?
(not at all) 1___2___3___4___5___6___7 (very much)

- Navigation Information (i.e, Distance and Direction of turn) 6.30.8232726
- Vehicle Condition Information (i.e, Engine Temperature) 5.01.5811388
- Road Sign Information (i.e., Stop, Slow) 4.91.5238839
- Warning Information (i.e., Children Crossing) 5.41.6465452
- General Communicating Information (i.e., Dispatch Message) 5.11.3703203

11. If you had a VISUAL-ONLY display system in your vehicle similar to the one in this experiment, how much would the following information help you pay attention to your driving?
(not at all) 1___2___3___4___5___6___7 (very much)

- Navigation Information (i.e, Distance and Direction of turn) 5.41.2649111
- Vehicle Condition Information (i.e, Engine Temperature) 5.11.5365907
- Road Sign Information (i.e., Stop, Slow) 4.91.5238839
- Warning Information (i.e., Children Crossing) 5.41.5055453
- General Communicating Information (i.e., Dispatch Message) 5.11.4491377

12. If you had a VISUAL-ONLY display system in your vehicle similar to the one in this experiment, how much would you be willing to pay for the following information?
$0-100 (1)
$101-200 (2)
$201-300 (3)
$301-400 (4)
$401-500 (5)
I am unsure at the moment (6)

- Navigation Information (i.e, Distance and Direction of turn) 4.21.9888579
- Vehicle Condition Information (i.e, Engine Temperature) 3.72.0575066
- Road Sign Information (i.e., Stop, Slow) 2.92.2335821
- Warning Information (i.e., Children Crossing) 3.82.0439613
- General Communicating Information (i.e., Dispatch Message) 4.51.7159384

13. How much did you like using the COMBINED (V+A) display? 5.61.4298407
(not at all) 1___2___3___4___5___6___7 (very much)

14. Overall, how useful was the COMBINED (V+A) display for your driving? 4.91.7288403
(not useful at all) 1___2___3___4___5___6___7 (very useful)

15. How understandable was the COMBINED (V+A) display? 5.80.6324555
(not at all) 1___2___3___4___5___6___7 (very understandable)

16. How much did the COMBINED (V+A) display help you pay attention to your driving? 4.71.6363917
(not at all) 1___2___3___4___5___6___7 (very much)

17. How easy was the COMBINED (V+A) display to learn? 5.70.6749486
(not easy at all) 1___2___3___4___5___6___7 (very easy)

18. How much did the COMBINED (V+A) display interfere with your driving? 3.81.2292726
(not at all) 1___2___3___4___5___6___7 (very much)

19. How difficult was the COMBINED (V+A) display information for you to follow? 3.21.8737959
(very easy) 1___2___3___4___5___6___7 (very difficult)

20. How much did the COMBINED (V+A) display distract you while driving? 3.20.9189366
(not at all) 1___2___3___4___5___6___7 (very much)

21. If you had a COMBINED (V+A) display installed in your vehicle, how much would this display help you navigate to unfamiliar destinations? 6.10.8755950
(not at all) 1___2___3___4___5___6___7 (very much)

22. If you had a COMBINED (V+A) display system in your vehicle similar to the one in this experiment, how much of the following information would be useful?
(not at all) 1___2___3___4___5___6___7 (very much)

- Navigation Information (i.e, Distance and Direction of turn) 5.91.2866839

- Vehicle Condition Information (i.e, Engine Temperature) 5.01.6329932
- Road Sign Information (i.e., Stop, Slow) 4.61.7126977
- Warning Information (i.e., Children Crossing) 5.01.8708287
- General Communicating Information (i.e., Dispatch Message) 5.61.2649111

23. If you had a VISUAL-ONLY display system in your vehicle similiar to the one in this experiment, how much would the following information help you pay attention to your driving?
(not at all) 1___2___3___4___5___6___7 (very much)

- Navigation Information (i.e, Distance and Direction of turn) 5.60.9660918
- Vehicle Condition Information (i.e, Engine Temperature) 4.551.7400511
- Road Sign Information (i.e., Stop, Slow) 4.51.5811388
- Warning Information (i.e., Children Crossing) 5.21.9888579
- General Communicating Information (i.e., Dispatch Message) 5.51.3540064

24. If you had a VISUAL-ONLY display system in your vehicle similiar to the one in this experiment, how much would you be willing to pay for the following information?
$0-100 (1)
$101-200 (2)
$201-300 (3)
$301-400 (4)
$401-500 (5)
I am unsure at the moment (6)

- Navigation Information (i.e, Distance and Direction of turn) 4.81.6865481
- Vehicle Condition Information (i.e, Engine Temperature) 3.62.1186998
- Road Sign Information (i.e., Stop, Slow) 3.91.9692074
- Warning Information (i.e., Children Crossing) 3.81.9888579
- General Communicating Information (i.e., Dispatch Message) 4.41.7126977

APPENDIX G. ANALYSIS OF VARIANCE TABLES

Table 2. ANOVA for driving performance measures (1 x 5 design for visual-only sensory mode of display).

Source	df	MS	F-ratio	p
Standard deviation of steering wheel position				
Task level	4	3.0938	13.61	0.0001
Task level x Subject	36	0.2273		
Mean vehicle speed				
Task level	4	25.5490	7.63	0.0001
Task level x Subject	36	2.4324		
Standard deviation of vehicle speed				
Task level	4	10.0449	4.13	0.0074
Task level x Subject	36	2.4324		
Standard deviation of accelerator pedal deflection				
Task level	4	0.0010	1.11	0.3650
Task level x Subject	36	0.0009		
Standard deviation of lane position				
Task level	4	0.2159	8.99	0.0001
Task level x Subject	36	0.0240		
Number of lane deviations per task				
Task level	4	7.8200	5.07	0.0024
Task level x Subject	36	1.5422		

Table 3. ANOVA for driving performance measures (1 x 5 design for the combination auditory and visual sensory mode of display).

Source	df	MS	F-ratio	p
Standard deviation of steering wheel position				
Task level	4	4.0638	16.93	0.0001
Task level x Subject	36	0.2400		
Mean vehicle speed				
Task level	4	35.9944	11.16	0.0001
Task level x Subject	36	3.2247		
Standard deviation of vehicle speed				
Task level	4	17.2883	6.59	0.0004
Task level x Subject	36	2.6216		
Standard deviation of accelerator pedal deflection				
Task level	4	0.0024	3.46	**0.0171**
Task level x Subject	36	0.0007		
Standard deviation of lane position				
Task level	4	0.1324	9.99	0.0001
Task level x Subject	36	0.0133		
Number of lane deviations per task				
Task level	4	5.1800	7.62	0.0001
Task level x Subject	36	0.6800		

Table 4. ANOVA for eye glance measures.

Source	df	MS	F-ratio	p
Duration of glance				
Task level	4	0.3081	1.19	0.3312
Task level x Subject	36	0.2591		
Number of glances per task				
Task level	4	125.9093	3.53	0.0158
Task level x Subject	36	35.7125		

Table 5. ANOVA for ATIS prototype use performance.

Source	df	MS	F-ratio	p
Time to complete task				
Sensory mode of display	1	215.21	1.75	0.2183
Task level	2	9257.54	143.89	0.0001
Sensory mode of display x Task level	2	6.46	0.10	0.909
Subject	9	89.30		
Sensory mode of display x Subject	9	122.85		
Task level x Subject	18	64.34		
Sensory mode of display x Task level x Subject	18	67.30		
Number of errors per required button press				
Sensory mode of display	1	0.0001	0.05	0.8321
Task level	2	0.0540	5.73	**0.0118**
Sensory mode of display x Task level	2	0.0220	4.74	0.0222
Subject	9	0.0566		
Sensory mode of display x Subject	9	0.0123		
Task level x Subject	18	0.1694		
Sensory mode of display x Task level x Subject	18	0.0418		

Table 6. ANOVA for subjective workload assessment.

Source	df	MS	F-ratio	p
Time stress				
Sensory mode of display	1	0.0250	0.10	0.7640
Task level	3	0.2917	1.43	0.2553
Sensory mode of display x Task level	3	0.2250	0.37	0.7757
Subject	9	0.4333		
Sensory mode of display x Subject	9	0.2611		
Task level x Subject	27	0.2037		
Sensory mode of display x Task level x Subject	27	0.6093		
Visual effort				
Sensory mode of display	1	0.1563	0.31	0.5911
Task level	3	0.0563	0.27	0.8471
Sensory mode of display x Task level	3	0.0563	0.07	0.9750
Sensory mode of display x Subject	9	0.5035		
Task level x Subject	27	0.2090		
Sensory mode of display x Task level x Subject	27	0.7924		
Psychological stress				
Sensory mode of display	1	0.0563	0.18	0.6849
Task level	3	0.2229	1.07	0.3797
Sensory mode of display x Task level	3	0.8229	1.40	0.2636
Sensory mode of display x Subject	9	0.3201		
Task level x Subject	27	0.2090		
Sensory mode of display x Task level x Subject	27	0.5868		
Combined measures				
Sensory mode of display	1	0.2250	0.09	0.7753
Task level	3	1.1000	1.00	0.4098
Sensory mode of display x Task level	3	1.0250	0.20	0.8944
Sensory mode of display x Subject	9	2.6000		
Task level x Subject	27	1.1046		
Sensory mode of display x Task level x Subject	27	5.0852		

Table 7. ANOVA for questionnaire data.

Source	df	MS	F-ratio	p
Usefulness of information for completing job				
Sensory mode of display	1	8.410	3.37	0.0998
Information type	4	16.835	5.88	0.0010
Sensory mode of display x Information type	4	0.335	0.50	0.7379
Subject	9	10.366		
Sensory mode of display x Subject	9	2.499		
Information type x Subject	36	2.862		
Sensory mode of display x Information type x Subject	36	0.674		
Help direct attention toward driving				
Sensory mode of display	1	2.560	0.29	0.6037
Information type	4	7.765	2.72	0.0446
Sensory mode of display x Information type	4	0.135	0.52	0.7181
Subject	9	13.529		
Sensory mode of display x Subject	9	8.849		
Information type x Subject	36	2.854		
Sensory mode of display x Information type x Subject	36	0.257		
Amount you would pay for information				
Sensory mode of display	1	0.749	2.55	0.1450
Information type	4	3.175	1.29	0.2919
Sensory mode of display x Information type	4	0.255	0.81	0.5288
Subject	9	40.095		
Sensory mode of display x Subject	9	0.294		
Information type x Subject	36	0.294		
Sensory mode of display x Information type x Subject	34	0.315		

Table 8. ANOVA for driving performance measures (1 x 5 design).

Source	df	MS	F-ratio	p
Standard deviation of steering wheel position				
Task level	4	12.4954	12.32	**0.0001**
Task level x Subject	36	1.0145		
Mean vehicle speed				
Task level	4	87.5060	9.14	**0.0001**
Task level x Subject	36	9.5791		
Standard deviation of vehicle speed				
Task level	4	13.5917	2.27	0.0803
Task level x Subject	36	5.9778		
Standard deviation of accelerator pedal deflection				
Task level	4	0.0006	0.74	0.5737
Task level x Subject	36	0.0008		
Standard deviation of lane position				
Task level	4	0.7133	5.69	**0.0012**
Task level x Subject	36	0.1254		

Table 9. ANOVA for number of lane deviations per task (2 x 4 factorial design).

Source	df	MS	F-ratio	p
Number of lane deviations per task				
Sensory mode of display	1	12.8000	8.57	**0.0168**
Task level	3	44.0000	4.07	**0.0165**
Sensory mode of display x Task level	3	9.9333	3.02	**0.0473**
Subject	9	82.8778		
Sensory mode of display x Subject	9	1.4944		
Task level x Subject	27	10.8056		
Sensory mode of display x Task level x Subject	27	3.2944		

Table 10. ANOVA for number of lane deviations per task (1 x 5 design partitioned by sensory mode of display).

Source	df	MS	F-ratio	p
Number of lane deviations per task (visual-only sensory mode of display)				
Task level	4	46.4300	5.20	**0.0021**
Task level x Subject	36	8.9300		
Number of lane deviations per task (combination visual and auditory sensory mode of display)				
Task level	4	47.9500	8.18	**0.0001**
Task level x Subject	36	5.8611		

Table 11. ANOVA for eye glance measures.

Source	df	MS	F-ratio	p
Duration of glance				
Task level	4	0.0686	0.24	0.9153
Task level x Subject	36	0.2889		
Number of glances per task				
Task level	4	701.9448	8.51	**0.0001**
Task level x Subject	36	82.4812		

Table 12. ANOVA for ATIS prototype use performance.

Source	df	MS	F-ratio	p
Time to complete task				
Sensory mode of display	1	3.48	0.06	0.8089
Task level	2	3517.85	46.63	**0.0001**
Sensory mode of display x Task level	2	16.18	0.36	0.7011
Subject	9	423.16		
Sensory mode of display x Subject	9	56.08		
Task level x Subject	18	75.44		
Sensory mode of display x Task level x Subject	18	44.65		
Number of errors per required button press				
Sensory mode of display	1	0.0001	0.03	0.8723
Task level	2	0.0119	1.32	0.2910
Sensory mode of display x Task level	2	0.0068	1.27	0.3044
Subject	9	0.0133		
Sensory mode of display x Subject	9	0.0047		
Task level x Subject	18	0.0090		
Sensory mode of display x Task level x Subject	18	0.0053		

Table 13. ANOVA for subjective workload assessment.

Source	df	MS	F-ratio	p
Time stress				
Sensory mode of display	1	0.0556	0.22	0.6476
Task level	3	0.2709	1.07	0.3773
Sensory mode of display x Task level	3	0.4119	1.47	0.2452
Sensory mode of display x Subject	9	0.2484		
Task level x Subject	27	0.2526		
Sensory mode of display x Task level x Subject	27	0.2804		
Visual effort				
Sensory mode of display	1	0.8889	2.69	0.1352
Task level	3	0.1500	0.15	0.9283
Sensory mode of display x Task level	3	0.5637	1.97	0.1429
Sensory mode of display x Subject	9	0.3301		
Task level x Subject	27	0.3315		
Sensory mode of display x Task level x Subject	27	0.2867		
Psychological stress				
Sensory mode of display	1	0.4939	1.02	0.3389
Task level	3	0.3978	1.13	0.3549
Sensory mode of display x Task level	3	0.7469	2.74	0.0625
Sensory mode of display x Subject	9	0.4843		
Task level x Subject	27	0.3524		
Sensory mode of display x Task level x Subject	27	0.2722		
Combined measures				
Sensory mode of display	1	3.5122	1.68	0.2270
Task level	3	1.8114	0.91	0.4507
Sensory mode of display x Task level	3	4.5095	2.55	0.0770
Sensory mode of display x Subject	9	2.0891		
Task level x Subject	27	1.9976		
Sensory mode of display x Task level x Subject	27	1.7714		

Table 14. ANOVA for questionnaire data.

Source	df	MS	F-ratio	p
Usefulness of information for completing job				
Sensory mode of display	1	0.671	0.61	0.4531
Information type	4	5.085	3.61	0.014
Sensory mode of display x Information type	4	0.761	1.56	0.2066
Subject	9	13.198		
Sensory mode of display x Subject	9	1.093		
Information type x Subject	36	1.425		
Sensory mode of display x Information type x Subject	34	0.487		
Help direct attention toward driving				
Sensory mode of display	1	0.2499	0.33	0.5823
Information type	4	2.025	1.51	0.2192
Sensory mode of display x Information type	4	0.725	1.48	0.2307
Subject	9	14.422		
Sensory mode of display x Subject	9	0.7679		
Information type x Subject	36	1.337		
Sensory mode of display x Information type x Subject	35	0.491		
Amount you would pay for information				
Sensory mode of display	1	1.96	5.8	**0.039**
Information type	4	4.835	4.5	**0**
Sensory mode of display x Information type	4	1.235	2.61	0.052
Subject	9	31.871		
Sensory mode of display x Subject	9	0.337		
Information type x Subject	36	1.074		
Sensory mode of display x Information type x Subject	36	0.474		

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