In-Vehicle Information Systems Behavioral Model and Design Support: Final Report

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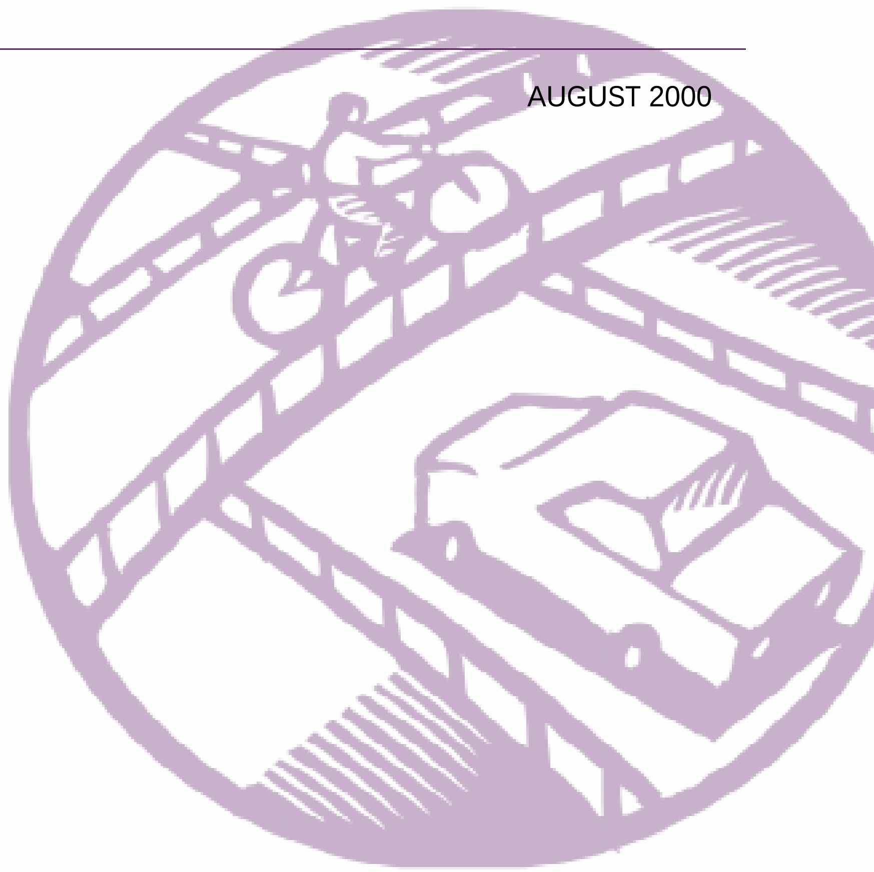

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Federal Highway Administration

Research, Development, and Technology
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FOREWORD

This report was produced as part of a contract to develop an in-vehicle information systems behavioral model and design support system. The software program resulting from this effort will aid designers to develop in-vehicle information system user interfaces that demand less of the driver's attention. The Design Evaluation and Model of Attention Demand (DEMAnD) software provides designers with a tool for predicting the attention demand of prototype displays for in-vehicle systems.

This report is the final report that describes the model, how it was developed, and its supporting research and rationale. It provides a detailed presentation of the theory and research that the model is based upon. It also includes descriptions of the algorithms that are the foundation of the model's predictions. This report will be a useful companion to the software and user's manual for researchers and designers.

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Michael F. Trentacoste
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NOTICE

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16. Abstract: A great deal of effort went into producing both the model and the prototype software for this contract. The purpose of this final report is not to duplicate the information provided about these and other topics in previous reports. The purpose is to summarize the important aspects of this project and to finalize the model and software prototype description not covered thoroughly in previous reports. This final report of the contract will summarize the following:

- A description of the behavioral model;
- The four studies that were conducted to supplement the research needed for the model;
- How tasks from the literature were modeled and included in the prototype software;
- The prototype software and some of its main modules;
- Recommendations for next steps;
- The titles and a brief summary of each of the previous reports written for this project.

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INTRODUCTION

The goal of intelligent transportation systems, in particular in-vehicle information systems (IVIS), is to increase the mobility, improve the efficiency, and increase the safety of the motoring public. To achieve this goal, in-vehicle information systems must be designed according to good human factors principles that consider the capabilities and limitations of the operators of these systems. Introduction of in-vehicle information systems should have minimal impact on driving performance and should, whenever possible, improve driver performance. The ultimate goal of this project is to provide designers of in-vehicle information systems with a set of tools and criteria that can be used in producing and evaluating alternative IVIS designs. To accomplish this, a behavioral model that predicts driving task performance decrements of drivers interacting with in-vehicle information systems has been developed, along with prototype software that integrates the behavioral model and past research on the behavior of drivers when using IVIS. The behavioral prototype software is termed IVIS DEMAnD for In-Vehicle Information System (IVIS) Design Evaluation and Model of Attention Demand.

A great deal of effort has gone into producing both the model and the prototype software for this project. The purpose of this final report is not to duplicate the information provided about these and other topics in previous reports, but rather to summarize the important aspects of this project and to finalize the model and software prototype description not covered thoroughly in previous reports. To provide an overview of the project, Figure 1, shown on the next page, illustrates all of the tasks conducted. As shown in Figure 1, it should be pointed out that the first three tasks are conducted largely in parallel. The results from Tasks A, B, and C provide the foundation for the computer-based model development effort for Tasks D and E. More detail on each of these tasks is presented in Appendix A.

This final report of the contract, Task F, summarizes the following:

- The behavioral model.
- The four studies that were conducted to supplement the research needed for the model.
- How tasks from the literature were modeled and included in the prototype software.

- The prototype software and some of its main modules.
- Recommendations for next steps.

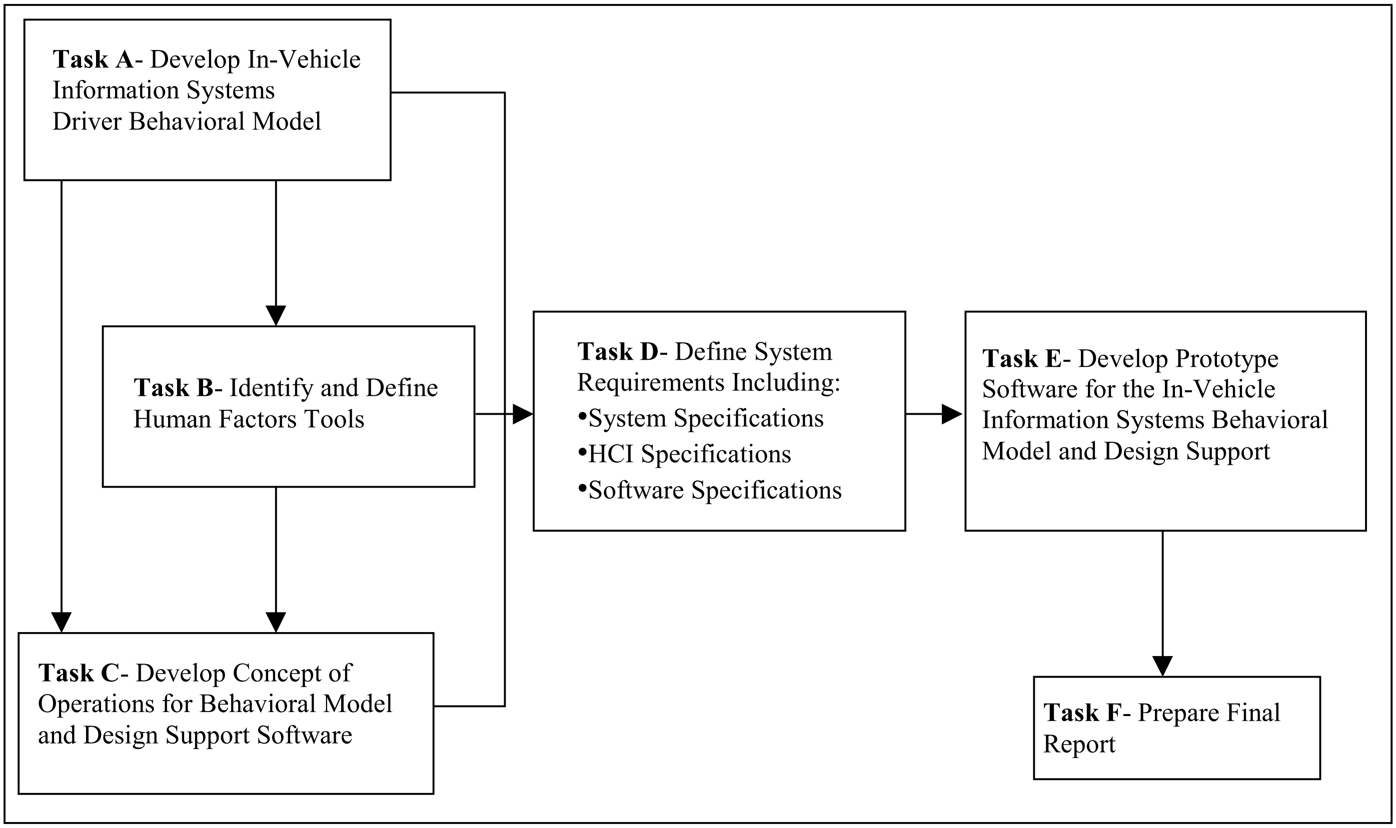


Figure 1. Project approach.

BEHAVIORAL MODEL

The model of the driver used in this study is a resource model; that is, the driver is viewed as a group of information processing resources. Conceptually, the driver's overall task can be viewed as performing the primary task of driving while also attending to in-vehicle tasks. Generally, the primary task of driving involves paying attention to what is going on outside the vehicle. Specifically, it consists of lateral/directional control, longitudinal control, and hazard detection. Within these three tasks are a variety of subtasks, such as selecting an appropriate speed, navigating, and viewing the environment for detection of hazards, such as keeping an eye on a cyclist nearby.

IVIS tasks, or other secondary tasks, also require the use of driver resources. For example, if the driver attempts to use an information display to find the location of a favored hotel, the driver must shift vision into the vehicle to access and extract the desired information. Even simple tasks such as adjusting the temperature on the climate control system require some diversion of resources into the vehicle.

The driver resource pool model used in this study has five components, as shown in Figure 2. The resource pool has been selected based on two criteria. First, the model is selected so that it is a reasonably accurate portrayal of resources used for driving and attending to in-vehicle systems; and second, the model is selected so that it is compatible with existing sources of data. The latter is an important consideration because lack of compatibility with previous work will require a major experimental effort. By selecting a model compatible with existing data sources, experimentation can be concentrated in those areas where data are lacking.

The concept of viewing the driver as a group of resources is not new. In fact, it has been used in pilot modeling for many years. Using this concept allows analysts to plot resource usage in performing a specific task as a function of time. For example, if the use of the right hand is required in two places at the same time, the task can then be separated into two parts, with one part of the task being assigned to another limb or voice command. Alternatively, the task itself can be redesigned so that it no longer requires the simultaneous use of the right hand. The time sequence of right hand usage is then changed. Essentially, these are pilot workload-related issues.

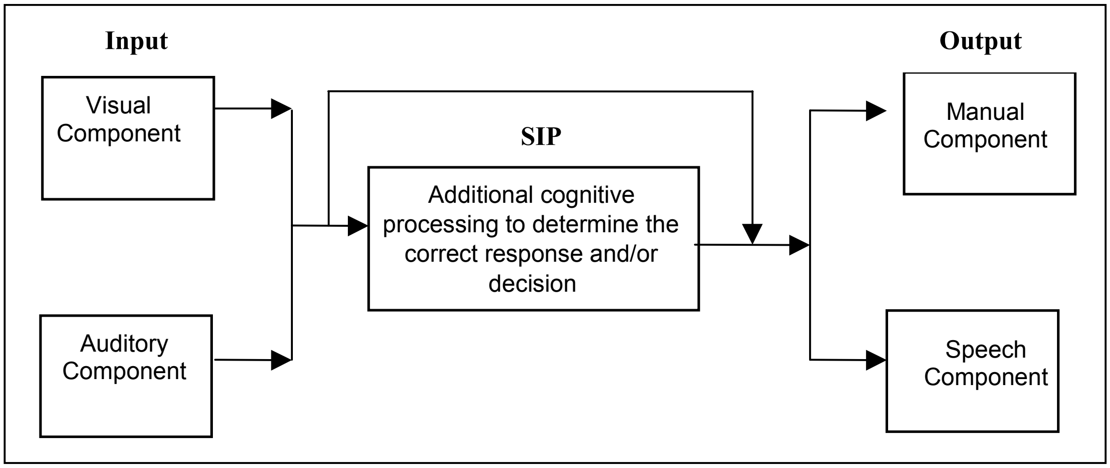


Figure 2. Behavioral model.

Although both pilots and drivers can be viewed as being a group of resources, piloting an aircraft is very different from driving a vehicle. Piloting an aircraft requires a great deal of attention to be devoted to what is occurring inside the cockpit. On the other hand, the primary task of driving requires very careful and relatively constant attention to what is going on *outside* the vehicle. It can be assumed that performing in-vehicle tasks represents a draw on the resources drivers should be using to attend to the primary task of driving. Small levels of resource draw are probably acceptable, but large levels are likely to be hazardous. Preliminary data suggest that the more demanding the in-vehicle task is and the more often it is performed, the greater the likelihood that the driver will be involved in a crash. By modeling the draw on resources needed to service the in-vehicle device or system, relative risk can be assessed. Thus, the model selected is one that accounts for the resources drawn from the primary task of driving.

The model in Figure 2 is made up of five components. Two information extraction components are on the left, a supplemental information processing (SIP) component is in the center, and two output/command components are on the right. Depending on the nature of the in-vehicle task, the various components of the model may or may not be included. For example, reading the speedometer requires only the visual component. Since this task is one of simple visual information extraction, the cognitive processing required to extract the information is assumed to be small; therefore, there is no *supplemental* information processing. In addition, reading the speedometer does not require any output or command from the driver.

The supplemental information processing component of the model is included to account for more complex processes, particularly those that go beyond information extraction. For example, if the driver is presented with the choice of selecting one hotel from a selected set of three and must choose on the basis of combined criteria of cost and distance, then a substantial supplemental information processing component exists.

The model also allows for auditory input. Although currently not widely used, it is possible that future displays will make more use of auditory displays, particularly of digitally recorded speech. In addition, various auditory (non-speech) advisories and warnings may be used as inputs to the driver.

The model currently does not include haptic display modality because there are no indications that inputs to the driver for in-vehicle information systems are likely to use haptic signals in the near future. If the trend changes and this modality is utilized, the model can easily be expanded.

Manual output is considered to be one of the resources that may be drawn from the primary task of driving when attending to an in-vehicle system. The driver currently commands most in-vehicle systems by use of one of the hands. Under most driving conditions, the driver can safely remove a hand from the wheel to actuate or adjust a control within the vehicle. In those cases in which the driver needs both hands on the wheel or needs to shift gears manually, the actuation or adjustment of the control can usually be delayed for a short period of time. In a few cases, controls may be mounted on the wheel, spokes, hub, or on the gearshift lever. While actuating these controls, the usefulness of the hand for helping in steering or gear shifting is usually limited. Thus, even with these designs, some manual load is present.

The driver may also command an in-vehicle system by voice. This resource is used in such tasks as dialing a cellular phone and adjusting a radio. The main advantage of voice command is that it is a largely untapped resource that does not appear to interfere heavily with vision. Therefore, the use of verbal commands for in-vehicle systems may increase. In many cases, speech recognition systems require actuation of a pushbutton at the side of the steering wheel or on one of the spokes. In this case, the speech command system must include a manual component.

As explained above, the five components of this model have been selected so that data already gathered can be presented or incorporated into the model. At the same time, the model accurately reflects the present and near-term future resources that are being drawn from driving to service in-vehicle systems. However, some additional aspects of the selected model need to be explained. As indicated, the model explicitly includes supplemental information processing. In this model, it is assumed that cognitive processing associated with extraction of information is included in the visual and auditory components. Under most conditions, this cognitive load will be relatively small. It is only when the cognitive load involves post-processing of the extracted information that the supplemental information processing component becomes active. In these cases, assessment of additional cognitive load becomes important and should be assessed.

This model (Figure 2) was chosen over one that lumps *all* cognitive resources into one block because it provides a better fit to presently available data. For example, visual glance data, in which there is no assessment of cognitive demands, are available for many tasks in the literature. If a total cognitive demand model component is included, it will make this research of limited use. In addition, the use of the supplemental information processing model assesses what is important, namely large cognitive demands. It could be assumed that small cognitive demands are associated with simple tasks, but these minor cognitive demands do not affect or interfere with the driving task. Only the large cognitive demands may interfere, possibly by creating perceptual narrowing or suppression of seemingly unimportant aspects of the primary task of driving.

It is important to note that the five resources are not considered to be of equal importance in terms of resource draw. Clearly, because vision is the fundamental input resource used for the primary task of driving, vision must be considered as the most important resource. The other resources may be ordered in various ways depending on circumstances and on the experts providing the opinions. It is nevertheless possible to carry the resources through an analysis and then make a judgment at a later time as to which system provides the least diversion of resources for a given in-vehicle task.

The five-component model that has been selected seems to have many advantages. It can be fitted to almost any in-vehicle information system task; it allows for unused resource components to be deleted; and it assesses the resources that are used and diverted from driving. In addition, the model allows for use of existing data, and it permits the use of new data in which high level information processing is assessed. Assuming that good data are available, the model seems to allow a reasonably complete assessment of the resources used in servicing an in-vehicle device or system.

RESEARCH CONDUCTED IN SUPPORT OF THE IVIS MODELING PROJECT

In the early stages of this research project, a plan was proposed to systematically construct the in-vehicle information system behavioral model (IVIS/BM). Several steps were involved in this plan, including:

- Carefully specify the precise objectives of IVIS/BM.
- Gather all relevant available information on previous models, partial models, usable equations, human factors guidelines and tools, and computer programs.
- Develop a taxonomy showing the availability and quality of information.
- Prioritize the deficiencies in the available information.
- Devise and plan a limited number of experiments to obtain high priority data needed for model building.
- Gather needed data for model development.

Once the objectives of the IVIS/BM had been clearly defined, information that could be used in the model was sought. The two primary efforts of uncovering this information involved: (1) an extensive literature review, and (2) contact with known practitioners. The literature review was conducted at Virginia Tech and was performed via several databases, including:

- Dialog Database, which consists of more than 400 different sub-databases, including (1) Compendex, a major technical science database, (2) PsychLit, a large psychology database, and (3) SAE technical papers.
- SAE Database, which consists of standards for transportation published by the Federal Highway Administration (FHWA).

In addition to conducting an extensive literature review, the data gathering effort also entailed contacting known practitioners in the field. It was hoped that by contacting these individuals, recent research and data not yet published might be made available. An abbreviated sample list of contact organizations and personnel is presented in Table 1.

Once the literature review was completed and all available research had been collected, an effort was undertaken to develop a taxonomy outlining the information that had been gathered and to determine the "holes" or deficiencies in the data (see Gallagher and

Dingus, 1997). After the deficiencies in the data were identified, they were prioritized. Once this was accomplished, project resources were allocated to "fill in" the most significant holes.

Table 1. Sample list of organizations and persons contacted during this project.

Organization	Contact Person
Ford Motor Corporation	Barry Grant Gene Farber
General Motors Corporation	Ray Kiefer
Freightliner	Jared Powell
National Highway Traffic and Safety Administration	Michael Perel Michael Goodman
Federal Highway Administration	Joseph Moyer Ronald Knipling Debbie Freund
Westat	Neil Lerner Eddy Llaneras
Transportation Research Center	Louis Tijerina[1]
Battelle	Barry Kantowitz[2]

Recall that there are five driver resources specified in the model: (1) visual, (2) auditory, (3) supplemental information processing (SIP), (4) manual, and (5) speech. Because "supplemental information processing" is a new concept, very little data were available describing it. As such, the primary focus of the project-specific experimentation was directed at providing data for the SIP resource (i.e., the biggest deficiency was related to available SIP data). In addition, limited IVIS-related CVO studies were available; none of which were related to CVO and SIP. Therefore, project resources were directed toward conducting four experiments. Three of the four experiments conducted for this project were used as partial fulfillment for graduate school requirements for students

[1] Now with Ford Motor Company.

[2] Now with University of Michigan Transportation Research Institute.

working at the Center for Transportation Research, now the Virginia Tech Transportation Institute. Labeled "Experiment 1" in the next section, the Gallagher (2000) study investigated IVIS tasks that taxed the automobile driver's visual and SIP resources. Experiment 2 involved gathering data from heavy vehicle drivers as they interacted with an IVIS (Blanco, 1999). Like the Gallagher effort, the Blanco CVO study focused on the driver's visual and SIP resources. Experiment 3, the Biever (2000) study, used an instrumented automobile to investigate the impact of IVIS use on auditory and SIP resources. Finally, Experiment 4 describes a research effort conducted by Westat, a subcontractor to the Virginia Tech Transportation Institute for this project. As will be described, the focus of the Westat study encompassed visual, auditory, and SIP resources. A primary feature of the Westat effort, as distinguished from Experiments 1 to 3, was that it was conducted in an urban environment (Washington, D.C.). The next section provides an overview of each of these four experiments.

EXPERIMENT 1: AN ASSESSMENT OF THE ATTENTION DEMAND ASSOCIATED WITH THE PROCESSING OF INFORMATION FOR IVIS VISUALLY DISPLAYED INFORMATION

Problem Statement

Limited attention resources can be diverted from the primary task of driving to a secondary in-vehicle task. It is recognized that many of the new in-vehicle information systems (IVIS) under development can potentially require a driver to not only extract information from the visual display but also to further process the displayed information in order to make a decision. For example, a driver can use the IVIS to display alternative routes to a destination and the associated delays for each of these routes, and select a route from this information. In the example above, the attention demand required as part of the process of extracting information has been studied relatively extensively. However, the processing required to make complex decisions is not well understood and provides cause for concern. The behavioral model categorizes these attention demand resources as “supplemental information processing.” The term “supplemental” is used to distinguish this processing from the cognitive processes associated with information extraction. This separation is important because, from a modeling perspective, all tasks have information extraction, but a relatively small subset have supplemental information processing requirements.

The primary purpose of the current study was to provide information suitable for modeling the supplemental information processing required by current and projected IVIS tasks. A secondary purpose of this study was to establish, for modeling purposes, criteria to differentiate "safe" driving performance from "unsafe" driving performance. The state of the art in driving safety research is such that while "rules of thumb" exist for safe versus unsafe driving (e.g., unplanned lane excursion, single display glance over 2.5 seconds, or static task completion time over 15 seconds), these rules need to be operationalized and formalized. This was the second purpose of this research.

Objectives

The specific objectives of this experiment are listed below:

1) To investigate driver performance during IVIS tasks that require supplemental processing of information after the extraction of information from a visual display.
2) To develop a methodology for establishing safety criteria for driver performance, i.e., safety "red lines" for modeling purposes.
3) To provide descriptive data on the proportion of drivers who exceeded a safety threshold of driver performance for each of the different IVIS tasks.

Methodology

This project built upon past studies that focused on the attention demand of IVIS, a topic that has been studied for more than 15 years. Recognizing the importance of minimizing the attention demand of IVIS, Kurokawa and Wierwille (1990) created a computer-based program to be used by design engineers. This program assisted designers in developing IVIS, including speedometers, gas/oil gauges, and radio/cassette players. Since the development of this design tool in 1990, new technological advances have made it possible to provide drivers with a much greater amount of information about the driving environment; therefore, additional empirical data were needed. Described below are the experimental approaches used to accomplish each of the stated objectives.

Experimental Approach for Objective 1

The first objective, to investigate driver performance during IVIS tasks that require supplemental processing of information after the extraction of information from a visual display, was accomplished by conducting an on-road study. This study is built from the work of Lee, Morgan, Wheeler, Hulse, and Dingus (1997), which characterized the decision-making process in information-processing terms. In-vehicle tasks were performed, and data were collected on U.S. Highway 460, a four-lane divided road with good visibility. Study participants drove from Blacksburg, Virginia, to Princeton, West Virginia, and then back to Blacksburg. Data were only collected during daytime hours and during clear weather conditions with no rain, snow, or ice on the roadway. A confederate vehicle was driven in front of the test vehicle throughout the drive to create a vehicle-following situation.

An instrumented 1995 Oldsmobile Aurora four-door sedan was used to investigate on-road driver behavior. The vehicle was instrumented with cameras and sensors to monitor and record driver behavior. Cameras were positioned to monitor and record (1) eye glance movements of the driver, (2) forward roadway, (3) position of the vehicle relative to the lane markers, and (4) information being displayed on the IVIS. Sensors were installed to monitor and record (1) longitudinal and lateral accelerations of the vehicle, (2) speed of the vehicle, (3) steering wheel position, (4) headway distance, and (5) in-vehicle auditory sounds. Data received from the cameras and sensors were time stamped and recorded both on videotape and in a data file on a computer installed in the vehicle.

The vehicle was equipped with an experimenter-operated IVIS. A PC laptop was used to operate the IVIS, and a series of slides were created and stored in the computer's memory. When the rear seat experimenter typed a slide number into the keypad of the computer, a tone was presented to the driver to alert him/her that a task was to begin. Auditory instructions for the task to be performed were then presented to the driver. At the conclusion of the instructions, information needed to complete the task was instantaneously displayed on a 10-inch LCD mounted to the right of the driver.

Age, presentation format, information density, and type of task were the independent variables used in this study. Thirty-six drivers participated in the study and were grouped into one of three groups: (1) younger (18 to25 years old), (2) middle age (35 to45 years old), or (3) older drivers (65^{+} years). Information was presented in four different presentation formats on the IVIS: (1) paragraph, (2) table, (3) graphic map with text, and (4) graphic map with icons. The information density was characterized as low, medium, high, or very high, based on the number of options and the categories of information presented for each option. Tasks presented required different types of information processing including: (1) scanning and locating information, (2) selecting a hotel, (3) selecting a route, (4) determining the cheapest route, or (5) determining the quickest route.

Experimental Approach for Objective 2

The second objective, to develop criteria for evaluating driver performance with regard to safety, was accomplished by performing an extensive review of the literature. Values were determined for different driver performance measures that, if exceeded, indicated high workloads and/or decreased situation awareness. Two composite measures were then created: a yellow-line threshold and a red-line threshold. Exceeding the yellow-line threshold indicated that driver performance was significantly negatively affected when compared with baseline driving. Exceeding the red-line threshold indicated that one or more driver performance measures had exceeded a specific value determined by past research and/or expert opinion. These two measures complemented one another. The yellow-line threshold provided a face valid indicator that driver performance was negatively affected, and the red-line threshold indicated if driver performance had exceeded safety parameters, based on expert opinion and past research. Figure 3 illustrates the concept of yellow-line threshold and red-line threshold measures: the green zone refers to driving performance not significantly different from baseline driving, the yellow zone refers to driving performance that exceeded the yellow-line threshold, and the red zone refers to driving performance that exceeded the red-line threshold.

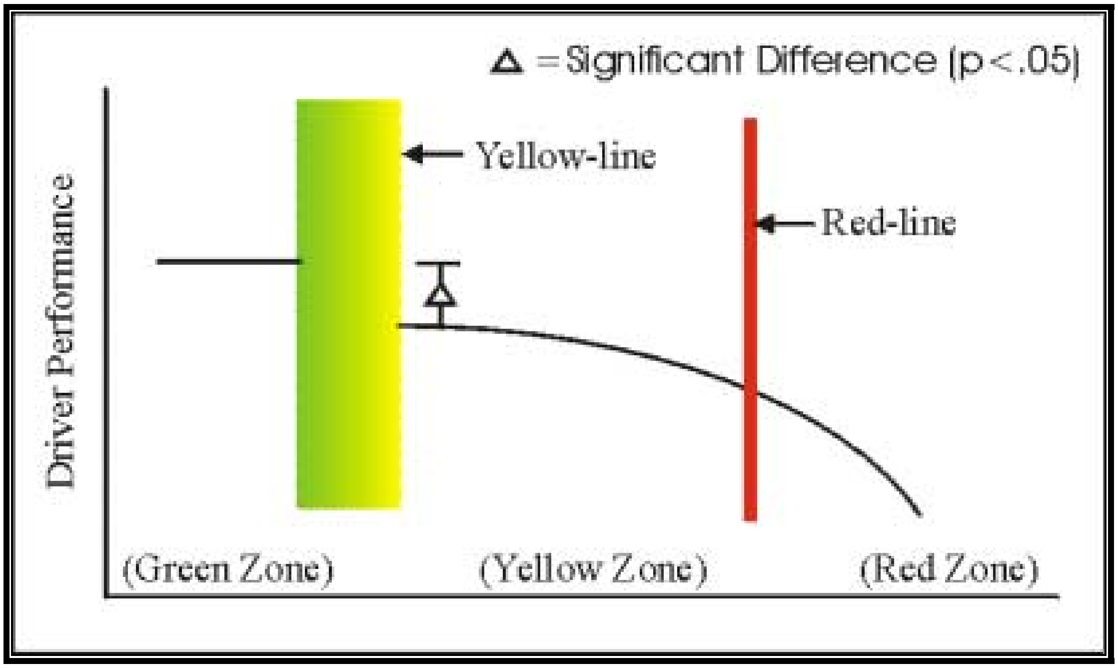


Figure 3. Illustration of red-line and yellow-line thresholds.

Experimental Approach for Objective 3

The third objective, to provide descriptive data on the proportion of drivers who exceeded a safety threshold of driver performance for each of the different IVIS tasks, was accomplished by using the red-line threshold. Designers were questioned as to their needs for evaluating potential IVIS designs. Feedback indicated that designers would prefer not only mean values of driver performance measures but also the proportion of drivers negatively affected when performing an IVIS task. It was recognized that designers may be designing for user groups composed of different age ranges; therefore, results are presented for young, middle age, and older drivers, as well as for the entire driving population.

Results

The data from this study were used to develop the supplemental information processing module within the IVIS DEMAnD software. In addition, the study showed several general research findings that are important for the understanding of driving safety while using in-vehicle devices. Specific findings are described below.

Statistical analyses were performed to investigate the effect of type of information processing, presentation format, density level, and age on driver performance. Results from this study confirmed that a high proportion of drivers were negatively affected when performing IVIS tasks that required complex supplemental processing of information extracted from an in-vehicle display, such as selecting a route or a hotel from several possibilities.

Specific conclusions are listed below:

- Tasks that require supplemental information processing after extraction have a high attention demand when compared with tasks that only require the scanning and extraction of information from a visual display.
- Computation tasks (e.g., involving the selection of the quickest or least expensive item) require high attention demand and generally should not be performed by drivers when the vehicle is being driven.
- Older drivers generally have difficulty with decision tasks at all information density levels.
- Young and middle age drivers have difficulty with decision tasks with more than two to three categories of information, for each available option, on the display at one time.
- Results support previous findings that the graphic map format should be used for navigation information.
- Text-based messages in "paragraph" format have the potential for causing high attention demand. Text with 1.5 line spacing or less should not be presented while the vehicle is in motion.

EXPERIMENT 2: EFFECTS OF IN-VEHICLE INFORMATION SYSTEM (IVIS) TASKS ON THE INFORMATION PROCESSING DEMANDS OF A COMMERCIAL VEHICLE OPERATIONS DRIVER

Problem Statement

Commercial vehicle operations (CVO) represent the mass movement of goods and services in the United States and many other countries. IVIS could help drivers reduce travel time by presenting real-time information on routes, delays, congestion, and warnings of potential hazards (Dingus and Hulse, 1993). This evolving technology may allow CVO drivers to obtain different types of navigation, planning, and hazard notification assistance in the near future. Thus, CVO drivers could perform their jobs with previous notice of what is happening or will be happening in their traveling routes. All these benefits suggest that research into the possible use of ATIS for CVO applications is merited.

Despite the importance of IVIS to CVOs, research was limited on the characteristics of an IVIS in this domain. The primary purpose of this study was to evaluate CVO driver attention demand and performance under several information presentation approaches to include in the IVIS DEMAnD program. These presentation approaches were used specifically to evaluate the drivers under differing types of tasks, presentation formats, and information densities. An additional goal of this experiment, as in Experiment 1, was to determine red-lines and yellow-lines for the design of information presentation approaches for CVO drivers.

Objectives

This study was conducted with three objectives in mind. The primary objective was to obtain a range of data in the CVO environment similar to what had been collected in the automobile environment in Experiment 1. This study was designed so that these data would also be included in the IVIS DEMAnD model.

The second objective was to understand and predict red-lines and yellow-lines in terms of what the CVO driver can process without hindering the primary task of driving. As in Experiment 1, a red-line was operationally defined as the point at which driving would be substantially degraded. Criteria for this were based on expert opinion and previous research. The operational definition of a yellow-line is the point where driving performance is significantly different ($p<0.05$) from the driving performance obtained from a set of baseline driving measures.

The third objective was to collect conventional secondary task data for CVO driving performance. Other research indicated a lack of data related to basic conventional in-vehicle tasks in a CVO environment. Thus, part of the effort of this study was to fill this specific gap.

Methodology
To achieve the research objectives, an on-road empirical study was conducted. All experimental tasks consisted of driving an instrumented 1997 Volvo/GM Heavy Truck with a 48-foot trailer and concurrently performing various in-vehicle tasks.

Type of task, presentation format, information density, and age were the independent variables used in the experiment. The age factor had two levels: 6 middle age participants (35 to 45 years old) and 6 older participants (55 years or older). Six different types of tasks were presented to the participants. The decision-making elements from the work of Lee, Morgan, Wheeler, Hulse, and Dingus (1997) were used as the types of tasks. The six types of tasks are: (1) search, (2) search-compute, (3) search-plan, (4) search-plan-compute, (5) search-plan-interpret, and (6) search-plan-interpret-compute. The information presented during the IVIS tasks followed one of four presentation formats: (1) tabular, (2) paragraph, (3) graphics with text, or (4) graphics with icons. To quantify the information and to identify the points at which driving performance starts to deteriorate, the information was presented to the driver in three different information densities. These densities were categories of information combined with number of alternatives: low, medium, and high. The low level was composed of two information categories and three alternatives. The medium level presented three information categories at each of the three alternatives. The high level was formed by four information categories and five alternatives.

A total of 22 dependent variables were analyzed. These dependent variables are divided into five major categories: (1) eye glance measures, (2) longitudinal driving performance, (3) lateral driving performance, (4) secondary task performance, and (5) subjective measures.

Results
The data obtained from this study have been integrated into the IVIS DEMAnD software. One objective of this study was to understand and predict red-lines and yellow-lines in terms of the information that the CVO driver can process without hindering the primary task of driving. Table 2 illustrates the tasks that resulted in red- and yellow-lines from this study.

Table 2. Summary of red- and yellow-line characteristics for IVIS/CVO tasks.

Type of Display	Type of Task	Density	Line Class
Table	S	L	Yellow
Paragraph	S	L	Red
Graph w/icon	S	L	
Table	S	M	Yellow
Paragraph	S	M	Red
Graph w/text	S	M	
Graph w/icon	S	M	Yellow
Table	S	H	Yellow
Paragraph	S	H	Yellow
Graph w/text	S	H	Yellow
Graph w/icon	S	H	
Table	SC	M	Yellow
Paragraph	SC	M	Red
Graph w/text	SC	M	Red
Table	SC	H	Red
Paragraph	SC	H	Red
Graph w/text	SC	H	Red
Table	SP	L	Red
Paragraph	SP	L	Red
Graph w/icon	SP	L	Red
Table	SP	M	Yellow
Paragraph	SP	M	Red
Graph w/text	SP	M	Red
Graph w/icon	SP	M	Yellow
Table	SP	H	Red
Paragraph	SP	H	Red
Graph w/text	SP	H	Red
Graph w/icon	SP	H	Red
Table	SPC	M	Red
Paragraph	SPC	M	Red
Graph w/text	SPC	M	Red
Table	SPC	H	Red
Paragraph	SPC	H	Red
Graph w/text	SPC	H	Red
Table	SPI	L	Red
Paragraph	SPI	L	Red
Table	SPI	M	Red
Paragraph	SPI	M	Red
Graph w/text	SPI	M	Yellow
Graph w/icon	SPI	M	Red
Table	SPI	H	Red
Paragraph	SPI	H	Red
Graph w/text	SPI	H	Red
Graph w/icon	SPI	H	Red
Table	SPIC	H	Red
Paragraph	SPIC	H	Red
Graph w/text	SPIC	H	Red

Under Type of Task, the abbreviations are: (S)earch, (P)lan, (I)nterpret, and (C)ompute.

Under Density, the abbreviations are: (L)ow, (M)edium, and (H)igh.

The following additional findings from this study may also help IVIS designers:

- The only type of task that exhibits a moderate attention demand compared with the conventional tasks is the Search task. The analysis performed suggests that any other type of task will increase attention demand that, in turn, can lead to an unsafe driving scenario.
- A low information density, which is composed of two categories of information and three alternatives from which the driver can choose, is the highest density that can be presented without causing a high attention demand.
- Graphic with Icons is the display type with the lowest attention demand.
- Paragraph presentation represents the highest visual attention demand among all types of formats.
- A Search task that takes advantage of a Graphic with Icons format with a low information density still represents a higher attention demand than that presented by a conventional task.

Examples of the results that led to these conclusions are presented as Figures 4 to 6. The levels of a given main effect with the same letter denote that the performance of those levels do not significantly differ.

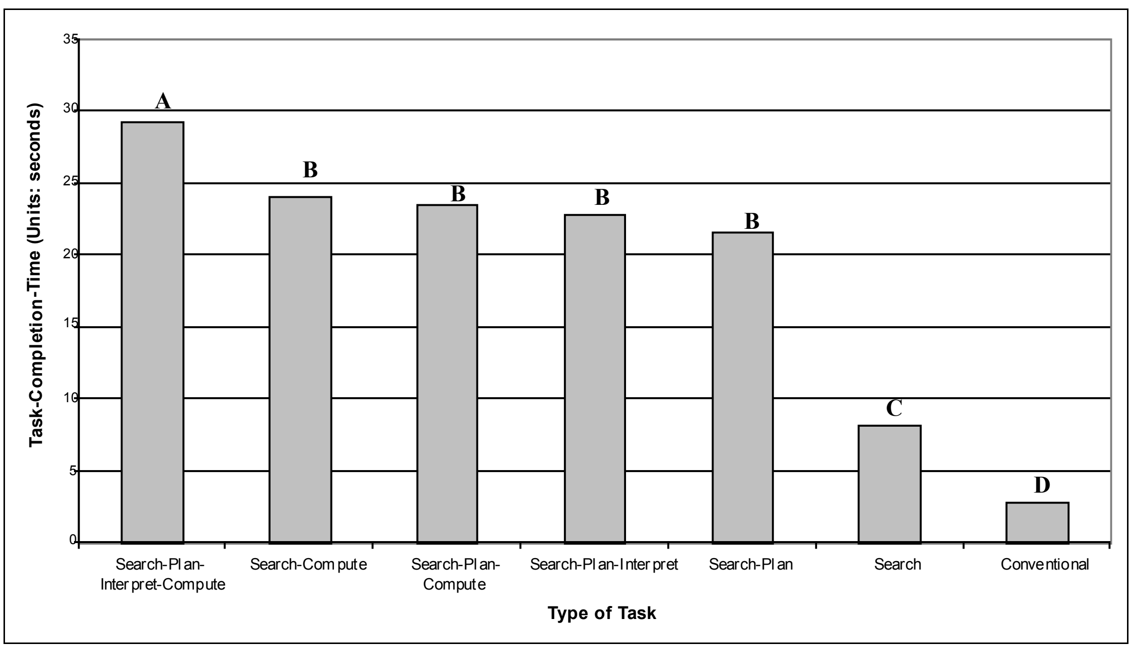


Figure 4. Example of the grouping of the different types of tasks compared with the conventional tasks.

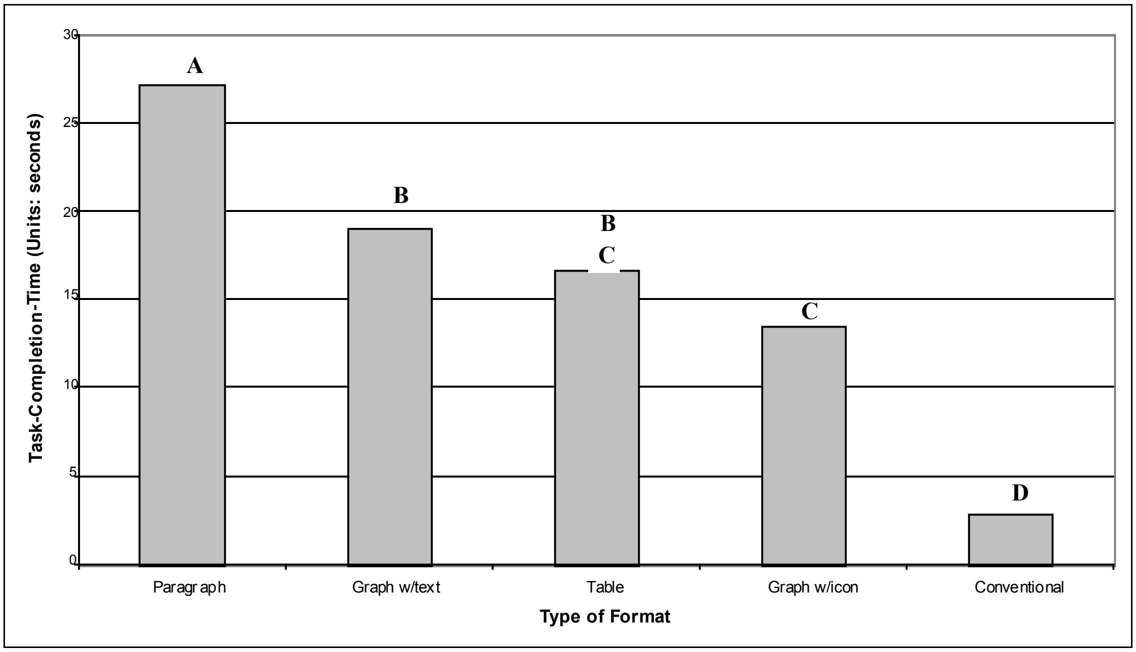


Figure 5. Example of the grouping of the different types of format compared with the conventional tasks.

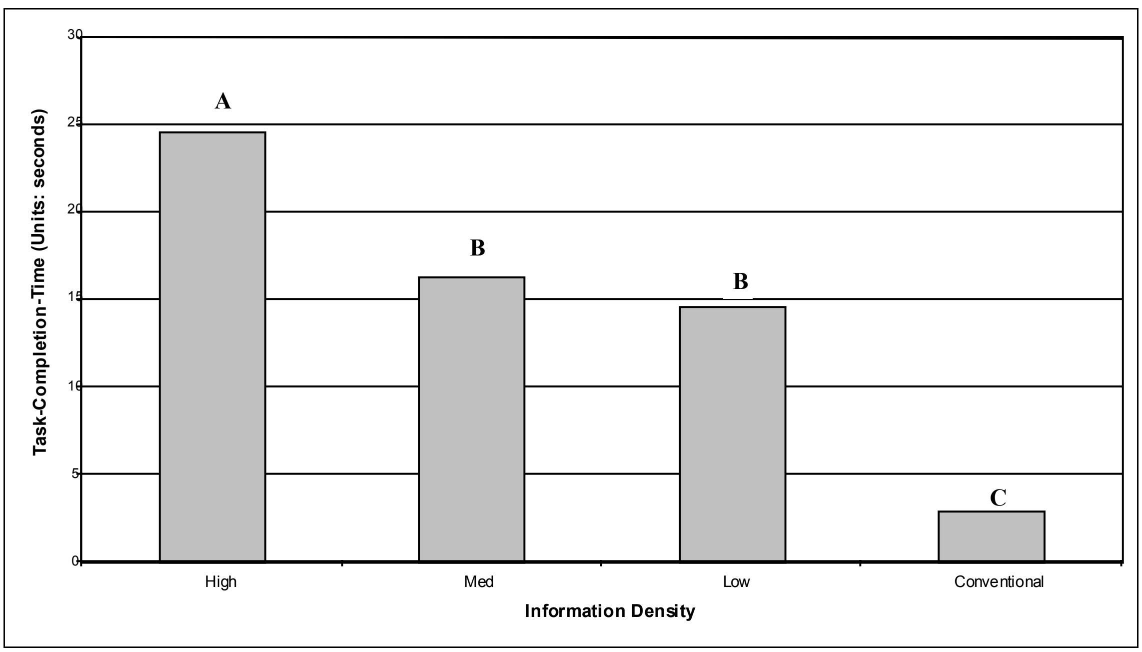


Figure 6. Example of the grouping of the different information densities compared with the conventional tasks.

EXPERIMENT 3: AUDITORY-BASED SUPPLEMENTAL INFORMATION PROCESSING DEMAND EFFECTS ON DRIVING PERFORMANCE

Problem Statement

As designers continue to take advantage of the ongoing technological revolution in sensors, computers, data presentation, and communications technologies in vehicles, they continue to search for better methods of interacting with the driver. One method that has been touted as reducing visual demand and increasing driver safety is presenting information to the driver verbally. Although this approach appears to have merit, research has shown that drivers talking on cell phones are more likely to be involved in crashes than other drivers. Therefore, additional research is required to determine the impact of varying verbal-based tasks on the driver.

Objectives

The main objective of this study was to provide input to the IVIS DEMAnD behavioral model by collecting data that indicated how driving was impacted by performing various tasks using the auditory channel as input. A secondary objective, as discussed in the previous studies, was to determine yellow-line and red-line thresholds in terms of what the driver can process auditorily without hindering the primary task of driving. The final objective was to conduct tasks similar to those conducted in Task 1 so that comparison could be made between tasks that use vision as the primary input and tasks that use auditory as the primary input. As a result, it was important for this study to have the same independent variables used in Experiment 1.

Methodology

Thirty-six drivers of both genders and from three different age groups performed the tasks. The drivers performed these tasks with an auditory component while driving the same instrumented vehicle used in Experiment 1.

The experimental design was a 3 (age) x 2 (task type) x 2 (information density) x 4 (element type). The age groups were (1) young (18 to 25 years old), (2) middle age (35 to 45 years old), or (3) older drivers (65 + years). The two task types were (1) the selection of a driving route from a list presented as a recorded sound and (2) a conversational type task designed to replicate the use of a cellular telephone while driving. These tasks consisted of two levels of information density that were a function of the number of options and the number of decision variables for each option. Finally, the tasks were also separated into the following four decision-making elements: (1) listen only; (2) listen, and plan or interpret; (3) listen and compute; and (4) listen (plan or interpret) and compute.

The effects of age, information density, and element type on driving performance were assessed using a composite set of performance measures. Measures of driving performance included lateral tracking, longitudinal control, and eye glances. Secondary task performance was assessed by task completion time and task errors. Additionally, subjective assessment was done using a situational awareness probe question and a modified NASA-TLX question set.

Results

All of the data from this study were used to develop the auditory and supplemental information processing module within the IVIS DEMAnD software. In addition, the study showed several general research findings that are important for the understanding of driving safety while using in-vehicle devices. Specific findings are described below.

Results showed that during tasks, drivers demonstrated a general decrease in their ability to track their lateral position, maintain their speed and following distance, and remain aware of their surrounding environment. This trend was more pronounced for older drivers. Additionally, for more complicated tasks, as well as ones presented using higher information density, drivers showed poorer results on the various measures of performance.

One result of particular interest was a decrease in speed and an increase in headway variance, coupled with decreased total number of eye glances and increased eye glance duration in the forward direction. This reaction is evidence of a condition in which a driver, although looking more extensively at the forward roadway, is still having difficulty tracking the lead vehicle. High cognitive load may be causing the driver to disregard or shed visual information to allow processing of auditory task-related information.

The strong implication of this study is that driving performance can be negatively impacted by fairly simple cognitive tasks. Even in the case of auditory task presentation, drivers can be cognitively overloaded to the point of safety concerns. Additionally, drivers underestimate the degree of their cognitive load and its impact on their driving performance.

EXPERIMENT 4: ATTENTION DEMAND OF IVIS DISPLAYS UNDER FREEWAY ENVIRONMENTS

Problem Statement

Both Experiment 1 and Experiment 3 were conducted in Blacksburg, Virginia, on a four-lane road with low to moderate traffic. It was important to the IVIS DEMAnD behavioral model to understand how a more congested freeway environment may affect drivers conducting the same tasks as were done in Experiment 1 and Experiment 3. The intention was to include this information in the model so users could determine how the same tasks would change under a higher workload driving environment.

Objectives

This study had two main objectives:

1) To provide data on driver IVIS auditory display interactions to support the overall IVIS DEMAnD behavioral model.

2) To extend the results from Experiment 1 and Experiment 3, which were both conducted in a relatively low traffic setting, to a setting with increased levels of traffic density. This extension was conducted by using the same methodology and a subset of the same tasks as were used in Experiments 1 and 3.

Methodology

In general, this study used the same methodology used in Experiment 1 and Experiment 3.

Independent and Dependent Variables

The same set of independent variables investigated in Experiment 1 was investigated here. These variables included: level of information complexity (two, three, four, or six units of information), task type (search; search and compute; search and plan; search, plan, and compute; search, plan, and interpret; search, plan, interpret, and compute), and age (young, middle age, older).

In addition, two auditory parameters were included in this study that were not included in Experiment 3. The two auditory parameters were message type (prose versus list) and speech rate (normal versus accelerated).

Message type was defined as the message being either in prose form or in list form. The prose form consisted of having the content spoken in complete declarative sentences, such as, "The Ramada has a vacancy and is a distance of 48 miles away." The list form conveyed the same information in list form and not embedded in sentences, such as, "Ramada, Vacancy, 48 miles."

The speech rate was defined as a transmission factor related to information rate and comprehension. Two levels of speech rate were manipulated:

- Normal: approximately 125 words per minute; consistent with typical speech rates.
- Accelerated: approximately 225 words per minute; time-compressed form.

The primary dependent variables in this study were, again, the same as those collected in Experiments 1 and 3. That is, the dependent variables included workload ratings, lane tracking, headway maintenance, speed management, task duration and accuracy, number of repetitions, and several eye glance measures for the visual tasks.

Procedure

Twenty-four subjects participated in the study. The number of subjects in each age group was equal and there were an equal number of men and women in each age group. All subjects had a valid driver’s license and were familiar with the driving route.

Each subject who participated completed a 4-hour session that included:

- Introduction, instruction, and training (45 minutes).
- Vehicle familiarization and practice trials (45 minutes).
- On-road testing (2 1/4 hours).
- Debriefing (15 minutes).

Subjects in the study drove on I-495 and the George Washington Parkway (Washington, D.C. area) during non-rush hours in clear, dry, daytime conditions. The same instrumented vehicle used in Experiments 1 and 3 (i.e.,1995 Oldsmobile Aurora) was used in this study. All subjects received the same fixed set of auditory and visual displays and all levels of each independent variable. The on-road testing portion of the study involved subjects receiving 28 display presentations (20 auditory and 8 visual) while driving on I-495. Drivers also received a subset of the displays (four auditory and four visual) while driving on the George Washington Parkway.

Results

The results of this study consisted of means and standard deviation scores for each task. For inclusion in the model, each task was grouped as a function of driver age. As such, the IVIS DEMAnD program allows users to select data for a task as a function of driver age (young, middle age, older, or all) for the tested tasks.

MODELING THE DATA FOR THE IVIS DEMAND PROGRAM

At the heart of the IVIS DEMAnD program are multiple sets of data and equations. It is from these data sets and equations that a set of summary measures is calculated for a given task or set of tasks. (These summary measures are described in more detail in the prototype overview section.) The development of these data sets and equations was an integral part of the creation of the IVIS DEMAnD program. Details of the data modeling effort have been previously outlined (Dingus, Hanowski, Wierwille, and Hankey, 1999). As such, for this final project report, only a basic overview of the modeling processes will be described.

IP ANALYZER

As outlined in Kurokawa and Wierwille (1990), a software program titled "IP (Instrument Panel) Analyzer" was developed in the late 1980s that allowed designers to evaluate IP tasks in terms of the demand those tasks place on the driver. The IP Analyzer program consists of an evaluation program that provides a computerized database of existing data and two procedures that provide driver performance estimates for IP tasks, for which no data are available.

The IVIS DEMAnD program, developed for the current project, shares several common features with IP Analyzer. For example, the method by which a user interacts with the systems is similar. That is, at a high level the user interacts with the program by selecting a task (IP task or IVIS task, as the case may be). With this task comes a set of *nominal* values (described in the next section) for a host of measures. For example, for a given task that requires visual resources from the driver, several glance time measures are provided (e.g., mean single glance time).

NOMINAL VALUES AND MODIFIERS

When a task is first selected, nominal (or default) values are retrieved by the program. These values represent the nominal case, which includes but is not limited to, all age groups of drivers, moderate traffic density, and moderate roadway complexity. The user can opt to modify the nominal values to better reflect the driver population of interest or the driving environment (e.g., roadway complexity, anthropometric factors, etc.).

Therefore, the modifiers are equations[3] that are applied to the nominal value, which result in a modified value that best reflects the designer's conditions of interest.

Once the user specifies the task(s) of interest and the conditions of the task (i.e., modifiers), an output value for each of the measures is presented. In the IVIS DEMAnD program, this output measure is either incorporated into a "figure of demand" model or presented to the user as a "summary measure." (The figure of demand model and the summary measures are described in more detail in the prototype overview section.)

TASKS INCLUDED IN IVIS DEMAND

One of the goals set at the beginning of this project was to include a wide array of tasks in the "task library" of the IVIS DEMAnD program. That is, the research team wished to have a substantial number of unique in-vehicle tasks available for the user to select from. As highlighted in Table 3 and detailed in Appendix B, a total of 198 tasks were modeled and included in the final prototype program.

The reader will notice that although a substantial number of tasks are included in the task library, not all driver resources, or combinations of resources, have been accounted for. The next section outlines the recommended approach for continuing the process of adding tasks to the IVIS DEMAnD program.

Table 3. Overview of the number of tasks included in the IVIS DEMAnD library, categorized by the driver resource(s) involved.

Resource(s) Involved in Task	Number of Tasks Currently in Task Library
Visual	34
Auditory	6
SIP	5
Manual	2
Speech	18
Visual and Manual	33
Visual and SIP	81
Auditory and SIP	16
Visual, SIP, and Manual	3
Total Number of Tasks in Library	198

[3] Note that the modifiers could either be equations, as suggested, or embedded values in a look-up table.

ADDING TASKS IN THE FUTURE

The IVIS DEMAnD program was developed such that tasks could be added by designers or researchers. This feature allows the software to be a living program that can be updated and kept current. The data for additional tasks can come from three sources. First, due to resource constraints, relevant tasks in existing and new research have not been included in the current version of the program. Second, designers can include their own proprietary designs and results in their personalized versions. Third, research is suggested that would provide data to allow tasks, where no data are currently available, to be modeled and included in the program.

In regard to the first source of tasks, research documents have been identified that contain data for tasks that can be included in the program. It is recommended that the next phase of research for this project start with further investigating the viability of including other tasks. Table 4 presents a list of these tasks, along with a supporting reference.

In addition to the tasks listed in Table 4, it is suggested that other tasks, for which no data have yet been collected, be included in the task library. Obviously, before such tasks can be included, research would be required to gather data on these tasks. Two tasks that may be suitable candidates for inclusion in future versions of the program include (1) in-vehicle tasks requiring use of a keypad and/or keyboard, and (2) *AutoPC* tasks. A section at the end of this report briefly outlines future recommended research. It is suggested that, as follow-up studies are conducted, data from IVIS tasks investigated in the studies be modeled and included in the IVIS DEMAnD program.

Table 4. Tasks that have been identified in the literature but have not yet been included in the IVIS DEMAnD program task library.

Task	References
Heavy Vehicle - Workload General	Kiger, Rockwell, Niswonger, Tijerina, Myers, and Nygren, 1996
Heavy Vehicle - Workload ATIS	Mollenhauer, Dingus, Hankey, Carney, and Neale, 1997
Cellular Phones - Dialing (Manual and/or Voice)	Tijerina, Kiger, Rockwell, and Wierwille, 1996 Serafin, Wen, Paelke, and Green, 1993 Hanowski, Kantowitz, and Tijerina, 1996
Cellular Phones - Conversation	Serafin, Wen, Paelke, and Green, 1993 Alm and Nilsson, 1994, 1995 Hanowski, Kantowitz, and Tijerina, 1996
Navigation - Route Following	Dingus, McGehee, Hulse, Jahns, Manakkal, Mollenhauer, and Fleischman, 1995 Mollenhauer and Dingus, 1997 Green, 1992 Hancock, Shekhar, Burrus, and Stephens, 1995 Burnett and Joyner, 1997
Navigation - Destination Entry	Tijerina, Parmer, and Goodman, 1998
General ATIS (Navigation and Other)	Green, Williams, Hoekstra, George, and Wen, 1993
Soft Key Menus (and Hard/Soft Combinations)	Monty, Snyder, Farley, Reger, Hunter, and Merriken, 1985 RandR Research, 1983 Gellatly, Shutko, Kieliszewski, and Dingus, 1998
HUD Fixed Segment and Reconfigurable	Jahns,1996 Wierwille* Kiefer*
Multi-Modality	Liu and Dingus, 1997 Mollenhauer, Lee, Cho, Hulse, and Dingus, 1994
Voice	Gellatly, 1998
Phone Dialing	See Cell Phone

IVIS PROTOTYPE OVERVIEW

The primary component of this project is a model/software prototype. The prototype is named IVIS DEMAnD. The purpose of this prototype is to determine if software that integrated the behavioral model and past research on driver behavior when using IVIS systems will be useful to IVIS designers. The prototype is designed to illustrate how a fully functioning computer program can be used during the design process. As part of this project, a user manual has been written that describes all the functions of the system. Therefore, the purpose of this overview will be to highlight some of the options. For a more thorough discussion of the prototype, please refer to the User's Guide.

The prototype has been designed to facilitate the user in developing a conceptual model of the driver as a collection of resources with limited capacity. As described earlier, these include visual, auditory, supplemental information processing, manual, and speech resources. It is important for users to perceive secondary tasks, such as IVIS tasks, as being potentially in competition for these resources with the primary task of driving the vehicle. Finally, it is important that users understand that the amount of additional load placed on the driver by these tasks depends on numerous factors, including:

- Driver-related factors such as age and the reliance drivers have on signs, symbols, or characters to complete a task.
- Driving environment factors such as the level of congestion and the complexity of the road the driver needs to navigate.
- Display factors such as the size of characters or symbols, their luminance in the displays, and the information density on the display.
- Task factors such as whether the task requires multiple pieces of information, whether planning is required, and the number of subtasks included in the task.

The prototype has been designed so that the user can describe various in-vehicle information systems in terms of the tasks a driver might routinely perform and to compare the effects on driver demand of different tasks and different systems. How these tasks were developed has been discussed earlier in the "Modeling the Data for the IVIS DEMAnD Program" section of this report.

To estimate the demand associated with discrete tasks, the behavioral model in the prototype derives measures such as expected single glance time to a display, the number of glances required to comprehend a message, or the amount of time the driver's hand is off the wheel. The measures of demand used by the model are shown in Table 5, along with their primary resource. Note that some of these measures (denoted with an *) are not used in the current task library but have the potential to be used in the future.

Table 5. The five resources and the associated measures of demand.

Resource	Demand Measure
Visual	Expected Single Glance Time (seconds)
	Expected Number of Glances
	Expected Eye Transition Time (seconds)
	Visual Time
Auditory	Expected Number of Message Presentations
	Expected Message Duration (seconds)
	Expected Word Length*
	Subjective Message Complexity Rating*
Manual	Hand at Task Time (seconds)
	Hand Travel Time to Task (seconds)
	Hand Travel Time From Task (seconds)
Supplemental Information Processing (SIP)	Subjective SIP Time-Sharing Demand Rating
	Subjective SIP Mental Demand Rating
	Subjective SIP Frustration Level Rating
Speech	Expected Command Input Time per Attempt (seconds)
	Expected Number of Command Attempts
	Subjective Speech Ease of Use Rating*
	Subjective Speech Comfort Rating*
	Subjective Speech Distraction Rating*
Overall	Time to Complete Task
	Expected Percentage of Drivers Unable to Complete the Task

Figure 7 provides an overview of the IVIS program. As illustrated in the figure, the prototype uses tasks and subtasks performed using an IVIS to estimate the attention demand on the driver. The prototype also provides a means by which the attention demand can be better estimated by specifying additional parameters. These parameters include:

- Vehicle Type.
- Task Modifiers.
- Subtask Modifiers.
- Control and Display Locations.

Three printable summary reports are included so that the user can review system level, task level, and/or subtask level information offline. The following section will discuss each of these reports, the metrics used to measure attention demand, the task library, the expert versus novice paths, and a brief overview of the interface design. For more detailed information, please refer to the User's Guide.

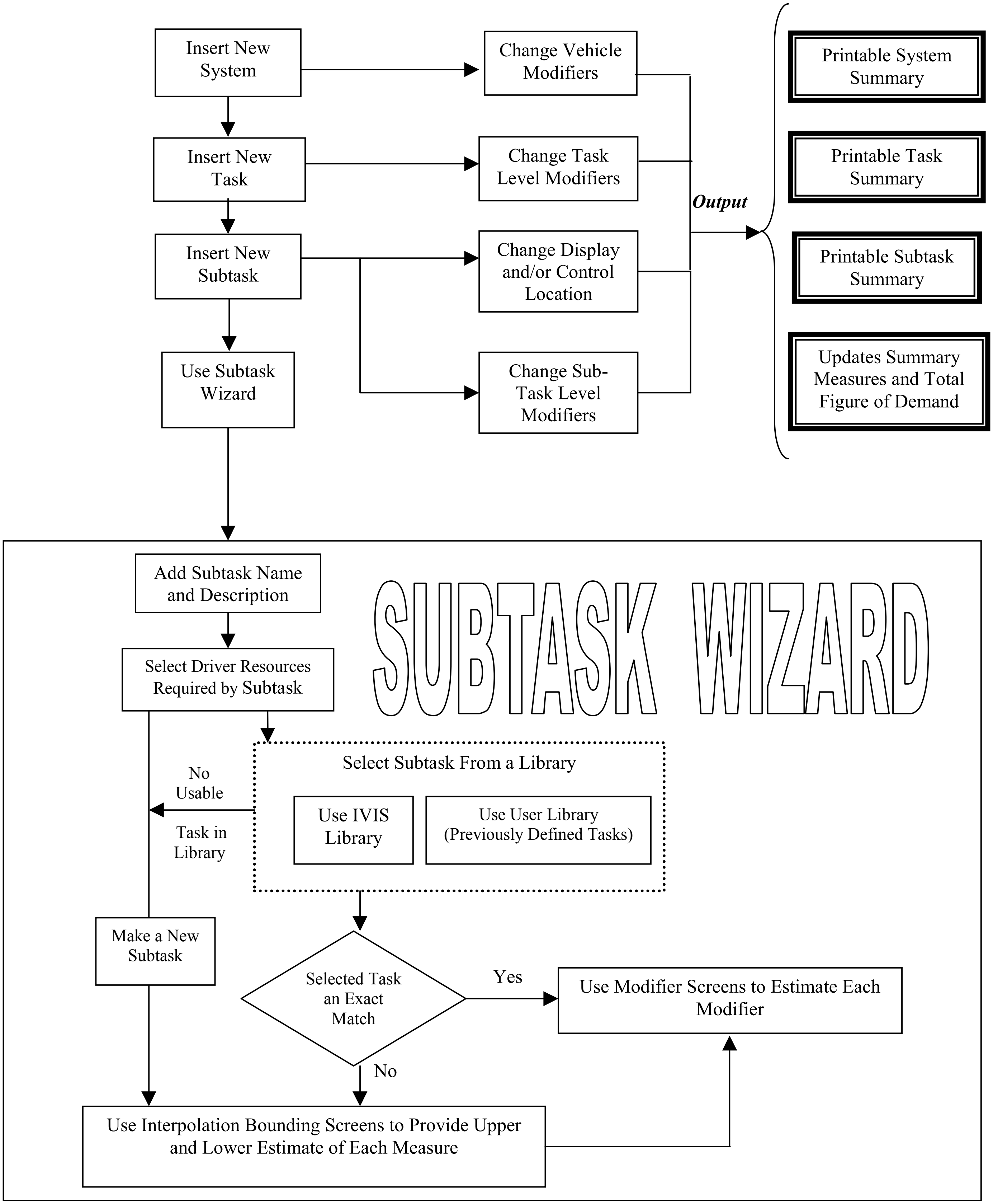


Figure 7. Prototype overview.

EXPERT USER GROUP

An expert user group (i.e., a group of experienced designers who would be candidate end users of the product) was used at each phase of the project to ensure that the project would provide a potentially useful end product. These experts were from Ford, Delphi, Visteon, GM, and Freightliner. The selection of this group provided us with experts from two of the major automotive industries, two system suppliers, and one heavy truck manufacturer. In each case, the colleagues of the experts were shown the system as well. This approach provided a great deal of feedback. In addition, the prototype was demonstrated at technical conferences to obtain as much feedback as possible (Table 6). This work resulted in numerous suggestions that were integrated into the program. Some of the suggestions that were integrated into the model will be described in the following sections. Those suggestions that were not integrated because of scope, cost, or time are shown in Appendix C. If follow-on work is conducted on this prototype, these suggestions should be reviewed and integrated if feasible.

Table 6. List of conferences at which the IVIS DEMAnD prototype was demonstrated.

Conference Title	Quarter and Year
Vision in Vehicles International Conference	Summer 1999
ITS Demo 99	Summer 1999
Human Factors and Ergonomics Society Annual Meeting	Fall 1999
Transportation Research Board Annual Meeting	Winter 2000
ITS America Annual Meeting	Spring 2000
Joint IEA and Human Factors and Ergonomics Society Conference	Summer 2000

USER INTERFACE DESIGN

In general, this program follows the Windows GUI guidelines. These guidelines were chosen because of the wide use of the Windows operating system. An example of these guidelines is shown in Figure 8. An "explorer" view is used to provide access to all the systems, tasks, and subtasks that have been entered into the system (Figure 8). An "explorer" view refers to the Windows interface technique of viewing files in a hierarchical format. Users can interact with this information within the explorer view or by using the menu system. As illustrated in Figure 8, in the explorer view users can use the right mouse option to initiate frequently required options such as cut, copy, and paste. As can also be seen in Figure 8, the program uses the common File, Edit, View, Window, Help menu structure and common icon buttons for frequently required functions. Such examples include the scissors for the cut function and the disk for the save option. For more detailed information on the functions available, the reader should review the User's Guide.

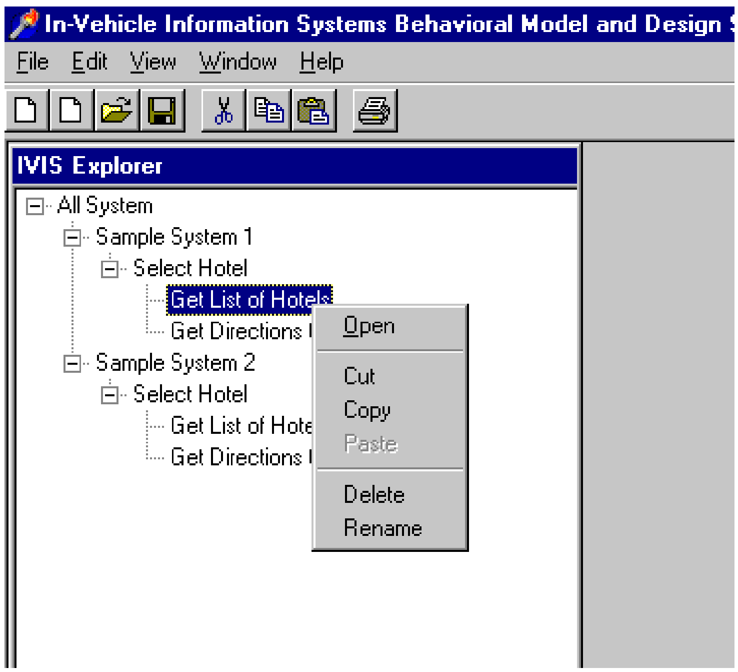


Figure 8. Explorer view.

TASK LIBRARY

As described earlier, a substantial task library is at the heart of this program. The task library is based on both research found in the technical literature and research done specifically for this project. The library contains 198 tasks, which are grouped by the five resources that were used to perform the task. As illustrated in Figure 9, this grouping allows the user to search for tasks by the resources that were required to perform the task. An "explorer" type view is provided at each relevant resource combination; users can either expand a view at a specific resource or "roll it" back under the resource title.

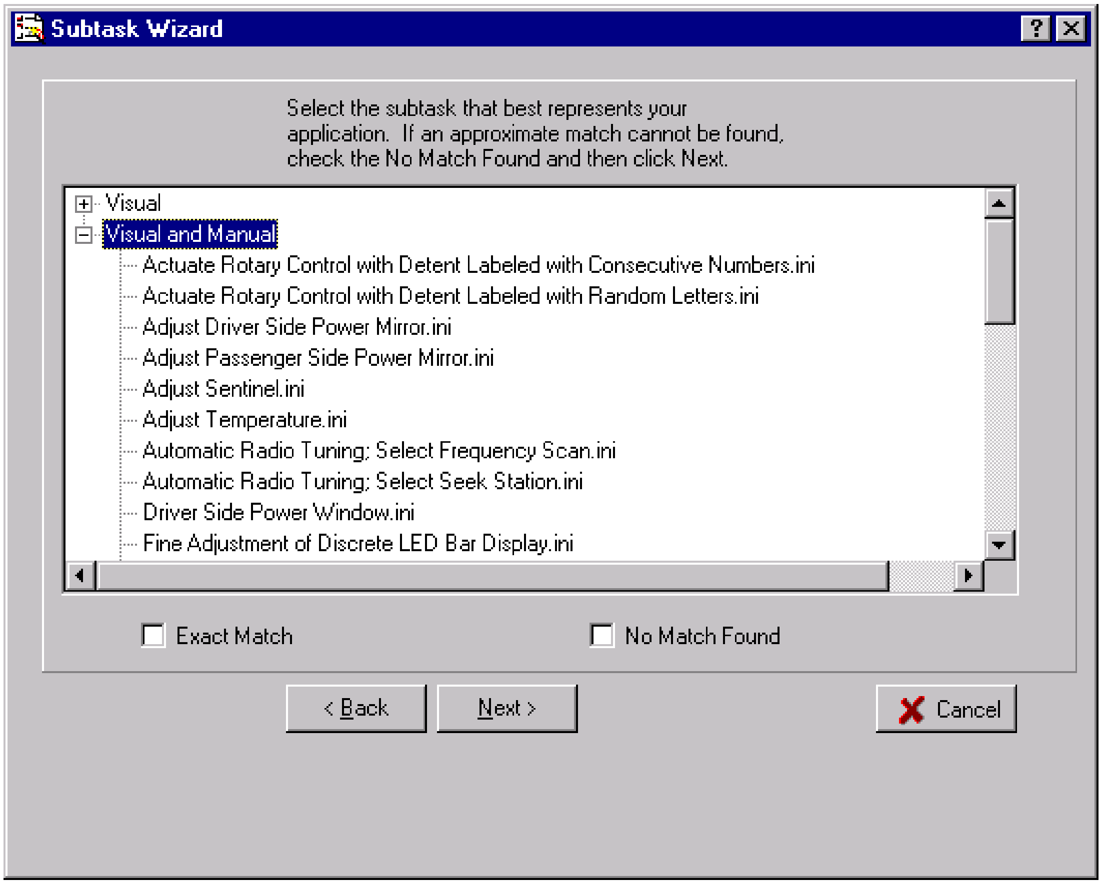


Figure 9. Task library in the Subtask Wizard.

Task templates have been included in the library for each resource. It is likely that users will eventually want the flexibility to add their own task templates. The program has been designed so that this can be done using a simple text editor. Appendix D illustrates the template for the task of "selecting M of N push buttons."

The IVIS DEMAnD software has been designed so users have the flexibility to use tasks they previously created rather than relying solely on the IVIS task library. To avoid confusion, tasks used previously by users are in a separate library from the IVIS task library (Figure 7). The user's library refers to existing analyses and contains all the previous analyses the user has saved. Some of our expert users believed that separating these libraries was important so users would be able to distinguish tasks derived from the technical literature from those modified by previous users. Tasks in the existing analyses library can be created from scratch or can be created by modifying a task from the IVIS library.

Recall that users have the flexibility to modify most of the demand measures in an IVIS library task by using the Subtask wizard. The wizard uses "interpolation screens" to allow the user to input actual data or to estimate the parameters of interest based upon previous experience or a similar system. An example of an interpolation screen from the Subtask wizard is illustrated in Figure 10. As shown in the figure, users can select an upper bound and lower bound if they are unsure of the actual value of a demand measure. A list of all the demand measures that are currently modifiable is shown in Table 7. Only the demand measure applicable to the resources identified by the user as belonging to the task can be modified. For example, if a task is identified as a visual-manual task, then none of the speech demand measures should be modified by the user, and as a result will not be presented by the wizard.

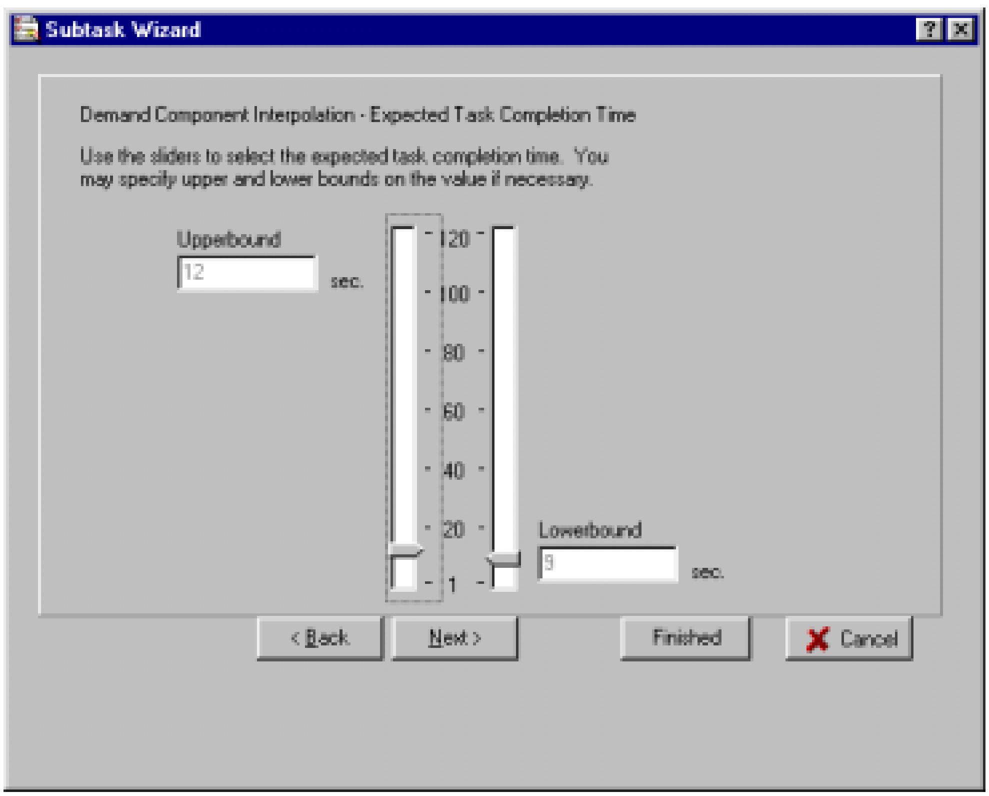


Figure 10. An example of an interpolation screen.

Table 7. Demand measures that were modifiable with the interpolation screens.

Demand Measure
Mean Single Glance Time (seconds)
Mean Number of Glances
Mean Number of Message Presentations
Mean Message Duration (seconds)
Subjective Message Complexity Rating
Mean Hand at Task Time (seconds)
Subjective SIP Time-Sharing Demand Rating
Subjective SIP Mental Demand Rating
Subjective SIP Frustration Level Rating
Mean Command Input Time per Attempt (seconds)
Mean Number of Command Attempts
Subjective Speech Ease of Use Rating
Subjective Speech Comfort Rating
Subjective Speech Distraction Rating
Mean Time to Complete Task

SUMMARY MEASURES

Keeping in mind that the IVIS DEMAnD software is designed for use by individuals familiar with driving and driver performance, it is important to provide data to users at a level of detail that they find useful. In addition, past research has shown that some individual measures are good predictors of driver performance. For example, mean single glance times of greater than 2 seconds to the display have been shown to cause lateral lane deviations (Zwahlen, Adams, and Debald, 1988). This program provides a window panel (Figure 11) that shows a critical set of these individual measures. Each relevant measure of a task is displayed in the expected demand summary panel as a low and high value. In cases in which a designer inputs a "range" via an interpolation screen (Figure 10), these values will be different. Otherwise, the values are the same. The user can then consider these individual measures when evaluating the proposed design. If a measure is not relevant, "n/a" is placed in the low- and high-value columns. Each measure has been color coded to indicate when there is a likely impact on driving performance. Yellow highlighting of the predicted measure indicates that driving performance will be affected relative to baseline driving with no in-vehicle task. Red highlighting of the value indicates that driving performance will be substantially affected relative to baseline driving with no in-vehicle task. The actual value is provided in addition to the color highlighting, so users who want to select a different value for indicating a potential problem have the flexibility to do so. Each of the measures included on the expected demand summary panel is shown in Table 8, along with the yellow (affected) and red (substantially affected) line values. For both Task Failure Rate (percent) and Hand at Task Time, no coding is provided to indicate affected and substantially affected. In these two cases, there were no known criteria or direct links to unsafe driving performance to support either coding.

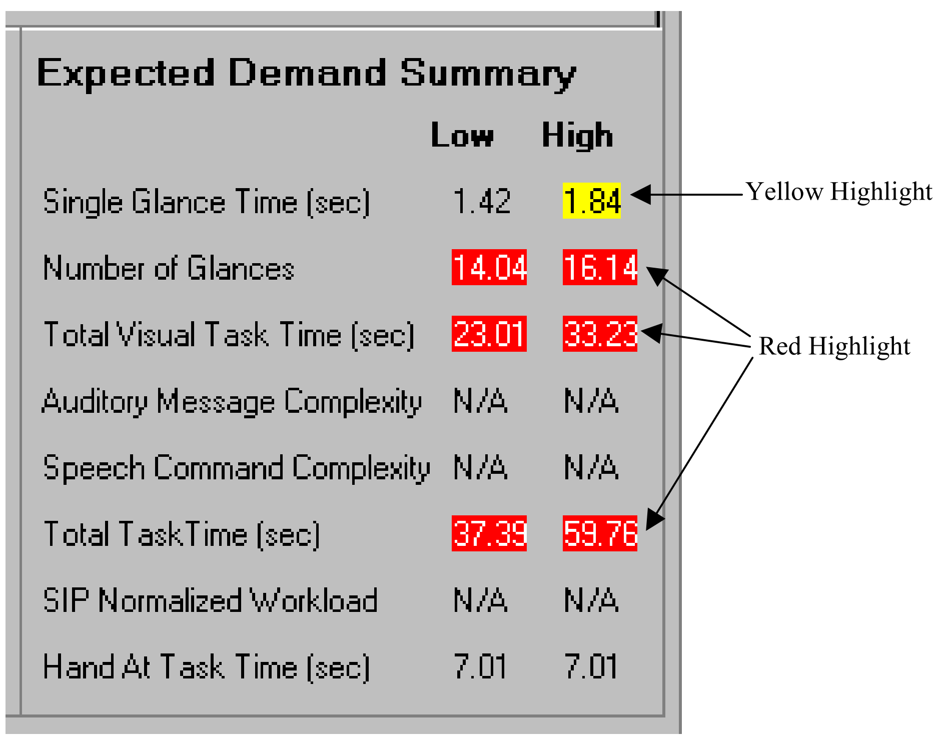


Figure 11. Expected demand summary panel.

Table 8. Measures in the expected demand summary and critical values.

Individual Measures	Affected (coded yellow)	Substantially Affected (coded red)
Single Glance Time	1.6 seconds	2.0 seconds
Number of Glances	6 glances	10 glances
Total Visual Task Time	7 seconds	15 seconds
Auditory Message Complexity Rating	Medium	High
Total Task Time	12 seconds	25 seconds
Speech Command Complexity Rating	Medium	High
Task Failure Rate (percent)	Not Coded	Not Coded
Hand at Task Time	Not Coded	Not Coded

FIGURE OF DEMAND

In addition to an individual measures summary, the IVIS DEMAnD software computes a single overall measure that assesses attention demanded of the driver. This overall measure is called the "figure of demand" or FOD. The FOD has been developed so that it can be displayed with the summary measures described in the previous section. The idea is that users can evaluate their design based on an overall measure of driver demand, as well as some combination of individual summary measures. For example, a navigation task may look acceptable when one is reviewing the individual summary measures but may indicate a problem when one is reviewing the overall figure of driver demand. On the other hand, the overall figure may indicate that the driver is minimally affected, but the summary measures might indicate that the mean single glance time is too high. It is hoped that by providing both the summary measures and the overall FOD measure, users can determine the impact of their design on the driving task more completely.

As described in the Behavioral Model section, tasks that impact the driver can be composed of five possible resources: visual, auditory, SIP, manual, and speech. Therefore, the overall figure of demand must take into account the relative contribution of each of these resources.

Since these resources vary significantly from one another with respect to their impact upon the driving task, this has posed a difficult problem. The solution is to find common dimensions upon which the resources can be combined.

The common dimensions selected are: (1) time to complete the task, and (2) proportion of the total driver information processing resources available. Task completion time has been proposed in several recent studies (e.g., work in support of the recent SAE proposed "15 second rule") as a measure to the acceptability of a task for inclusion. Processing resources demanded is a face valid dimension that allows, at least conceptually, differing resource types to be treated on a common scale.

Since the time and resource demand dimensions differ from one another, the concept of using the "area under the curve" of a two-dimensional time/resource plot was established. This concept is depicted in Figure 12. Several important features of this concept are illustrated in Figure 12. First, subtasks that use differing resources can be combined to provide an overall assignment of task demand, because (and assuming) they are conducted serially and in close time proximity. Second, as discussed below, differing subtasks require differing levels of driver resources, but for this calculation these are equated on the same scale.

The figure shows that as the length of a subtask is increased or as more subtasks are added, the area under the curve (depicted in gray) and the associated FOD increases. Likewise, as the resources demanded increase at any moment or period of time, the FOD also increases.

While the FOD time dimension is straightforward to model from existing data sources, the resource demand dimension is more difficult. It is important to develop a scheme that penalizes more heavily those resources that compete to a greater extent with the driving task. For example, the resource most important to the driving task is the visual resource. Therefore, it is assumed that for the time period that the driver is looking away from the roadway at a display, 100 percent of the resources are demanded (i.e., a "1" on the resource axis in Figure 12). This assumption means that no processing of the driving task is being performed while looking away. Although not perfect (e.g., some low level of processing of movement on peripheral vision is probably occurring), this assumption is probably valid for all practical purposes.

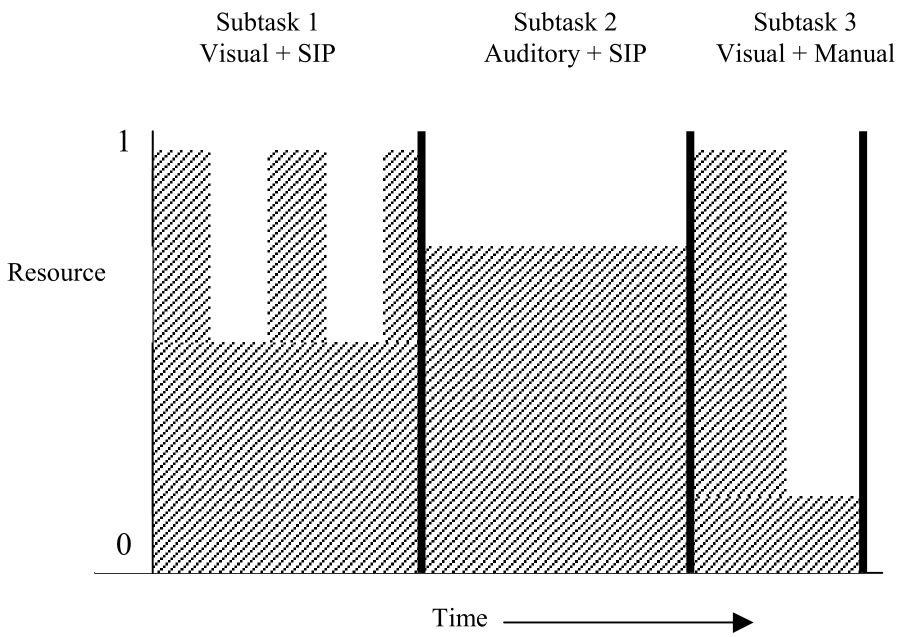


Figure 12. Conceptual representation of FOD calculation.

The relative proportions of resources demanded by the other resources (that is auditory, SIP, speech, and manual) are estimated by equating subjective workload and situation awareness estimates and objective measures of driving performance. These data are able to support the categorization of the resource demand as low, moderate, or high. Low is defined as the load imposed by performing a task that requires no supplemental information processing, defined as complex planning or decision making. This level is essentially a “cost of concurrence” factor associated with performing a secondary task in a dual task environment. Cost of concurrence states that there is some nominal load present as a result of having to perform two simultaneous tasks, even if the current resource demanded by the secondary task is zero. This occurs because the operator must plan to periodically switch attention and monitor the secondary task. Based on the available data, the low, moderate, and high levels of non-visual resource demand have been estimated to be 0.16, 0.5, and 0.7, respectively, as compared with 1.0 for the visual resource demand.

Figure 12 is constructed to illustrate a cellular phone task. Subtask 1 is a dialing task that is classified as a Visual + SIP task. When the driver is glancing away from the roadway to dial, the resources demanded equal 1.0. When the driver is glancing at the roadway the resources demanded are estimated to be moderate (i.e., 0.5) because the driver is keeping the number to be dialed in short-term memory for this particular subtask. The second subtask is the conversation task, shown with a high level of non-visual resources demanded (i.e., 0.7). This second subtask will be characterized as one that requires complex planning or decision making, such as selecting a flight from several options for an upcoming trip, or selecting a hotel when several options are available. Since the driver is never glancing away from the roadway, the resources demanded are never 1.0 and are assumed to be constant during the subtask. Subtask 3 is the subtask for hanging up the phone. The driver must look to hang it up but the non-visual resources demanded are low because this subtask requires no supplemental processing resources.

Based on the above logic, the equation required to calculate the FOD is as follows (how visual time, resource weighting, and the correction factor are calculated will each be explained below):

FOD = ((Visual Time)*1) + ((Total Task Time - Visual Time)* Resource Weighting) * Correction Factor

As shown in the equation, the time using the visual resource is the most detrimental to the driving task and is therefore multiplied by 1. As illustrated in the following equation, visual time also includes time when the driver's eyes are in transition to and from the "display."

Visual Time = ((Mean Single Glance Time + (2 * Mean Transition Time)) * Number Of Glances)

As described above, the remaining time to complete the task is less detrimental to the driving task and is multiplied by the resource weighting factor (i.e., 0.16, 0.5, or 0.7). As shown in the following formula, the resource weighing takes into account the proportion of each resource other than the visual one that is required to perform the task, and multiplies that proportion by a resource-specific weighting factor. All the weighted time periods from each resource are then combined together and divided by the combined non-weighted time from each resource. This produces the resource weighting to be multiplied with the remaining task time.

Resource Weighting = ((Auditory Time * Auditory Weighting) + (SIP Time * SIP Weighting) + (Speech Time * Speech Weighting) + (Manual Time * Manual Weighting))/ (Auditory Time + SIP Time + Speech Time + Manual Time)

The final variable in the FOD calculation for IVIS DEMAnD is a correction factor. The purpose of this factor is to shift the scale to a meaningful, or at least usable, context for the user. A value of 100 has been selected to be the point where the driver is judged to be substantially affected by the task demand (i.e., red-line). The point 100 has a specific meaning. By shifting the scale so the driver is substantially affected at 100, the data indicate that a driver will begin to be affected at approximately 40. This relationship is depicted in Figure 13 and is displayed to the user in the bottom left-hand window of the IVIS DEMAnD software.

Figure 13 illustrates task demand using a traditional (though hypothetical) human performance curve. That is, as task demand increases, driving performance begins to degrade. This curve has also been included to help the user see the driver as a pool of resources with a limited capacity. That is, when the task demand draws heavily on these resources, an accompanying decrement in driving performance is likely. Color has been used to provide redundant cues to the user, with green indicating nominal, yellow indicating affected, and red indicating substantially affected. The program has been developed so that the line will be "painted" to the point that is the task demand. Therefore, Figure 13 shows the driver substantially affected with a task demand of approximately 150.

As described earlier, if users are unsure of the value of a specific variable, they are allowed to input a lower and upper bound for that variable. This range selection also creates a range in the FOD calculation. In the FOD figure the range is depicted by a wider line. Thus, the line is wider between 130 and 150 compared with the remainder of the line. This means that the lower FOD bound is 130 and the upper bound is 150 (Figure 13).

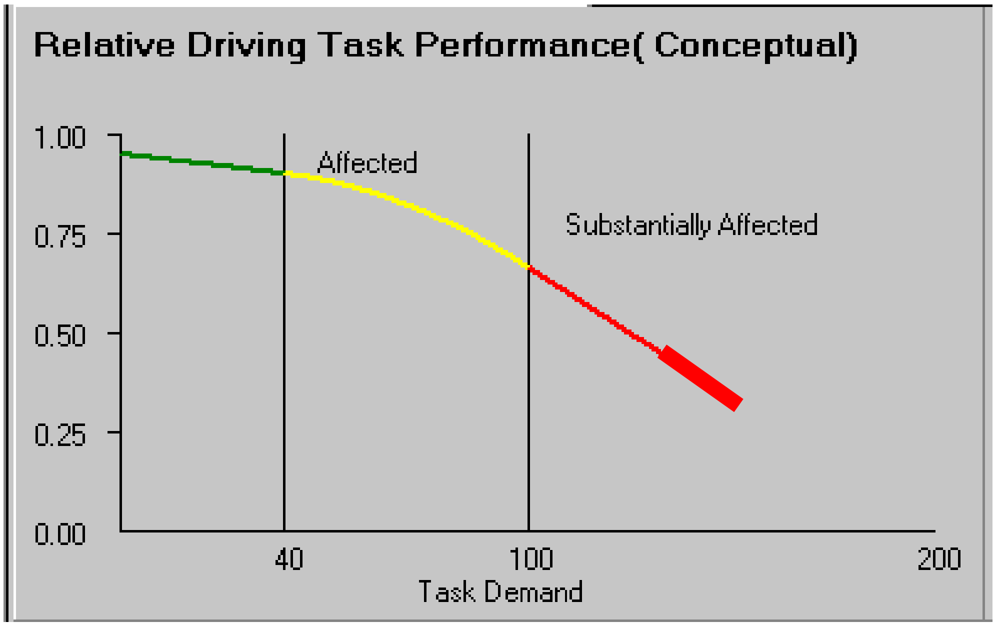


Figure 13. Figure of demand.

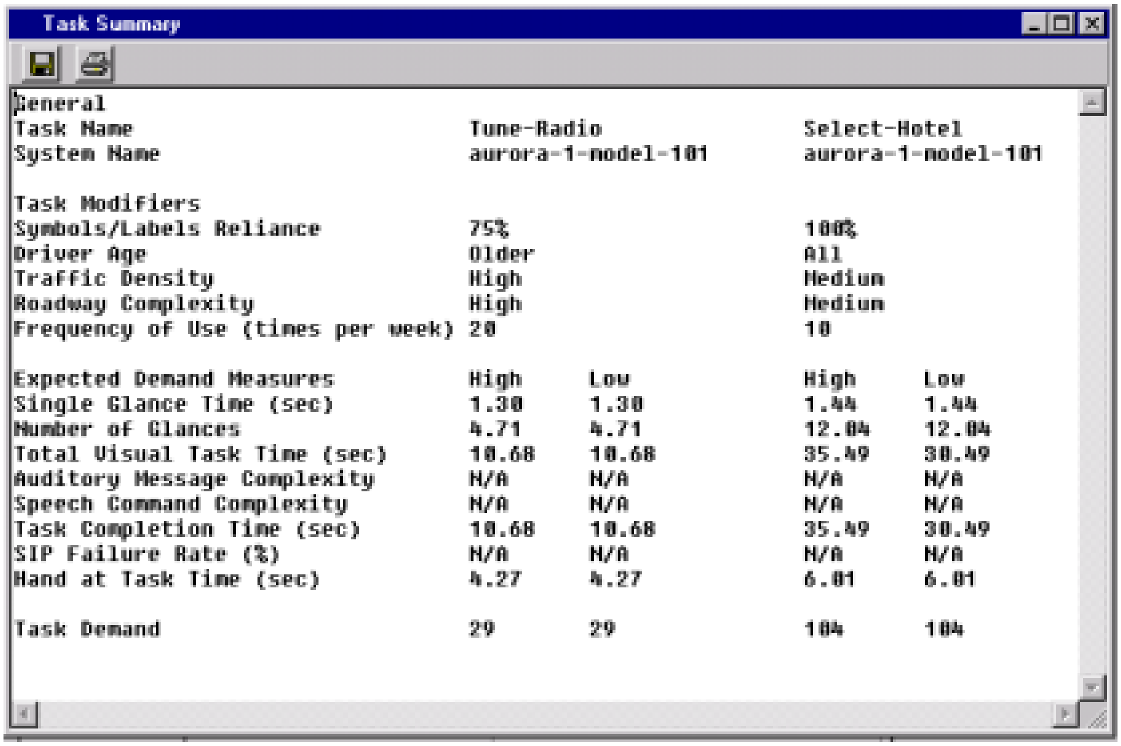
SUMMARY REPORTS

This program also provides a set of summary reports to help users analyze, compare, and present similar subtasks and tasks both within one system and two or more systems. Our expert user group believed that this was an important module to include in the program. The set of reports includes a Task Summary, Subtask Summary, and a System Summary. Task and subtask comparisons may only be made among tasks that are currently in use in the program (i.e., open). Each report may be printed, saved to a text file, or manipulated with other applications such as spreadsheet or word processing applications.

The task report has been designed to allow users to make comparisons between tasks within the same system or to make comparisons between the same task using different systems. The task report has been designed to provide the user with all the necessary information to make an informed decision about either of these comparisons. An example of a task report is shown in Figure 14. The information in the task report and a brief description of each information item follows:

- Task Names: The task names are originated by the user to describe a task.
- System Names: The system names are originated by the user to describe a system.
- Task Modifiers: The task modifiers are set by the user to account for such aspects as the probable driving environment or the probable driver's age. The selected values of all task-level modifiers are included.
- Expected Demand Measures: The expected demand measures are the measures that appear in the summary measures window to give the user added information about the demand of a specific task or subtask. An example of an expected demand measure is mean single glance time. Both the low and high values for each relevant demand measure at the task level are displayed.
- Figure of Demand: The FOD is the single measure of task demand in which a value greater than 40 indicates driving performance may be affected, and a value greater than 100 indicates that driving performance may be substantially affected. Both the low and high values of this measure are displayed.

As stated above, the task summary allows users to make direct comparisons of different tasks using the same system or the same task using different systems. By showing all the expected demand measures and showing the FOD values, users can make informed decisions about the inclusion of a task or the merit of one system over another. Also, by reviewing the setting of the modifiers, the user can be assured that the difference in one task over another is not attributable to a modifier being set incorrectly. However, it is still possible for a difference in a task to occur if a value of a nominal demand measure in a subtask is set incorrectly. These values are displayed in the subtask report. This is described in more detail in the following subtask report discussion.



Task Summary

General				
Task Name	Tune-Radio		Select-Hotel	
System Name	aurora-1-model-101		aurora-1-model-101	
Task Modifiers				
Symbols/Labels Reliance	75%		100%	
Driver Age	Older		All	
Traffic Density	High		Medium	
Roadway Complexity	High		Medium	
Frequency of Use (times per week)	20		10	
Expected Demand Measures	High	Low	High	Low
Single Glance Time (sec)	1.30	1.30	1.44	1.44
Number of Glances	4.71	4.71	12.04	12.04
Total Visual Task Time (sec)	10.68	10.68	35.49	30.49
Auditory Message Complexity	N/A	N/A	N/A	N/A
Speech Command Complexity	N/A	N/A	N/A	N/A
Task Completion Time (sec)	10.68	10.68	35.49	30.49
SIP Failure Rate (%)	N/A	N/A	N/A	N/A
Hand at Task Time (sec)	4.27	4.27	6.01	6.01
Task Demand	29	29	104	104

Figure 14. Task summary report.

As with the task report, the subtask report allows the user to select any open subtask to include in the task report. As illustrated in Figure 15, more information is included in the subtask report than the task report. This information is described in the following bulleted list.

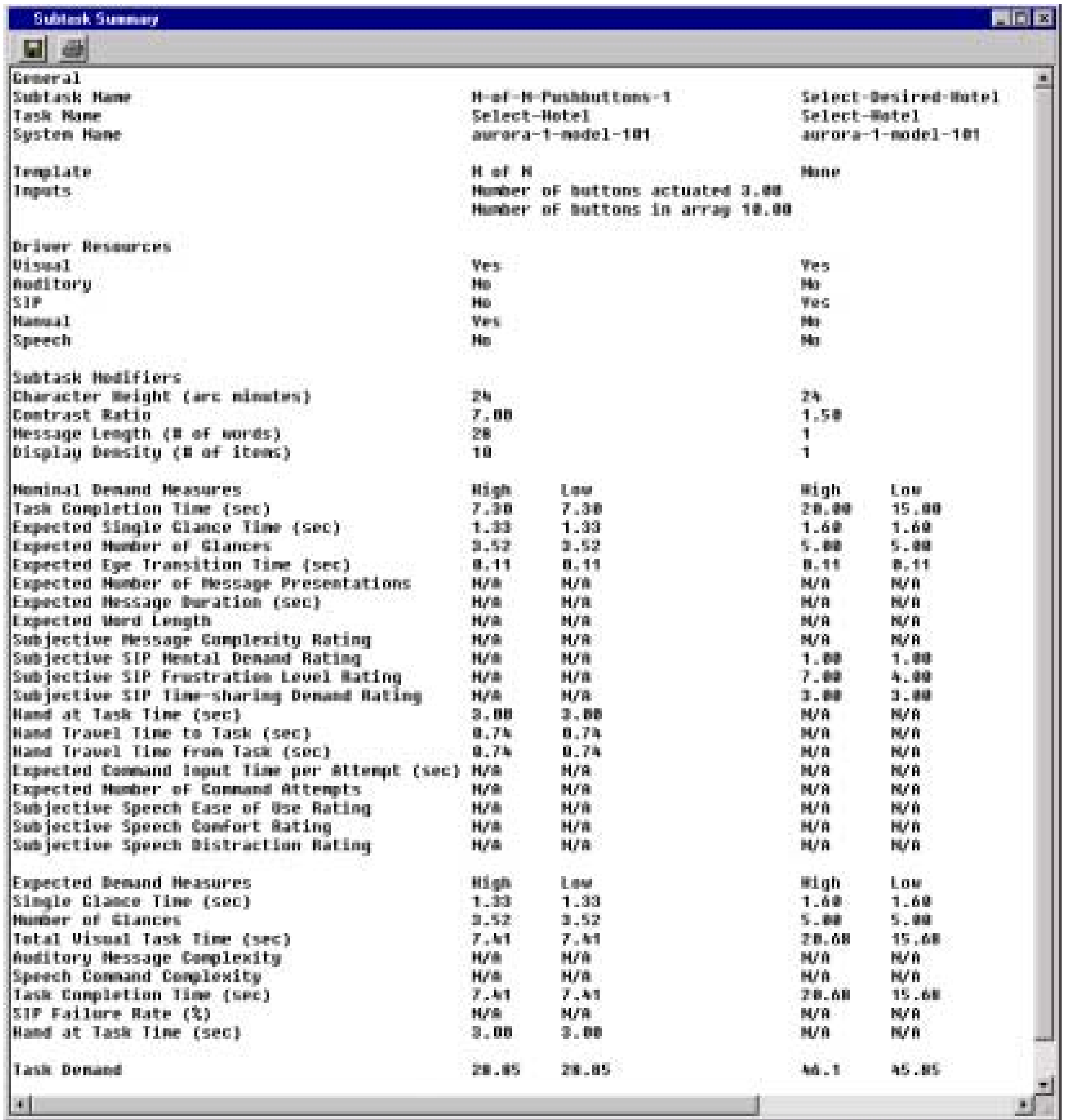
- Subtask Names: The subtask names are originated by the user to describe a subtask.
- Task Names: The task names are originated by the user to describe a task.
- System Names: The system names are originated by the user to describe a system.
- Template Name: Template name is the name of the file in the subtask library that is used to create the subtask. As applicable, any current input value required by the user is also included. For example, as shown in Figure 15, "3 of 10" are the input values of the M of N push buttons template.
- Driver Resources Selected: The driver resources selected are the behavioral model resources that the user believes are required to perform the subtask. Recall that the user can select any subset of the five resources.

- Subtask Modifiers: The subtask modifiers are set by the user to account for such aspects as the expected contrast of a display or the expected character height. The selected values of all subtask-level modifiers are also included.
- Nominal Demand Measures: The nominal demand measures are calculated by the subtask template and include all the measures that are used to calculate the expected demand measures and the FOD measures. Both the low and high nominal values of all relevant demand measures are displayed. Note that the user can optionally adjust these default demand measures through the New Subtask or Edit Subtask wizards. In doing this, the user can produce a value different from the one calculated initially by the template (see below for further discussion).
- Expected Demand Measures: The expected demand measures are the measures that appear in the summary measures window. These are intended to give the user added information about the demand of a specific task or subtask. Both the low and high values are displayed for each relevant demand measure at the subtask level.
- Figure of Demand: The FOD is the single measure of task demand. Both the low and high values are displayed for this measure.

As with the task summary, the subtask summary allows users to make direct comparisons of different subtasks using the same system or the same subtask using different systems. By showing all the expected demand measures and showing the FOD values, users can make informed decisions about the inclusion of a subtask or the merit of one system over another. Also, by reviewing the settings of the subtask modifiers and the nominal demand measures, the user can ensure that the difference between one subtask and another is not a result of a demand measure or a modifier being set incorrectly.

One concern of the expert panel was abuses of the IVIS DEMAnD software by either (1) unqualified users who might make a mistake setting values for the modifiers or the nominal demand measures or (2) users who might purposely set the values on one system different than another system to obtain a desired result. The subtask summary measure provides a means to verify that all the inputs to the model are set correctly and are verifiable by qualified users. Ultimately, it is up to the user to use the program correctly and not to abuse it. Neither Virginia Tech nor the Federal Highway Administration are responsible for improper use, system misuse, or system abuse.

Finally, the system summary report provides users with the system name, vehicle class, and all dimensions from Vehicle Options. This report is described in more detail in the User's Guide.


Subtask Summary

General				
Subtask Name	N-of-N-Pushbuttons-1		Select-Desired-Hotel	
Task Name	Select-Hotel		Select-Hotel	
System Name	aurora-1-model-101		aurora-1-model-101	
Template	N of N		None	
Inputs	Number of buttons actuated 3.00			
	Number of buttons in array 10.00			
Driver Resources				
Visual	Yes		Yes	
Auditory	No		No	
SIP	No		Yes	
Manual	Yes		No	
Speech	No		No	
Subtask Modifiers				
Character Height (arc minutes)	24		24	
Contrast Ratio	7.00		1.50	
Message Length (# of words)	20		1	
Display Density (# of items)	10		1	
Nominal Demand Measures	High	Low	High	Low
Task Completion Time (sec)	7.30	7.30	20.00	15.00
Expected Single Glance Time (sec)	1.33	1.33	1.60	1.60
Expected Number of Glances	3.52	3.52	5.00	5.00
Expected Eye Transition Time (sec)	0.11	0.11	0.11	0.11
Expected Number of Message Presentations	N/A	N/A	N/A	N/A
Expected Message Duration (sec)	N/A	N/A	N/A	N/A
Expected Word Length	N/A	N/A	N/A	N/A
Subjective Message Complexity Rating	N/A	N/A	N/A	N/A
Subjective SIP Mental Demand Rating	N/A	N/A	1.00	1.00
Subjective SIP Frustration Level Rating	N/A	N/A	7.00	4.00
Subjective SIP Time-sharing Demand Rating	N/A	N/A	3.00	3.00
Hand at Task Time (sec)	3.00	3.00	N/A	N/A
Hand Travel Time to Task (sec)	0.74	0.74	N/A	N/A
Hand Travel Time From Task (sec)	0.74	0.74	N/A	N/A
Expected Command Input Time per Attempt (sec)	N/A	N/A	N/A	N/A
Expected Number of Command Attempts	N/A	N/A	N/A	N/A
Subjective Speech Ease of Use Rating	N/A	N/A	N/A	N/A
Subjective Speech Comfort Rating	N/A	N/A	N/A	N/A
Subjective Speech Distraction Rating	N/A	N/A	N/A	N/A
Expected Demand Measures	High	Low	High	Low
Single Glance Time (sec)	1.33	1.33	1.60	1.60
Number of Glances	3.52	3.52	5.00	5.00
Total Visual Task Time (sec)	7.41	7.41	20.68	15.68
Auditory Message Complexity	N/A	N/A	N/A	N/A
Speech Command Complexity	N/A	N/A	N/A	N/A
Task Completion Time (sec)	7.41	7.41	20.68	15.68
SIP Failure Rate (%)	N/A	N/A	N/A	N/A
Hand at Task Time (sec)	3.00	3.00	N/A	N/A
Task Demand	20.05	20.05	46.1	45.05

Figure 15. Subtask summary report.

ANTHROPOMETRY

An anthropometry module has also been included so users can evaluate how the location of their display and controls impacts some of the measures in the demand summary measure panel and the FOD. Display and control locations affect primarily the visual and manual resources. For example, a display located in the instrument cluster will require less visual demand than a display located near the stack (i.e., near the radio and environmental controls). The primary difference in this case would be eye transition time, or the time it takes the driver to change gaze between the forward roadway and the display. Note that other considerations, such as the impact of the display location relative to other displays or the location of a control relative to a display, were not included in the prototype. The objective of this module is strictly to estimate changes in driver demand as a result of control and display location. Our expert user group indicated that many of them already had computer-aided design (CAD) software that integrated many of the common SAE standards needed to perform their duties. In general, they believed it was unlikely that they would use another software package to lay out the controls and displays. Therefore, it has been decided that the anthropometry module should be detailed enough to account for changes in the behavioral model, but not detailed enough to replace any aspects of the existing CAD software.

The anthropometry module works only at the task or subtask level. It is necessary to have the module work at this lower level because a single task can have subtasks that require different controls or displays. The coordinates of display and/or control units are recorded for each subtask because these may differ from subtask to subtask or from task to task within a vehicle. For example, the location of the display and control for the task of tuning the radio is different from that for the task of checking the odometer or adjusting the driver mirror.

As illustrated in Figure 16, three views are used to show the location of the control and display. A dash view, a top view, and a view from the perspective of the car door. Using a three-dimensional coordinate system common to the automotive industry, these views are listed as follows:

- The left-most image shows the y-z plane, where y is the dimension from the driver's door to the passenger's door, and z is the vertical dimension from the road to the roof.
- The middle image shows the x-y plane, where the x dimension is the dimension from the rear bumper to the front bumper, and y is the dimension from the driver's door to the passenger's door.
- The right-most image shows the x-z plane, where the x dimension is the dimension from the rear bumper to the front bumper, and z is the vertical dimension from the road to the roof.

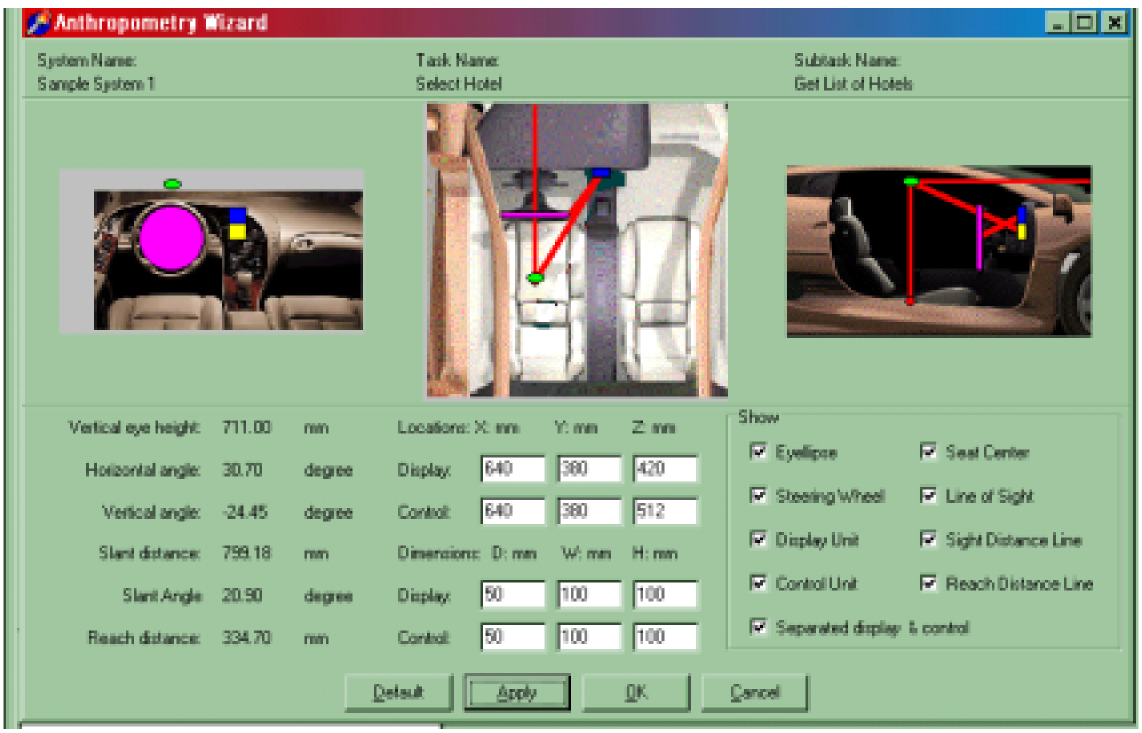


Figure 16. Anthropometry wizard.

The origin in this three-dimensional space is the driver's seated reference point (i.e., H-point). Using any of the three views the user can move the location of the display and/or control within this three-dimensional space. The positions of the display and/or control relative to the steering wheel and driver's line of sight provide the data needed to adjust nominal values of visual and manual driver resources. The position of the steering wheel, eyellipse, and seat are determined by the dimensions specified in Vehicle Options. They may not be moved using these views. The vehicle dimensions determine the volume of space in which the in-vehicle information system, driver, and steering wheel exist. The images of the vehicle in each view are provided merely as a reference to help specify the location of equipment. Therefore, different companies can import their own vehicle images if desired. Several of the expert users believed that being able to import an image of a vehicle into these views from their company would be desirable.

The physical location of the control and/or display can also be changed by entering the x, y, and z manually in the location fields shown under the middle image (Figure 16). The control and display dimensions can also be entered manually. In addition, the user has the flexibility to display or not to display such elements as the line of sight or the eyellipse on the three views. Finally, three dimensions and three angles are included for the user's review. The three dimensions are as follows:

- Vertical Eye Height: Vertical eye height is the vertical distance from the seated reference point to the center of the eyellipse.
- Slant Distance: Slant distance is the distance from the center of the eyellipse to the center of the display.
- Reach Distance: Reach Distance is the distance from the edge of the steering wheel to the control unit. If the control unit is to the right of the driver's line of sight, it is assumed the driver will use the right hand to manipulate the control. If the control unit is to the left of the driver's line of sight, it is assumed the driver will use the left hand to manipulate the control. It is also assumed the driver's hands will be at 9:00 and 3:00 on the steering wheel before being moved to manipulate the control.

The three angles are the horizontal, vertical, and slant angles; they are illustrated in Figure 17 as Θ_H, Θ_V, and Θ_{Slant}, respectively.

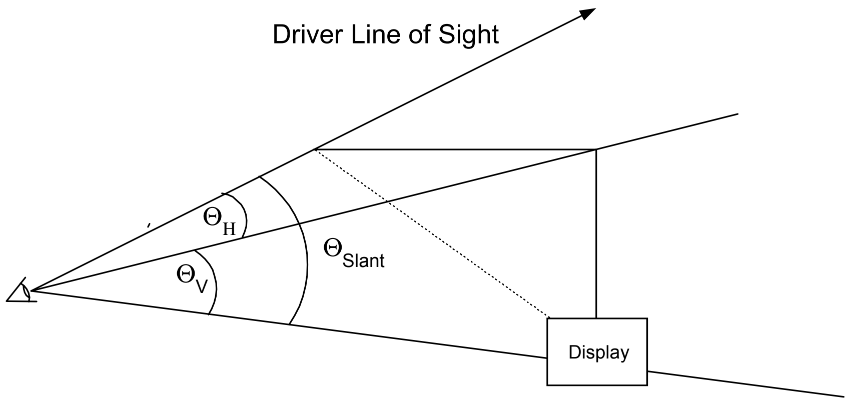


Figure 17. Angles calculated using Anthropometry wizard.

EXPERT AND NOVICE USER PATHS

The prototype has been designed for both expert users and novices. For novices, preview and tutorial options have been included as buttons on the opening screen. The preview shows a short sequence of help screens that explain the objectives of the IVIS prototype and its basic capabilities. The tutorial walks a novice user step by step through the process of:

- Creating systems.
- Creating tasks.
- Creating subtasks.
- Changing driver or driving environment modifiers.
- Changing the anthropometry of a subtask.
- Analyzing the summary measures and overall measures for tasks and subtasks.
- Generating summary reports on task and subtask demand.

During the step-by-step process the user can either interact with the IVIS prototype, thereby performing each of the steps, or simply review each step of the tutorial and independently interact with the prototype. Figure 18 illustrates the opening screen of the tutorial.

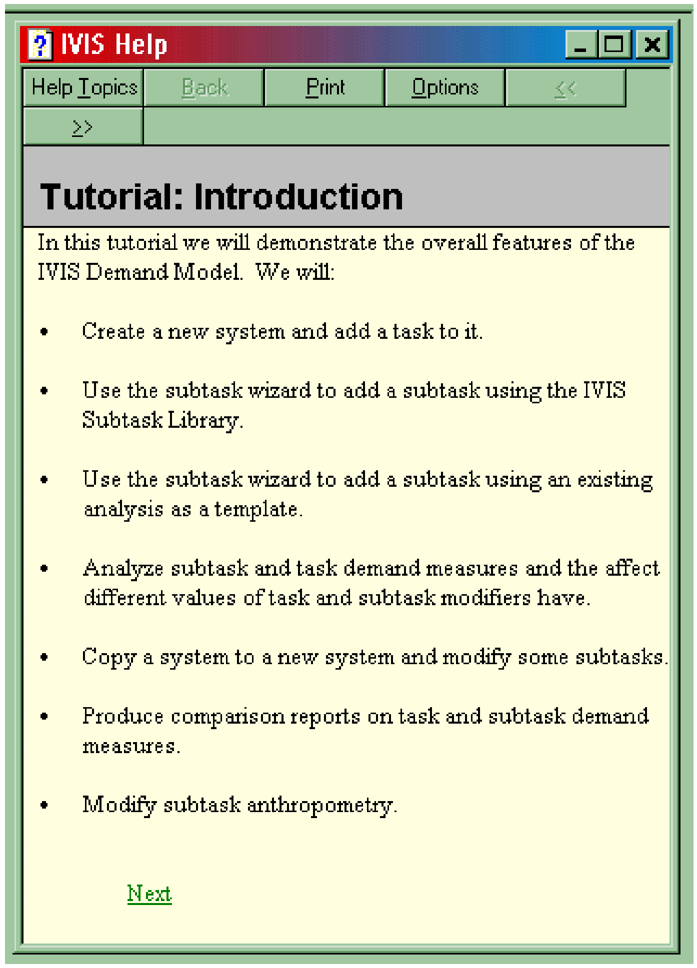


Figure 18. Opening screen of IVIS DEMAnD software tutorial.

The system also includes on-line help available any time through the main Help menu. Users can search the on-line help for information through its table of contents, index, or find function. Once in the help system, other features are available by selecting the available menu items. This system has been designed to be consistent with the Windows GUI design. The options available in the Help system are shown in Figure 19.

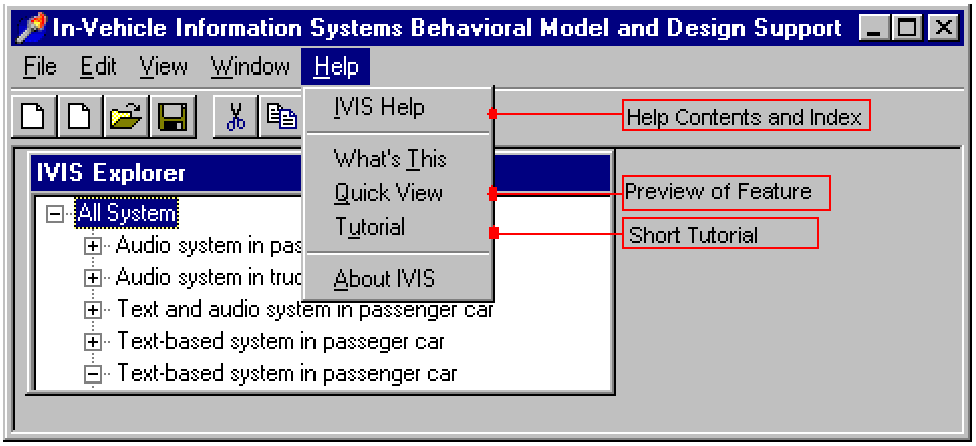


Figure 19. Options available in the Help system.

The Help system also includes quick, context-sensitive help that takes the user directly to needed information. Context-sensitive help can be obtained by clicking the **What's This** button, , in a dialog box and then clicking on the item for which information is needed. This option provides the user with a quick overview of the selected topic. For more extensive information on a particular dialog or window, the user can use the on-line help.

Wizards are also used to help novice users perform specific functions. As highlighted in Figure 7, the Subtask wizard helps the user through all the steps of adding a subtask and making the appropriate modifications to the subtask. This helps ensure that no steps are missed when a novice adds a subtask to a system. Expert users can bypass the wizard in several ways or jump out of the wizard early if desired.

RECOMMENDATIONS

RECOMMENDATIONS FOR FUTURE RESEARCH

Two research paths are recommended for future related experimental efforts. The first research path will follow the same goals as the research conducted in this project. That is, future research should continue to fill gaps in the available data to support the modeling effort. It is believed that future research should be specifically directed at gathering data for additional and novel tasks. For instance, it is recommended that data be collected on drivers interacting with keypads/keyboards and an *AutoPC*, and similar advanced in-vehicle systems. Should a project extension occur, an early task in the new project might be to define the latest IVIS tasks and prioritize them in terms of several factors, including "safety" and likelihood of future large-scale deployment. Those systems that are either available or soon to be available, are suspected of being particularly hazardous (i.e., involve tasks with presumed high FOD levels), and/or that are projected to be popular with the driving public, should be given high priority for testing and data collection.

A second path for future research involves in-depth validation of the current model. It is proposed that this might occur by using the prototype software to develop systems (i.e., design two or more systems using the design support program). For example, one system that can be developed with the help of the prototype program might have a relatively high associated FOD, while a second system may have a lower FOD. A field study might then be planned where data are collected to determine whether the FODs of the two systems are similar to those estimated by the prototype software program. It is suggested that several small on-road tests of this type can be accomplished, thereby validating different segments of the model. For example, one experiment might include systems that involve the visual and SIP resources, a second experiment might investigate systems using auditory and SIP resources, and a third study might consider visual, SIP, and speech resources.

In summary, it is suggested that future research efforts might include an effort to (1) collect data on new and innovative IVIS tasks and (2) validate the prototype software program in depth. It is believed that both of these research efforts will further the development of the IVIS DEMAnD program and help to ensure effectiveness and usability.

UPDATING THE PROTOTYPE TO A FIRST RELEASE PROGRAM

As discussed earlier, IVIS DEMAnD has been designed to be a proof of concept prototype. The primary purpose is to develop and integrate the IVIS behavioral model with IVIS related research and criteria used to quantify the driver's transfer of attention to in-vehicle tasks. It is hoped that this prototype will show the usefulness of the approach to the intended end users. In fact, there has been a great deal of support and interest in this program. It is important to note, however, that the software and model are not ready for a general first release.

To update the program from a prototype to a first release, the software will require alpha and beta testing. Car companies, truck companies, after-market providers, and academia have offered to volunteer their time to help perform the required testing. This testing can be an iterative process. In cases in which the program has a limited release to alpha testers, feedback will be integrated into the program, and a second release will then occur. Once the alpha test is complete, a beta test can be conducted using a larger sample and the same iterative approach to testing.

It is also important to note that valuable suggestions have been received from our expert users that were beyond the scope of the current project. These suggestions should be reviewed and integrated into the IVIS DEMAnD program where appropriate.

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APPENDIX A: TASK REPORT ABSTRACTS

TASK A: BEHAVIORAL MODEL

Gellatly, A.W., Wierwille, W.W., Dingus, T.A., and Gallagher, J.P. (January, 1997). *In-Vehicle Information System Design Evaluation and Model of Attention Demand - Task A: Behavioral Model Working Paper*. Contract No. DTFH61-96-C-00071. Blacksburg, VA: Center for Transportation Research.

Abstract

The objective of this working paper is to describe the In-vehicle Information System (IVIS) Behavioral Model in detail. Included in the paper are the rationale for the model design; the input and output parameters of the model; the limitations of the model design; and the database gaps found in the model. Specific inputs, such as font type and luminance contrast ratios, and specific outputs, such as mean single glance time, are covered in more detail in the Task B, Human Factors Tool Design Working Paper. The development and documentation of this model is an evolutionary and time-consuming endeavor. Therefore, as work progresses on the project, it is anticipated and required that reasonable changes be made to the model and its underlying assumptions as the empirical data used for modeling are incorporated and the software program is developed. A complete description of the model will be incorporated into the Task F Final Report.

The model developed by the project team incorporates the fundamental concepts behind the IVIS Demand Evaluation and Model of Attention Demand (DEMAnD) prototype software program. In addition, model development aided the identification and definition of human factors tools that are used for evaluating candidate IVIS designs. The model differs from previous theoretical models of information processing in that our model evaluates the attention resources demanded by a candidate IVIS design and relates those attention demands to the driver's expected performance (both driving and using the system) when performing an in-vehicle task. The project team envisions that the behavioral model and human factors tools will be utilized by IVIS designers to evaluate interface designs. Designers are expected to use the model and tools to develop optimal interfaces from the driver's (i.e., the end user's) perspective.

TASK B: HUMAN FACTORS TOOL DESIGN

Wierwille, W.W., Gellatly, A.W., and Dingus, T.A. (January, 1997). *In-Vehicle Information System Design Evaluation and Model of Attention Demand - Task B: Human Factors Tool Design Working Paper*. Contract No. DTFH61-96-C-00071. Blacksburg, VA: Center for Transportation Research.

Abstract

The objectives of the Human Factors Tool Design Working Paper are to: 1) describe the IVIS design process; (2) present the concept behind the human factors tools selected; and (3) discuss the technologies and techniques integrated by the tools that will be incorporated into the prototype design evaluation software program (i.e., the IVIS DEMAnD program). As described in the Task C Operations Concept document, the human factors tools comprise actual modules in the design evaluation software program. The tools, or modules, will be used by designers of in-vehicle information systems to evaluate the demands that a given system imposes on the driver and the primary driving task. A detailed description of each tool is provided below, including specific inputs required from the software user (e.g., the IVIS designer) and specific outputs from the IVIS design evaluation software. However, it is important to note that at this time, the inputs and outputs for some tools are more developed and refined than others. Small-scale research is currently under way to provide data to fill in gaps for the less developed tools. The project team and Contracting Officer's Technical Representative (COTR) realized, through meetings and discussion, that it would be impossible to have all the tools specified in the greatest detail at the same time. Documenting the human factors tools (i.e., program modules) for the IVIS Design Evaluation and Model of Attention Demand (DEMAnD) software program is a painstaking and time-consuming task. Therefore, plans have now changed to hand over individual modules (or tools) to the software programmers as they are developed and defined in detail. Included in this process will be individual, detailed papers describing each module, or tool, including specifications for coding. The specifications would include, but are not limited to, the following:

- Equations and algorithms for converting user inputs into tool outputs.
- Empirical data for use in lookup tables.

- Specific inputs that the user is allowed to make for each tool.
- Specific outputs that each tool should generate.
- The degree to which inputs to a specific tool are used by other tools.

This working paper and the individual module (or tool) papers will be the primary means by which information is transferred from the Virginia Tech team to the software developers. The system specifications, the detailed human-computer interface specifications, and the software specifications will be developed with input from the software programmers during the performance of Task D of the contract. Figure 1 graphically depicts how module/tool development and software programming are anticipated to occur for the duration of the project. This paper accomplishes the overall objectives for the human factors tool design working paper at a "high level" of detail.

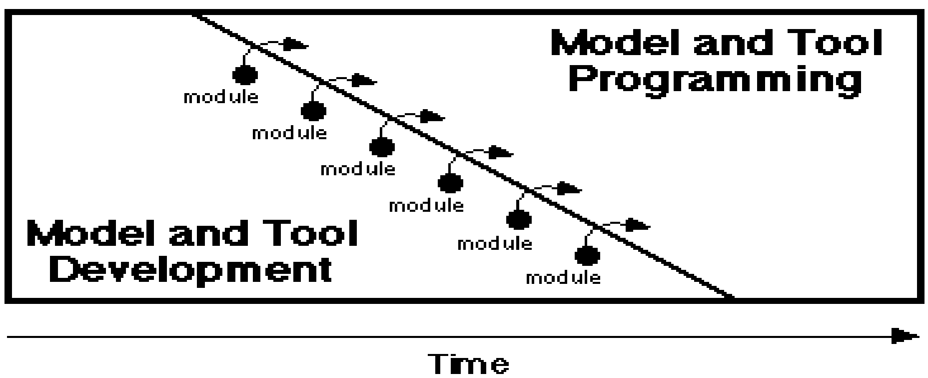

Figure 1. Graphical depiction of IVIS DEMAnD product development.

TASK C: OPERATIONS CONCEPT

Wierwille, W.W., Gellatly, A.W., Dingus, T.A., Gallagher, J.P., and Benel, D.C.R. (October, 1997). *In-Vehicle Information System Design Evaluation and Model of Attention Demand - Task C: Operations Concept*. Contract No. DTFH61-96-C-00071. Blacksburg, VA: Center for Transportation Research.

Abstract

The objective of Task C is to develop a "high-level" concept of operations for the In-Vehicle Information System (IVIS) Design Evaluation and Model of Attention Demand (DEMAnD) software product. An operational concept describes a broad scenario in which a product or tool must function. Product or tool design must reflect the intended use, the requirements of the user, and the user's existing resources/facilities. To that end, the intention of this document, consistent with the intent of the contract, is to define how designers of in-vehicle information systems will use the software product for the evaluation of candidate IVIS designs. The operations concept will also define the high-level tasks to be accomplished when using the software and the steps performed in accomplishing the tasks. This document will define users' tasks from the perspective of the desired outcomes of the IVIS DEMAnD prototype software system and the user's capabilities and skills (a user-centered design process).

Specifically, this document will briefly describe how IVIS DEMAnD tools will be used in the operational environment, the IVIS system design process, by major users. This document explains at a high level how the IVIS DEMAnD tools will fit into the current design process, enhancing the capabilities of the designer. This document includes the following information:

- A description of the typical user and the user survey.
- A description of the typical IVIS design process.
- A description of the attention demand model used for developing the IVIS DEMAnD tools.
- The fundamental operating concept of the model and tools.
- A description of desired considerations for the model and tools.

TASK D: SYSTEM SPECIFICATIONS

Andrews, C., Wierwille, W.W., Hanowski, R.J., and Dingus, T.A. (February, 1999). *In-Vehicle Information System Design Evaluation and Model of Attention Demand - Task D: System Specifications Paper*. Contract No. DTFH61-96-C-00071. Blacksburg, VA: Center for Transportation Research.

Abstract

The objective of Task D of the In-Vehicle Information Systems (IVIS) Behavioral Model and Design Support project is to accomplish the basic analysis and design for the IVIS Design Evaluation and Model of Attention Demand (DEMAnD) software. This includes

- Development of the functional requirements and system specifications.
- Development of human-computer interface requirements.
- Development of a prototype of the human-computer interface.
- Development of a system design that meets all the requirements.

The purpose of this document is to address the first of these objectives. Requirements are concise statements regarding necessary functionality, data, interfaces, and operating environment. Note that the second objective, the human-computer interface requirement, is addressed in a sister document submitted in parallel with this report.

The software product requirements are based on an evolving concept of operations. The original concept was developed in Task C. The general process for IVIS design evaluation has evolved with the addition of new information gathered from experiments, and as new insight has been gathered from potential end users of the IVIS software product.

The remainder of this document is organized as follows.

- Overview of the current operational concept, which provides a frame of reference for the system requirements.
- Functional specifications covering all aspects of conceptual characteristics, component model requirements, and general system requirements.
- Operating environment in which the IVIS software product is expected to function.

TASK D: HCI SPECIFICATIONS

Dingus, T.A., Hanowski, R.J., Wierwille, W.W., and Hankey, J.M. (February, 1999). *In-Vehicle Information System Design Evaluation and Model of Attention Demand - Task D: Human-Computer Interface Specifications Paper*. Contract No. DTFH61-96-C-00071. Blacksburg, VA: Center for Transportation Research.

Abstract

The objective of Task D of the In-Vehicle Information Systems (IVIS) Behavioral Model and Design Support project is to accomplish the basic analysis and design for the IVIS Design Evaluation and Model of Attention Demand (DEMAnD) software.

This report outlines the development of the human-computer interface (HCI) requirements/specifications. A sister report is being submitted with this report that outlines the development of the functional requirements and system specifications.

As noted, the purpose of this report is to outline the HCI specifications for the program. This document:

- Details the flow of the software program.
- Outlines the concept-content screens of the human-computer interface.
- Provides an outline of a series of human factors HCI design guidelines that will help guide the HCI design.
- Provides two prototype screens that provide examples of the application of the HCI guidelines.
- Provides a set of additional high-level requirements that the program will be designed to meet.

TASK D: SOFTWARE SPECIFICATIONS PAPER

Christina Andrews. (November, 1999). *In-Vehicle Information System Design Evaluation and Model of Attention Demand - Task D: Software Specifications Paper*. Contract No. DTFH61-96-C-00071. Blacksburg, VA: Center for Transportation Research.

Abstract

The objective of Task D of the In-Vehicle Information Systems (IVIS) Behavioral Model and Design Support project is to develop the In-Vehicle Information System Driver Demand Analysis Tool (IVIS DEMAnD). The requirements for IVIS DEMAnD are documented in the two papers from Task D, *System Specifications Paper* and *Human-Computer Interface Specifications Paper*. The purpose of this document is to present the system design for meeting these requirements. It is intended for personnel who may further develop or provide maintenance for the IVIS DEMAnD model. It is assumed the reader is familiar with object-oriented design terminology.

This *Software Specification Paper* describes the software design as follows:

- High-Level Data and Program Flow: Identifies the primary producers and consumers of data at the highest level and the data exchanged among them. Also provides the high-level logical flow that is the basis for analyzing the driver demand associated with a particular task.
- System Overview: Provides an overview of the components that make up the IVIS DEMAnD model and the basic interactions among components. Most of the components include graphical objects (forms) handling user input, data validation, calculation, and display of demand measures. Other objects provide utilities necessary to evaluate the mathematical relationships among demand measures and to manage the IVIS DEMAnD data.
- Component Details: These sections provide details of the design of each of the components of the IVIS DEMAnD model. These components include:
    - Main Form – the main window of the IVIS DEMAnD model.
    - Welcome Form – the IVIS DEMAnD welcome window.

- Open Task Form – the window from which users may open a particular task.
- Save Task As Form – the window from which users may save an open task as a different task.
- IVIS Explorer – the window providing a tree view of the hierarchy of user-created IVIS systems, tasks, and subtasks, as well as the utilities needed to manage the IVIS database.
- Task Graph Form – the window into which tasks are opened and with which users may analyze driver demand for a task and its individual subtasks.
- Subtask Wizard – the wizard that aids users in creating new subtasks and editing existing subtasks associated with a particular driving task.
- Anthropometry – the window that allows users to specify the position of in-vehicle information system display and control units within a particular type of vehicle.
- Template Evaluator – the collection of classes that evaluate text-based files describing the mathematical relationships among demand measures and modifiers for a particular driving task.

TASK E: USER MANUAL, PROTOTYPE SOFTWARE, AND SOURCE CODE

Christina Andrews. (December, 1999). *In-Vehicle Information System Design Evaluation and Model of Attention Demand - Task E: User Manual, Prototype Software, Source Code*. Contract No. DTFH61-96-C-00071. Blacksburg, VA: Center for Transportation Research.

Abstract

The objective of Task E of the In-Vehicle Information Systems (IVIS) Behavioral Model and Design Support project was to provide the following:

- A short user manual describing the primary functions of the IVIS DEMAnD prototype software.
- IVIS DEMAnD prototype software.
- Source code for the IVIS DEMAnD prototype software.

The user manual covers the following topics:

What is IVIS DEMAnD?

- Getting Help as You Work
- On-Line Help
- IVIS Preview
- IVIS Tutorial
- Context-Sensitive Help

Managing Systems, Tasks, and Subtasks

- Creating Systems and Tasks
- Opening Tasks
- Renaming Systems, Tasks, and Subtasks
- Copying and Moving Systems, Tasks, and Subtasks
- Deleting Systems, Tasks, and Subtasks
- Changing System Vehicle Options

Creating and Saving Subtasks

- Creating a Subtask
- Saving a Subtask

Analyzing Tasks and Subtasks With the Task Window

- Changing Task and Subtask Descriptions

APPENDIX B: LIST OF ALL TASKS INCLUDED IN THE PROTOTYPE IVIS DEMAND SOFTWARE

Task Titles From the IVIS Library
Check Driver Side Mirror
Check Passenger Side Mirror
Check Rear View Mirror
Check Remaining Fuel
Check Speedometer
Check Warning Lights
CVO Search for Route, High Density Graphic Icon Display
CVO Search for Route, High Density Graphic Text Display
CVO Search for Route, High Density Paragraph Display
CVO Search for Route, High Density Table Display
CVO Search for Route, Low Density Graphic Icon Display
CVO Search for Route, Low Density Paragraph Display
CVO Search for Route, Low Density Table Display
CVO Search for Route, Medium Density Graphic Icon Display
CVO Search for Route, Medium Density Graphic Text Display
CVO Search for Route, Medium Density Paragraph Display
CVO Search for Route, Medium Density Table Display
Read Odometer
Search for Generic Target, High Density Paragraph Display
Search for Generic Target, High Density Table Display
Search for Generic Target, Low Density Paragraph Display
Search for Generic Target, Low Density Table Display
Search for Generic Target, Medium Density Paragraph Display
Search for Generic Target, Medium Density Table Display
Search for Generic Target, Very High Density Table Display
Search for Hotel, Medium Density Graphic Icon Display
Search for Route, High Density Graphic Icon Display
Search for Route, High Density Graphic Text Display
Search for Route, Low Density Graphic Icon Display
Search for Route, Medium Density Graphic Icon Display
Search for Route, Medium Density Graphic Text Display
Search for Route, Very High Density Graphic Text Display
Determine Direction to Destination Relative to Driver's Vehicle Using ETAK Navigator
Determine Distance to Destination Using ETAK Navigator

Task Titles From the IVIS Library
Listen for Route, Medium Density List Presentation at Normal Speech Rate
Listen for Route, Medium Density Prose Presentation at Normal Speech Rate
Listen for Route, Medium Density Prose Presentation at Fast Speech Rate
Listen for Route, High-Density List Presentation at Normal Speech Rate
Listen for Route, High Density Prose Presentation at Normal Speech Rate
Listen for Route, High Density Prose Presentation at Fast Speech Rate
Find Low Cost Route Using Computation, High Density Paragraph Display
Find Quickest Route Using Computation, High Density Graphic Text Display
Find Quickest Route Using Computation, High Density Paragraph Display
Find Route Using Planning and Computation, High Density Paragraph Display
Find Route Using Planning and Computation, High Density Table Display
Operate Turn Signal Lever
Press Stalk-end Button
Lock Vehicle Doors
Unlock Vehicle Doors
Activate Cruise Control and Set Cruise Speed to Current Travel Speed
Resume Cruise Speed
Activate Turn Signals, Change Lanes, and Deactivate Turn Signals
Activate Windshield Wipers
Adjust Temperature Control on Climate System
Adjust Fan Speed on Climate System
Change Climate Mode to Panel Vents on Climate System
Change Climate Mode to Bi-level on Climate System
Display Average Fuel Economy on Driver Information Computer
Display Trip Distance on Driver Information Computer
Tune Radio to Station Stored in Preset or Memory
Tune Radio to Specific Radio Frequency
Seek up to Next Receivable Radio Station Using Seek Function on Radio
Mute Radio
Dial a Number Stored in Memory Using the Cell Phone
Dial 7-digit Home Telephone Number Using the Cell Phone
Actuate Rotary Control with Detent Labeled with Consecutive Numbers
Actuate Rotary Control with Detent Labeled with Random Letters
Adjust Driver Side Power Mirror
Adjust Passenger Side Power Mirror
Adjust Sentinel

Task Titles From the IVIS Library
Adjust Temperature
Automatic Radio Tuning; Select Frequency Scan
Automatic Radio Tuning; Select Seek Station
Driver Side Power Window
Fine Adjustment of Discrete LED Bar Display
Fine Adjustment of Slide Control with Detent
Fine Adjustment on Continuous LED Bar Display with Discrete Controls
Gross Adjustment of Discrete LED Bar Display
Gross Adjustment of Slide Control with Detent
Gross Adjustment on Continuous LED Bar Display with Discrete Controls
Open Center Vent
Passenger Side Power Window
Pushbutton Telephone Keypad
Select AM-FM and Tune Radio with Digital Display, Deflection Tuning Knob
Select AM-FM on Radio and Tune
Select and Read Fuel Data
Select and Read Fuel Economy
Select and Read Fuel Range
Select and Read Time
Select M of N Pushbuttons
Step-wise Adjustment of Discrete LED Bar Display
Step-wise Adjustment of Slide Control with Detent
Step-wise Adjustment on Continuous LED Bar Display with Discrete Controls
Tune Radio to Frequency
Turn on Interior Light
Turn on Map Light
Turn On, Tune, Adjust Radio Volume with Digital Display, Deflection Tuning Knob, Rotary Volume
Turn On, Tune, and Set Volume on Radio
CVO Find Route Using Computation, High Density Graphic Text Display
CVO Find Route Using Computation, High Density Paragraph Display
CVO Find Route Using Computation, High Density Table Display
CVO Find Route Using Computation, Medium Density Graphic Text Display
CVO Find Route Using Computation, Medium Density Paragraph Display
CVO Find Route Using Computation, Medium Density Table Display
CVO Find Route Using Planning and Computation, High Density Table Display
CVO Find Route Using Planning and Computation, Medium Density Table Display

Task Titles From the IVIS Library
CVO Find Route Using Planning and Interpretation, High Density Table Display
CVO Find Route Using Planning and Interpretation, Low Density Paragraph Display
CVO Find Route Using Planning and Interpretation, Low Density Table Display
CVO Find Route Using Planning and Interpretation, Medium Density Graphic Icon Display
CVO Find Route Using Planning and Interpretation, Medium Density Graphic Text Display
CVO Find Route Using Planning and Interpretation, Medium Density Paragraph Display
CVO Find Route Using Planning and Interpretation, Medium Density Table Display
CVO Find Route Using Planning, High Density Graphic Icon Display
CVO Find Route Using Planning, High Density Graphic Text Display
CVO Find Route Using Planning, High Density Paragraph Display
CVO Find Route Using Planning, High Density Table Display
CVO Find Route Using Planning, Interpretation and Computation, High Density Graphic Text Display
CVO Find Route Using Planning, Interpretation and Computation, High Density Paragraph Display
CVO Find Route Using Planning, Interpretation and Computation, High Density Table Display
CVO Find Route Using Planning, Low Density Graphic Icon Display
CVO Find Route Using Planning, Low Density Paragraph Display
CVO Find Route Using Planning, Low Density Table Display
CVO Find Route Using Planning, Medium Density Graphic Icon Display
CVO Find Route Using Planning, Medium Density Graphic Text Display
CVO Find Route Using Planning, Medium Density Paragraph Display
CVO Find Route Using Planning, Medium Density Table Display
Find Hotel Using Planning, High Density Graphic Icon Display
Find Hotel Using Planning, High Density Graphic Text Display
Find Hotel Using Planning, High Density Paragraph Display
Find Hotel Using Planning, High Density Table Display
Find Hotel Using Planning, Low Density Graphic Icon Display
Find Hotel Using Planning, Low Density Graphic Text Display
Find Hotel Using Planning, Low Density Paragraph Display
Find Hotel Using Planning, Low Density Table Display
Find Hotel Using Planning, Medium Density Graphic Icon Display
Find Hotel Using Planning, Medium Density Graphic Text Display
Find Hotel Using Planning, Medium Density Paragraph Display
Find Hotel Using Planning, Medium Density Table Display
Find Hotel Using Planning, Very High Density Graphic Icon Display

Task Titles From the IVIS Library
Find Hotel Using Planning, Very High Density Graphic Text Display
Find Hotel Using Planning, Very High Density Table Display
Find Low Cost Route Using Computation, High Density Graphic Text Display
Find Low Cost Route Using Computation, High Density Table Display
Find Low Cost Route Using Computation, Medium Density Paragraph Display
Find Low Cost Route Using Computation, Medium Density Table Display
Find Quickest Route Using Computation, High Density Graphic Text Display, Visual
Find Quickest Route Using Computation, High Density Table Display
Find Quickest Route Using Computation, Medium Density Graphic Text Display, Visual
Find Quickest Route Using Computation, Medium Density Paragraph Display
Find Quickest Route Using Computation, Medium Density Table Display
Find Route Using Planning and Computation, High Density Graphic Text Display
Find Route Using Planning and Computation, Medium Density Paragraph Display
Find Route Using Planning and Computation, Medium Density Table Display
Find Route Using Planning and Interpretation, High Density Graphic Icon Display
Find Route Using Planning and Interpretation, High Density Graphic Text Display
Find Route Using Planning and Interpretation, High Density Table Display
Find Route Using Planning and Interpretation, Low Density Paragraph Display
Find Route Using Planning and Interpretation, Low Density Table Display
Find Route Using Planning and Interpretation, Medium Density Graphic Icon Display
Find Route Using Planning and Interpretation, Medium Density Graphic Text Display
Find Route Using Planning and Interpretation, Medium Density Paragraph Display
Find Route Using Panning and Interpretation, Medium Density Table Display
Find Route Using Planning and Interpretation, Very High Density Graphic Icon Display
Find Route Using Planning, High Density Graphic Icon Display
Find Route Using Planning, High Density Graphic Text Display
Find Route Using Planning, High Density Table Display
Find Route Using Planning, Interpretation and Computation, High Density Table Display
Find Route Using Planning, Low Density Graphic Icon Display
Find Route Using Planning, Low Density Paragraph Display
Find Route Using Planning, Low Density Table Display
Find Route Using Planning, Medium Density Graphic Icon Display
Find Route Using Planning, Medium Density Graphic Text Display
Find Route Using Planning, Medium Density Paragraph Display
Find Route Using Planning, Medium Density Table Display
Find Route Using Planning, Very High Density Graphic Icon Display

Task Titles From the IVIS Library
Determine General Vehicle Heading Using ETAK Navigator
Determine if Current Direction of Travel is Appropriate to Get to Destination Using ETAK Navigator
Determine Distance to Near Roadway Appropriate to Get to Destination Using ETAK Navigator
Conversation Responding to Live Person at Normal Speech Rate
Conversation Responding to Recorded Voice at Normal Speech Rate
Find Hotel Using Planning, High Density List Presentation at Normal Speech Rate
Find Hotel Using Planning, High Density Prose Presentation at Normal Speech Rate
Find Hotel Using Planning, Medium Density List Presentation at Normal Speech Rate
Find Hotel Using Planning, Medium Density Prose Presentation at Normal Speech Rate
Find Route Involving Computation, High Density List Presentation at Normal Speech Rate
Find Route Involving Computation, High Density Prose Presentation at Normal Speech Rate
Find Route Involving Computation, Medium Density List Presentation at Normal Speech Rate
Find Route Involving Computation, Medium Density Prose Presentation at Normal Speech Rate
Find Route Using Planning and Interpretation, High Density List Presentation at Normal Speech Rate
Find Route Using Planning and Interpretation, High Density Prose Presentation at Fast Speech Rate
Find Route Using Planning and Interpretation, High Density Prose Presentation at Normal Speech Rate
Find Route Using Planning and Interpretation, Medium Density List Presentation at Normal Speech Rate
Find Route Using Planning and Interpretation, Medium Density Prose Presentation at Fast Speech Rate
Find Route Using Planning and Interpretation, Medium Density Prose Presentation at Normal Speech Rate
Set Proper Zoom Level on ETAK Navigator Based on Destination Distance
Determine Name of Next Cross Street Using ETAK Navigator
Determine Name of Near Roadway Appropriate to Get to Destination Using ETAK Navigator

APPENDIX C: EXPERT USER SUGGESTIONS NOT PERFORMED

Expert User Suggestions (paraphrased)
For the voice system, recognition accuracy should be included.
Include a measure/modifier that looks at error recovery and percent accuracy.
For voice, a modifier that includes digitized versus synthesized should be included.
Include modifier for an unexpected event such as pedestrian stepping into traffic.
Can we enter in the size of the display relative to the amount of information as a modifier?
Include reach envelope for anthropometry module.
Include wrap around console for truck.
Be able to change eyellipse in anthropometry module.
Could use a method to change SGRP, but not sure how much it would really be used.
Provide as much detail as possible for the speech analysis.
Consider adding a more sophisticated option that takes into account the dynamic nature of driving such as when certain features should be locked out, etc.
Need to validate model with research.
Look specifically at touch screen relative to other controls
Include tasks that include scrolling text, both where drivers control the rate and fixed rate.
Assumption of linearity of the modifiers needs to be tested.
Assumption that the addition of the subtask equals the overall task needs to be tested.
Need more auditory and speech tasks.
Consider adding parameters, like number of times run-off-road to summary screen.
Consider obtaining data for the ends of the distribution, not just the means.
Are you going to make some distinction between static and dynamic tasks?
Error correction should be included as modifier under speech.

Expert User Suggestions (paraphrased)
Error correction should be included under all tasks.
Most difficult thing in speech is remembering the command. How are you going to handle that?
Will button size and Fitts law be included?
Validation of the model is needed.
Research to validate the total FOD is needed.
Add tasks that include scrolling lists.
A method that we can look at the cumulative results across all the tasks of the system and make a judgment about the goodness of that system.
Should allow the windows to be resized.
Wizard library window should allow more tasks to be shown simultaneously.
In the existing task library, the user should be able to see which tasks were library tasks and which tasks were interpolated tasks.
Additional contracts are needed to fill in the data and validate the model.
Need a mechanism to keep the data updated (i.e., maintenance plan).

APPENDIX D: SELECT M OF N PUSH BUTTONS TEMPLATE AND KEY FOR ABBREVIATIONS

Names expected for IVIS required formulas

Abbreviations	Name
;MSGTnom	Nominal Mean Single Glance Time
;MSGT	Mean Single Glance Time
;MNGnom	Nominal Mean Number of Glances
;MNG	Mean Number of Glances
;ETTnom	Nominal Mean Eye Transition Time
;ETT	Mean Eye Transition Time
;HATnom	Nominal Hand at Task Time
;HAT	Hand at Task Time
;TTTnom	Nominal Hand Travel Time to Task
;TTT	Hand Travel Time to Task
;TTFnom	Nominal Hand Travel Time from Task
;TTF	Hand Travel Time from Task
;HOFFnom	Nominal Total Time Off Wheel Time
;HOFF	Total Time Off Wheel Time
;MNMPnom	Nominal Mean Number of Message Presentations
;MNMP	Mean Number of Message Presentations
;MMDnom	Nominal Mean Message Duration
;MMD	Mean Message Duration
;MWLnom	Nominal Mean Word Length
;MWL	Mean Word Length
;SMCnom	Nominal Subjective Measure of Complexity
;SMC	Subjective Measure of Complexity
;TCTnom	Nominal Task Completion Time
;TCT	Task Completion Time
;OMCnom	Nominal Objective Measure of Complexity
;OMC	Objective Measure of Complexity
;SMDnom	Nominal Subjective SIP Mental Demand
;SMD	Subjective SIP Mental Demand
;SFLnom	Nominal Subjective SIP Frustration Level
;SFL	Subjective SIP Frustration Level
;STSDnom	Nominal Subjective SIP Time-sharing Demand

Abbreviations	Name
;STSD	Subjective SIP Time-sharing Demand
;OWRnom	Nominal Objective SIP Workload Rating
;OWR	Objective SIP Workload Rating
;SIPFRnom	Nominal SIP Failure Rate
;SIPFR	SIP Failure Rate
;MCITnom	Nominal Mean Command Input Time per Attempt
;MCIT	Mean Command Input Time per Attempt
;MNCnom	Nominal Mean Number of Command Attempts
;MNC	Mean Number of Command Attempts
;SSEUnom	Nominal Subjective Speech Ease of Use
;SSEU	Subjective Speech Ease of Use
;SSCnom	Nominal Subjective Speech Comfort
;SSC	Subjective Speech Comfort
;SSDnom	Nominal Subjective Speech Distraction
;SSD	Subjective Speech Distraction
;OSCnom	Nominal Objective Speech Complexity
;OSC	Objective Speech Complexity

;Names of IVIS Supplied Values

;IVISInput1	IVIS Input value one
;IVISInput2	IVIS Input value two
;SymReliance	Reliance on Symbols (0.0 - 1.0)
;SymContrast	Symbol Contrast
;SymHeight	Symbol Height
;DriverAge	Modifier, Driver Age (1=Young, 2=Middle, 3=Older, 4=All)
;TrafficDensity	Modifier, Traffic density (1=Low, 2=Medium, 3=High)
;RoadComplexity	Modifier, Road Complexity (1=Low, 2=Medium, 3=High)
;HorizAngle	Horizontal Angle Eye to Display
;VertAngle	Vertical Angle Eye to Display
;DiagDistance	Diagonal Distance Hand to Control

; Special case name of IVIS Supplied Values

;ETTnomDefaultLoc	ETT nominal at Default Location
;TTFnomDefaultLoc	TTF nominal at Default Location

;IVIS required formulas

```
[FORMULAS]
; Default input values
IVISInput1      = 4
IVISInput2      = 10
SymReliance     = 0.75
SymContrast     = 2
SymHeight       = 13
DriverAge       = 4
TrafficDensity  = 3
RoadComplexity  = 3
HorizAngle      = 35.2
VertAngle       = 41.3
DiagDistance    = 158.75
; Conversion factor, millimeters per inch mmPerInch  = 25.4
M = round(IVISInput1)
N = round(IVISInput2)

; Task completion time
TCT = TCTnom * K_tct_age * K_tct_wl * K_tct_ident * K_tct_loc
TCTnom = 0.945+1.682*M + 0.131*N
;
; Mean singl glance time
MSGT = MSGTnom * Kmsgt_age * K1_wl * K1_ident
MSGTnom = 1.159239 + .02048*M + .011305*N
;
; Mean Number of Glances
MNG = MNGnom * Kmng_age * K2_wl
MNGnom = 1.099102 +0.741377*M + 0.019759*N
;
; Eye Transition Time
ETT = ETTnom * Kett_age * K3_wl
ETTnom = 0.0845 + 0.000512 * Abs(HorizAngle) + 0.000444 * Abs(VertAngle)
;
; Hand at Task Time
HAT = HATnom * K1_ident * K4_wl * Khat_age
HATnom = if(M<2, HATm1, HATm2)
HATm1  = -0.16116 + 0.233332*N - 0.0111111*sqr(N)
HATm2  = -1.54630 + 1.221*M + 0.0888*N
```

;

; Hand Travel Time to Task

TTT = TTTnom * K_ttt_age * K4_wl

TTTnom = (0.0466 / mmPerInch) * DiagDistance

;

; Hand Travel Time from Task

TTF = TTT

TTFnom = TTTnom

;

; Total Time Off Wheel Time

HOFF = TTT + HAT + TTF

HOFFnom = TTTnom + HATnom + TTFnom

;

; Age modifier MSGT

Kmsgt_age =

if(DriverAge=1,ageYmsgt,if(DriverAge=2,ageMmsgt,if(DriverAge=3,ageOmsgt,ageAmsgt)))

ageYmsgt = 0.914

ageMmsgt = 1.037

ageOmsgt = 1.049

ageAmsgt = 1.0

;

; Age modifier MNG

Kmng_age = if(DriverAge=1,ageYmng,if(DriverAge=2,ageMmng,if(DriverAge=3,ageOmng,ageAmng)))

ageYmng = 0.8239

ageMmng = 0.972

ageOmng = 1.204

ageAmng = 1.0

;

; Age modifier ETT

Kett_age = if(DriverAge=1,ageYett,if(DriverAge=2,ageMett,if(DriverAge=3,ageOett,ageAett)))

ageYett = 0.9439

ageMett = 0.9159

ageOett = 1.1402

ageAett = 1.0

;

; Age modifier HAT & TTT & TTF

```
Khat_age = if(DriverAge=1,ageYhat,if(DriverAge=2,ageMhat,if(DriverAge=3,ageOhat,ageAhat)))
K_ttt_age= Khat_age
ageYhat  = 0.7255
ageMhat  = 0.9804
ageOhat  = 1.2941
ageAhat  = 1.0
;
; Age modifier TCT
K_tct_age = if(DriverAge=1,ageYtct,if(DriverAge=2,ageMtct,if(DriverAge=3,ageOtct,ageAtct)))
ageYtct  = 0.779379
ageMtct  = 0.975576
ageOtct  = 1.245045
ageAtct  = 1.0
;
; Work Load modifiers
K1_wl = 1.1179975 - .052435*L + .0043675*sqr(L)
K2_wl = 0.7941 + 0.06863*L
K3_wl = K1_wl
K4_wl = 0.8290375 + 0.0175*L + 0.0131625*sqr(L)
K_tct_wl = K4_wl
L = RoadComplexity + (TrafficDensity-1)
;
; Identifier Modifier 1
K1_ident  = SymReliance * (K1_cc_age - 1) + 1
K1_cc_age = Kett_age * (K1_cc - 1) + 1
K1_cc     = ((SymContrast - 1.5) * Z2 - (SymContrast - 7) * Z1) / 5.5
z1 = 3.925 - 0.2671875*SymHeight + 0.0060546875*sqr(SymHeight)
z2 = 2.125 - 0.09609375*SymHeight + 0.00205078125*sqr(SymHeight)
; TCT Ident Modifier
K_tct_ident= (TCTnom + (K1_ident - 1) * MSGTnom * MNGnom) / TCTnom
;
; TCT Location Modifier
K_tct_loc = (TCTnom + TCT_incr) / TCTnom
TCT_incr = 2 * (ETTnom - ETTnomDefaultLoc) * MNGnom + (TTFnom - TTFnomDefaultLoc)

[IVIS Inputs]
NumberOfInputs = 2
TextLabel1 = Number of buttons actuated
```

TextLabel2 = Number of buttons in array

InitValue1 = 2

InitValue2 = 6

MinValue1 = 1

MinValue2 = 2

MaxValue1 = 6

MaxValue2 = 15

NumDecimals1 = 0

NumDecimals2 = 0

Validation1 = if(IVISInput1<IVISInput2,IVISInput1,Let("IVISInput1",IVISInput2-1))

Validation2 = if(IVISInput2>IVISInput1,IVISInput2,Let("IVISInput1",IVISInput2-1))

[SUB TASK MODIFIERS]

SubTaskName=Select M of N Pushbuttons

NOLSubTaskDescription=3

DescriptionLine1=This is the first

DescriptionLine2=IVIS Subtask

DescriptionLine3=M of N

VASorCSH=1

CharacterSymbolHeight=1

VisualAngleSubtended=24

LuminanceModUsed=1

LuminanceOfCharacter=0

LuminanceOfBackground=0

Contrast=0

ContrastRatioN=2

ContrastRatioD=1

CharacterSymbolContrast=0

MessageLength=4

NumberInformationItems=2

UpperBoundTCT=60

LowerBoundTCT=60

NormalizedWorkloadRating=0.16

DisplayX=640

DisplayY=380

DisplayZ=420

DisplayDepth=50

DisplayWidth=100

DisplayHeight=100

ControlX=640

ControlY=380

ControlZ=512

ControlDepth=50

ControlWidth=100

ControlHeight=100

SeparateFlag=1

[VISUAL COMPONENT]

HasVisualComponent=0

UpperBoundMSGT=1.334

LowerBoundMSGT=1.334

UpperBoundMNG=3.521

LowerBoundMNG=3.521

[AUDITORY COMPONENT]

HasAuditoryComponent=1

UpperBoundMNMP=0

LowerBoundMNMP=0

UpperBoundMMD=0

LowerBoundMMD=0

ObjectiveOrSubjective=2

ObjectiveUpperBoundMCR=0

ObjectiveLowerBoundMCR=0

SubjectiveUpperBoundMCR=0

SubjectiveLowerBoundMCR=0

[SIP COMPONENT]

HasSIPComponent=1

UpperBoundMentalDemand=0

LowerBoundMentalDemand=0

UpperBoundFrustrationLevel=0

LowerBoundFrustrationLevel=0

UpperBoundTimeSharingDemand=0

LowerBoundTimeSharingDemand=0

UpperBoundFailureRate=30

LowerBoundFailureRate=10

[MANUAL COMPONENT]

HasManualComponent=0

UpperBoundHAT=3.005

LowerBoundHAT=3.005

[SPEECH COMPONENT]

HasSpeechComponent=1

UpperBoundMCITA=0

LowerBoundMCITA=0

UpperBoundMNCA=0

LowerBoundMNCA=0

ObjectiveOrSubjective=2

ObjectiveUpperBoundEaseOfUse=0

ObjectiveLowerBoundEaseOfUse=0

ObjectiveUpperBoundComfort=0

ObjectiveLowerBoundComfort=0

ObjectiveUpperBoundDistraction=0

ObjectiveLowerBoundDistraction=0

SubjectiveUpperBoundEaseOfUse=0

SubjectiveLowerBoundEaseOfUse=0

SubjectiveUpperBoundComfort=0

SubjectiveLowerBoundComfort=0

SubjectiveUpperBoundDistraction=0

SubjectiveLowerBoundDistraction=0

APPENDIX E: FORMULAS REQUIRED TO CALCULATE FIGURE OF DEMAND

FOD = ((Visual Time)*1) + ((Total Task Time - Visual Time)* Resource Weighting) * Correction Factor

Visual Time = ((Mean Single Glance Time + (2 * Mean Transition Time)) * Number Of Glances)

Resource Weighting = ((Auditory Time * Auditory Weighting) + (SIP Time * SIP Weighting) + (Speech Time * Speech Weighting) + (Manual Time * Manual Weighting))/(Auditory Time + SIP Time + Speech Time + Manual Time)

Auditory Time = Mean Message Duration * Number of Sequential Messages

SIP Time = Total Task Time - Visual Task Time - (Auditory Time + Speech Time + Manual Time)

Manual Time = Number Of Manual Operations * (Mean Hand At Task Time + (2 * Mean Transition Time))

Speech Time = Mean Command Input Time * Mean Number Of Command Attempts * Number Of Sequential Commands