The Development of a Design Evaluation Tool and Model of Attention Demand

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INTRODUCTION

The goal of in-vehicle information system (IVIS) technologies is to increase the mobility, improve the efficiency, and increase the safety and/or convenience of the motoring public. To achieve this goal, in-vehicle information systems must be designed to include 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. That is, these systems should not introduce significant distraction or additional cognitive workload to the driver. This requires that in-vehicle information systems do not overload the limited driver attentional resources that are devoted to the driving task itself. Examples of these systems include computerized traveler information systems such as navigation and services location, and business-related systems such as on-line email and facsimile. Because of the complexity of these systems, it is important to assess the demands of using these systems on the driver's resources used for the primary task of driving

The U. S. Federal Highway Administration (FHWA) recently completed a research project with two main objectives: to provide designers of IVIS technologies with a set of tools and criteria that could be used in evaluating the attentional resources required by IVIS designs, and to provide highway planners and engineers with tools and criteria to evaluate proposed IVIS requirements. More specifically, the goals of the project included: (i) developing a behavioral model that predicts the driving task performance of drivers interacting with in-vehicle information systems, and (ii) developing a prototype software package that uses the behavioral model to evaluate the attention demand required to operate a given IVIS. The behavioral prototype software was termed *IVIS DEMAnD* for In-Vehicle Information System (<u>IVIS</u>) <u>D</u>esign <u>E</u>valuation and <u>M</u>odel of <u>A</u>ttention <u>D</u>emand.

BEHAVIORAL MODEL

When evaluating IVIS designs, human factors engineers and system designers need answers to several questions, including those related to usability, driver preference, and most importantly, driver safety. One promising approach for evaluating the safety of IVIS designs is to determine the attention demands placed on the driver while interacting with these devices. Attention demand is defined as the magnitude of attention required of the driver to interact with the IVIS, where the word "attention" is used in a broad sense. (It should be noted that visual demands are among the most important attentional resources.) For example, driving a vehicle imposes a particular load on the drivers' attentional resources. These attentional resources are used to safely perform the primary task of driving the vehicle (i.e., vehicle control, navigation, and hazard detection). Interaction with in-vehicle information systems can increase the load on these attentional resources, possibly interfering with the driver's ability to perform the primary task of driving. The design characteristics of an IVIS can affect the amount of driver attentional resources needed to service the system. Attentional resources can be thought of as a pool from which all tasks and mental activities are drawn. Decreased resources for primary task performance may lead to decreased driving performance, thereby affecting the safety of the driver and those nearby. It is from this theoretical basis that the IVIS evaluation software was designed.

As shown in Figure 1, the behavioral model used in the present research is comprised of five driver resources: (i) Visual Demand, (ii) Auditory Demand, (iii) Supplemental Information Processing (SIP) Demand, (iv) Manual Demand, and (v) Speech Demand. There are two important considerations regarding this model. First, because the majority of in-vehicle systems require use of one or more of these five driver resources, the behavioral model is widely applicable. Second, existing sources of data found in the literature generally refer to one or more of these five resources. As such, this behavioral model is compatible with previous work.

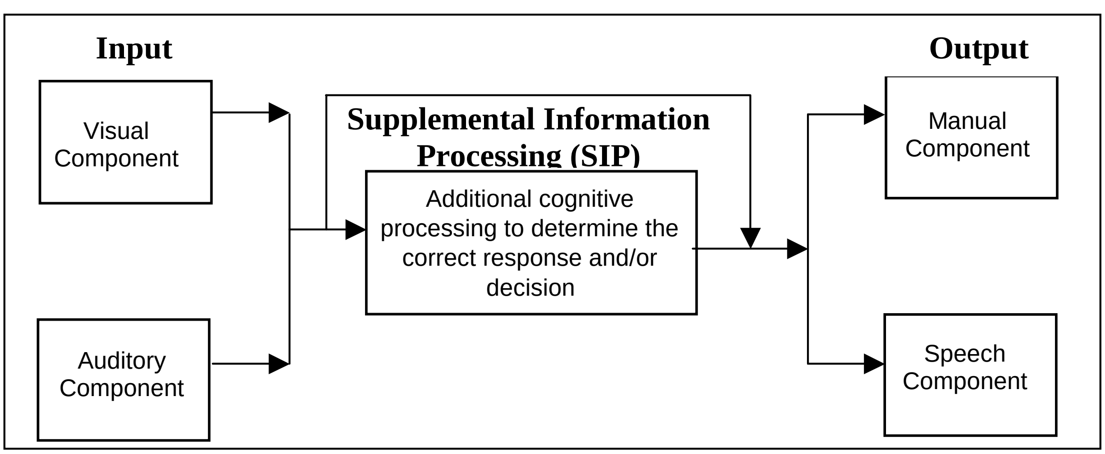


Figure 1: Behavioral model.

DEVELOPMENT OF THE IVIS DEMAnD PROGRAM

The data used to develop the IVIS DEMAnD program came from three general sources: (i) an extensive literature review, (ii) contact with known practitioners, and (iii) a set of four on-road field studies conducted by the research team specifically for this project. The purpose of the literature review and the discussion with human factors practitioners was to gather existing data on driver-task measures. A review of the existing/available data revealed several research "holes," or data deficiencies. As highlighted in Table 1, field studies conducted using simulated in-vehicle information systems in actual vehicle tests were used to supplement the existing data (i.e., fill in the "holes"). The model equations and analytical tools used in the IVIS DEMAnD program were then developed from this "real-world" data.

Table 1: Summary of the field studies conducted for this project.

Experiment Number	Title	Summarized Objectives
1	An assessment of the attention demand associated with the processing of information for IVIS visually displayed information	Provide information suitable for modeling the SIP processing required by current and future IVIS tasks. In addition to investigating SIP demand, all IVIS tasks in this study required visual processing.
2	Effects of IVIS tasks on the information processing demands of a commercial vehicle operations driver	Similar objectives to Experiment 1, except that commercial vehicle operations drivers participated.
3	Auditory based SIP demand effects on driving performance	Similar to Experiment 1, except that tasks required auditory (and SIP) processing.
4	Attention demand of IVIS displays in urban freeway environments	Similar to Experiment 1 and Experiment 3 in that tasks involved visual and/or SIP, and auditory and/or SIP. Unlike Experiments 1 and 3 that were conducted in a relatively low traffic setting, Experiment 4 was conducted in a relatively high traffic environment.

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" are calculated for a given task or set of tasks. (These summary measures are described in more detail later.)

The program philosophy is similar to an evaluation program that was developed approximately one decade earlier under General Motors sponsorship (Wierwille, 2000). The earlier program dealt with visual and manual demands only, and was directed at somewhat more conventional in-vehicle tasks. Nevertheless, the earlier program, which was considered proprietary until recently, provided an appropriate starting point for the IVIS DEMAnD program development effort.

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[1] 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. (Note that *figure of demand* refers to a single overall measure that assesses the attention demand of the driver.)

There are a total of 198 tasks included in the prototype IVIS DEMAnD program. Table 2 outlines the number of tasks for each driver resource category. As can be seen, though there are a wide array of tasks in the "task library," not all combinations of resources have been accounted for (e.g., there are no visual + speech tasks). In an effort to expand the types of tasks included in the task library, several IVIS-related data sources have been

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

identified (see Table 3). Should a follow-up IVIS DEMAnD program be developed, the tasks outlined in Table 3 would be strong candidates for inclusion. In addition to the tasks listed in Table 3, it is suggested that other tasks, for which no data have yet been collected, be included in future iterations of the program. 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: (i) in-vehicle tasks requiring use of a keypad and/or keyboard, and (ii) *AutoPC* tasks.

Table 2: Number of tasks included in the task library.

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

Table 3: Tasks that could be included in future program iterations.

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, L., Kiger, S. M., Rockwell, T. H., and Tornow, C. (1995) 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, 1995
Navigation - Route Following	Dingus, T. A., McGehee, D., Hulse, M., Jahns, S., Manakkal, N., Mollenhauer, M., and Fleischman, R. (June, 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 R and R Research, 1983 Gellatly, Shutko, Kieliszewski, and Dingus, 1998
HUD Fixed Segment and Reconfigurable	Jahns,1996 Grant, Wierwille, Ellsworth, Stewart, Wreggit, and Buchanan (July, 1992)
Multi-Modality	Liu and Dingus, 1997 Mollenhauer, Lee, Cho, Hulse, and Dingus, 1994
Voice	Gellatly, 1998
Phone Dialing	See Cell Phone

It should be pointed out that the IVIS DEMAnD program was developed in modules such that it can be easily modified and expanded. For example, as new data becomes available, the task library can be expanded to include new IVIS-related tasks. The modular design of the IVIS DEMAnD program promotes adaptability and paves the way for revisions, updates, and future versions.

IVIS PROTOTYPE OVERVIEW

What does the IVIS DEMAnD program do?

The purpose of the IVIS DEMAnD program is to assist human factors designers and engineers in evaluating the demands placed on the driver's attentional resource pool by IVIS designs. More specifically, the program can be used to (i) compare two or more candidate IVIS designs, (ii) evaluate an upgrade for a current design, or (iii) evaluate a given design or task against a set of benchmark criteria. The benchmark criteria can be safety-related performance measure “redline” values (such as looking at a display for greater than 2.0 seconds at a time), and designer-specified values for performance and usability.

The prototype was designed to assist the user in developing a conceptual model of the driver as a collection of resources with limited capacity. As described earlier, these resources include visual, auditory, supplemental information processing, manual, and speech. It was also important for the user 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 was important that the user 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, and their luminance in the displays;
- 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 was designed so that the user could describe various in-vehicle information systems in terms of the tasks a driver might routinely perform. The prototype was also designed to allow comparison of the *effects on driver demand* of different tasks and different systems. The *effects on driver demand* refers to measures of interest to human factors design engineers that can be used to evaluate a given IVIS. Table 4 outlines the different measures that are calculated by the program for each driver resource.

Table 4: The five resources and the associated measures of demand.

Resource	Demand Measure
Visual	Mean Single Glance Time (sec)
	Mean Number of Glances
	Mean Eye Transition Time (sec)
	Visual Time
Auditory	Mean Number of Message Presentations
	Mean Message Duration (sec)
Supplemental Information Processing (SIP)	Subjective SIP Time-sharing Demand Rating
	Subjective SIP Mental Demand Rating
	Subjective SIP Frustration Level Rating
Manual	Hand at Task Time (sec)
	Hand Travel Time to Task (sec)
	Hand Travel Time from Task (sec)
Speech	Expected Command Input Time per Attempt (sec)
	Expected Number of Command Attempts
	Probability of a Recognition Error
	Probability of a Substitution Error
Overall	Time to complete task
	Expected % of Drivers Unable to Complete the Task

How does the IVIS DEMAnD program work?

Figure 2 provides an overview of how the IVIS DEMAnD program operates. As illustrated, the program estimates the attention demand placed on the driver that can be attributed to the IVIS. Knowing the attention demand placed on the driver allows the designer (program user) to evaluate an IVIS task/system.

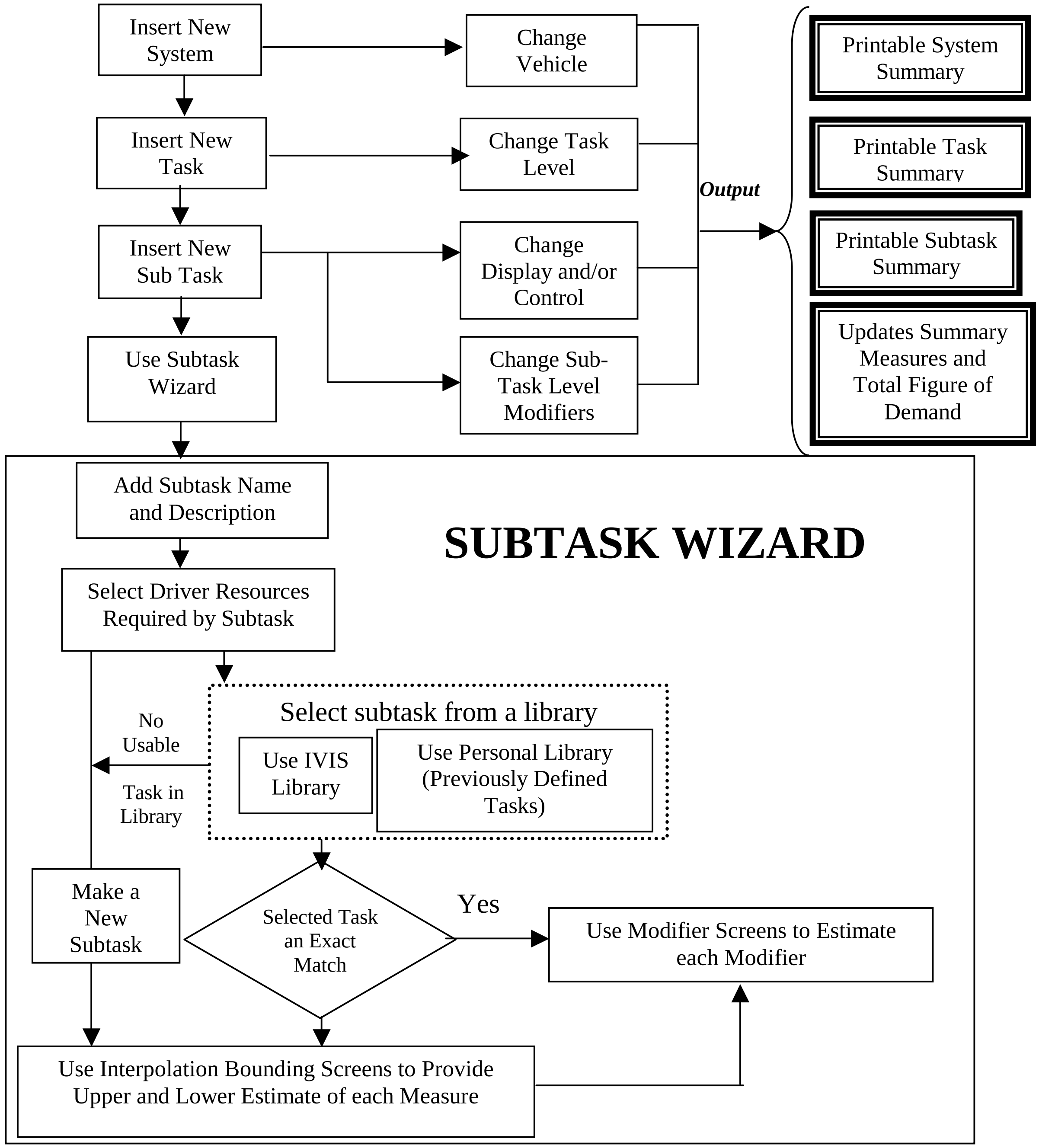


Figure 2: IVIS DEMAnD prototype overview.

The evaluation of an IVIS begins with the user specifying what the IVIS task(s) is (are). Figure 3 shows one of the initial program screens that helps the user specify the task. In specifying the task of interest, the user indicates what driver resources are involved in performing the task. As described previously, the task can draw upon one or more of the following five resources: (i) Visual Demand, (ii) Auditory Demand, (iii) Supplemental Information Processing (SIP) Demand, (iv) Manual Demand, and (v) Speech Demand.

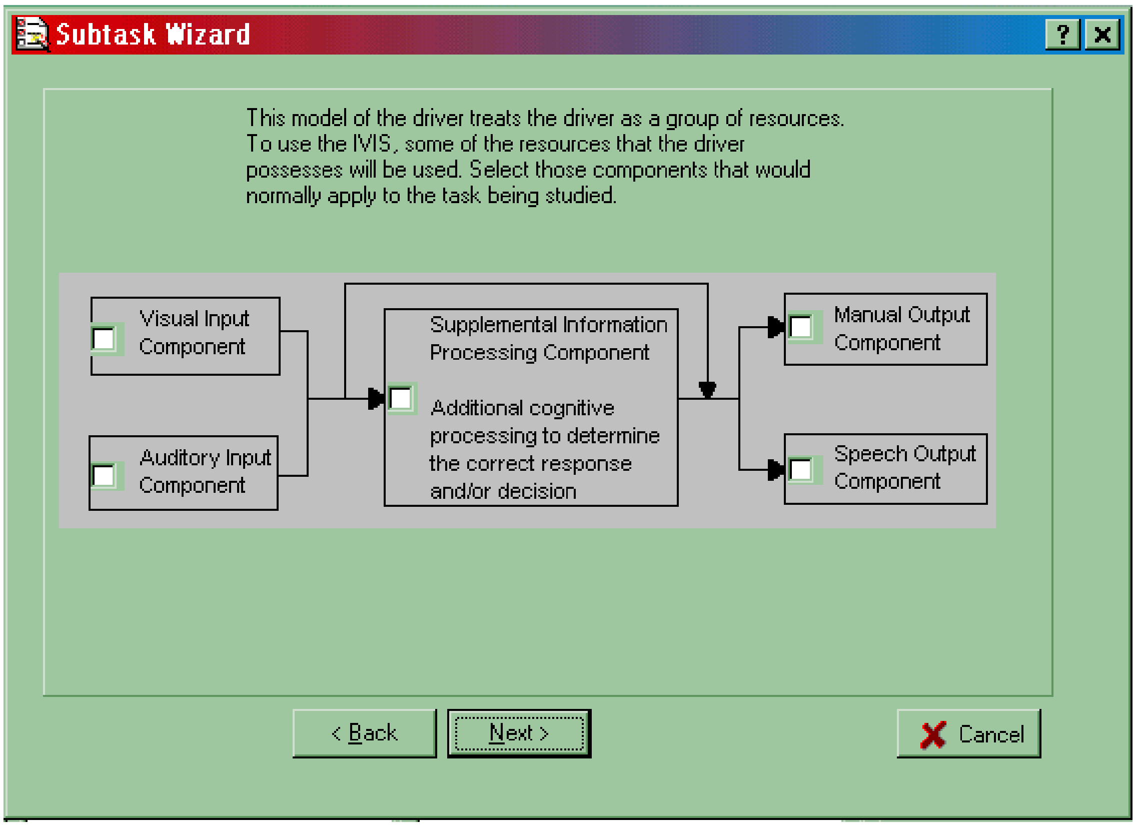


Figure 3: IVIS DEMAnD program screen outlining driver resource model.

After the designer has selected one or more resources that define the task of interest, the designer then selects a task from a library that closely matches the task of interest (note that a task can either be a single item from the library, or comprised of multiple subtasks from the library). Two libraries can be used: a library based on tasks taken from the technical literature (Figure 4), or a library based on tasks previously used by the designer.

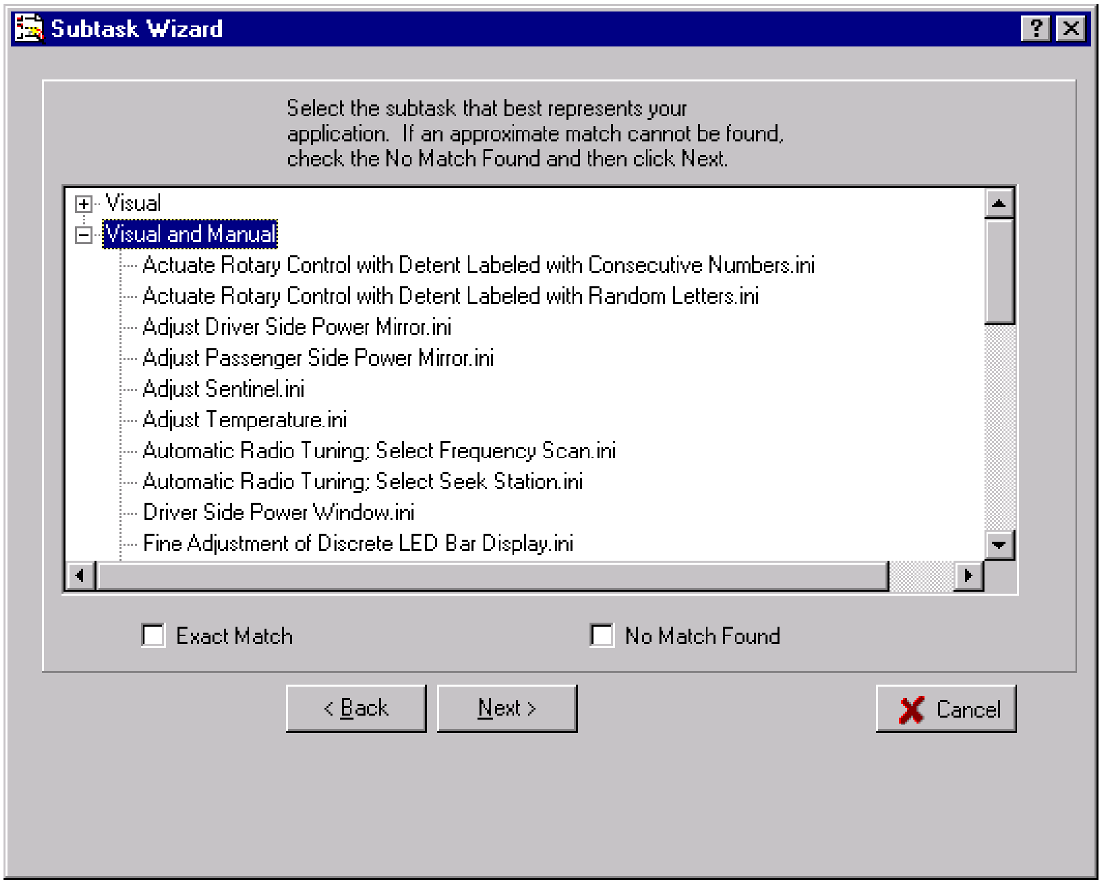


Figure 4: Task library comprising IVIS tasks found in the literature.

If the task cannot be found in either task library (e.g., is an uncommon task and/or a task without data), the user can specify the characteristics of the task by comparing it to other more common tasks. An evaluation tool ("Wizard") is used to guide the user through the process of specifying the various characteristics of a task that is not in the libraries. This process of specifying task characteristics, such as the required mean single glance time, is shown in Figure 5. A user can specify a single value, or an upper and lower bound on a value. Note that the user can specify a number of task characteristics (i.e., measures). A list of these characteristics is shown in Table 5.

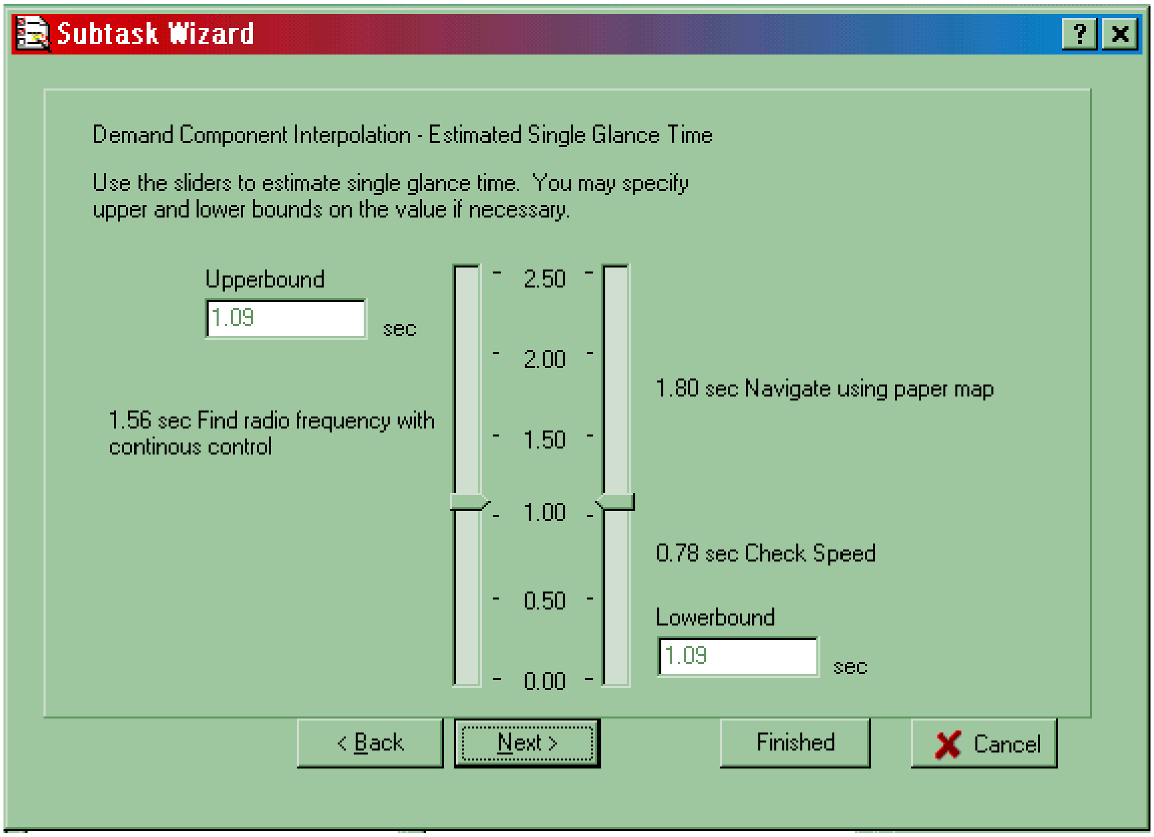


Figure 5: The user can specify characteristics of a task not found in the task library.

Table 5: Task characteristics that can be specified by the user.

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

Once a task has been selected, the program extracts a set of primary measures associated with the resources of the task. These nominal values can then be modified by the user by means of several unique parameters at the Task level or at the Subtask level. Task modifiers, highlighted in Table 6, are applicable to all tasks. Subtask modifiers are subtask dependent and can vary from one subtask to another. Examples of subtask modifiers are also shown in Table 6.

Table 6: Sample of user modifiable task parameters.

Task Parameters	Subtask Parameters
Roadway Complexity	Character Height
Frequency of Use	Luminance
Symbols/Labels Reliance	Message Length
Driver Definition	Display Density
Traffic Density	Task Specific Modifiers

At this point in the evaluation, the user has specified (i) the driver resource categories germane to the task of interest, (ii) the task of interest or characteristics of the task of interest, and (iii) modifiers relevant to the design. Once these items have been specified, the user can view the results of the evaluation. As shown in Figure 6, the evaluation is displayed graphically, and illustrates the relative driving task performance (conceptual) and the degree to which driver resources are affected by the task. This conceptual driving task performance measure is called the *figure of demand*, and is a single overall measure that assesses the attention demanded of the driver. A Demand Measures Summary is also provided that outlines what measures are affected, and the degree to which they are affected. In addition, the user can view a printable report at the system level, task level (Figure 7), or subtask level. This report can be saved and read into common spreadsheet and word processor programs. If it is determined that a task poses heavy demands on driver resources, the user can modify the IVIS design and try to lower these demands.

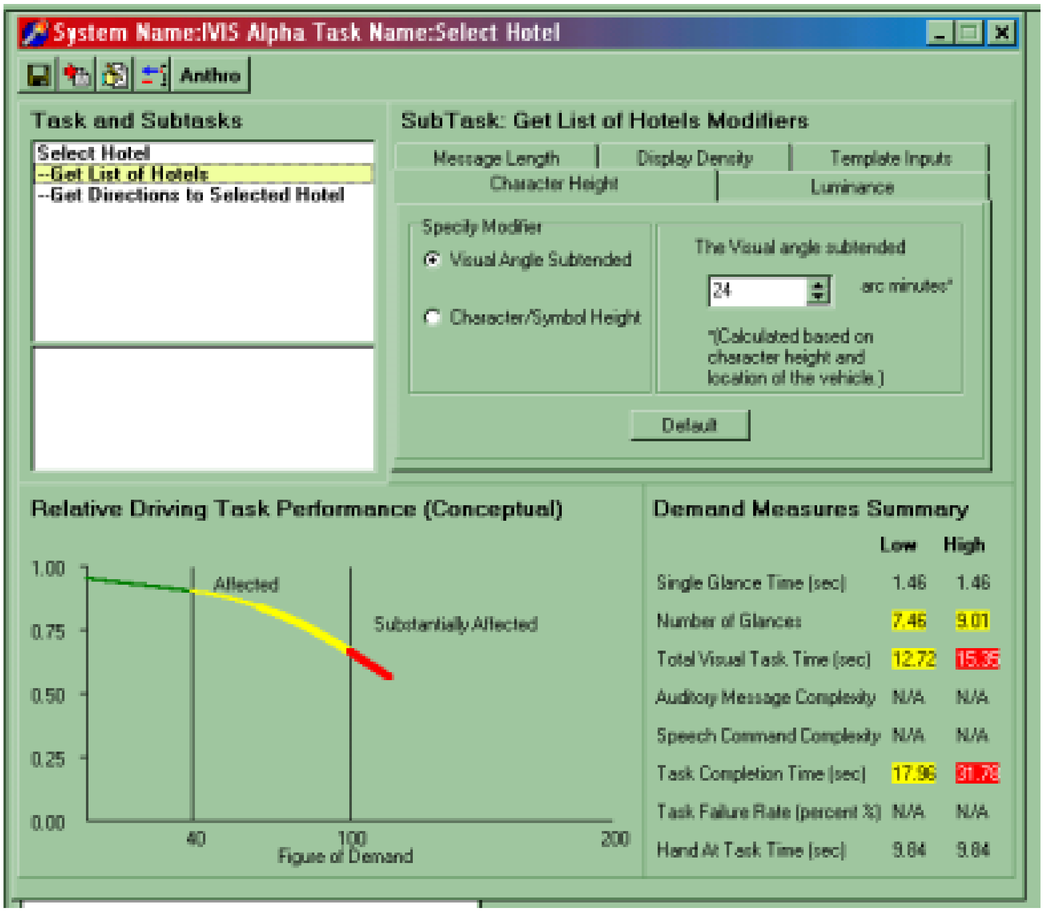
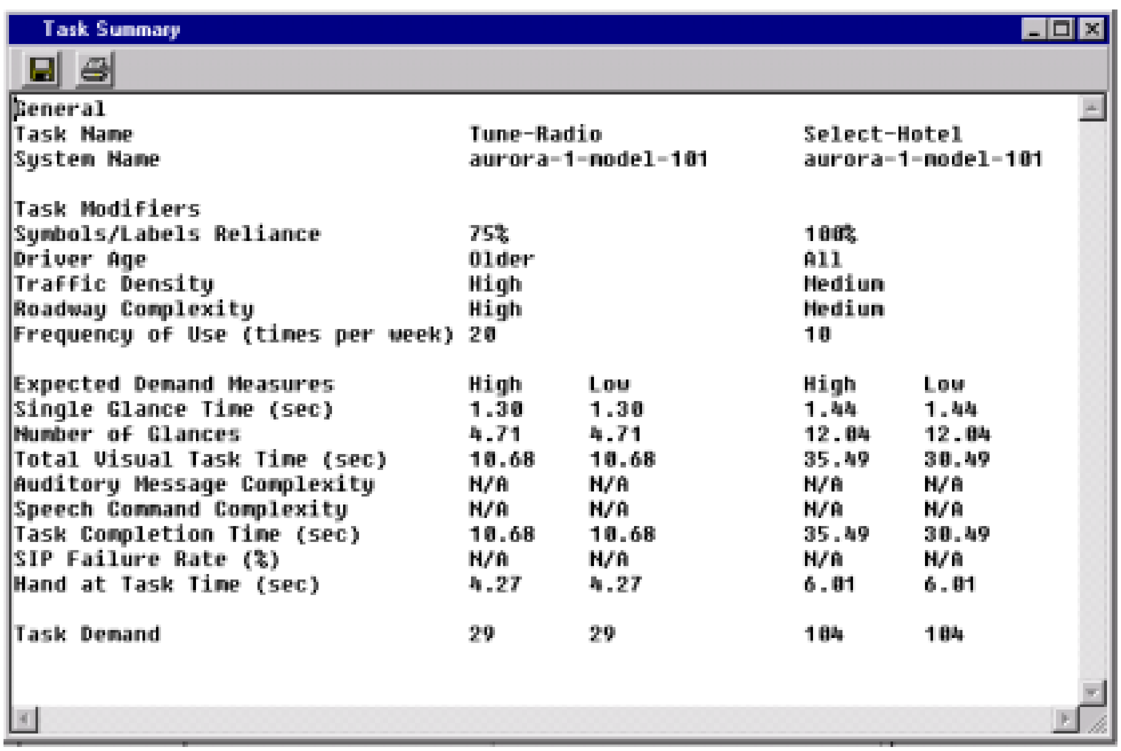


Figure 6: IVIS DEMAnD program window shown at the subtask level.



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 7: Task summary report.

CONCLUDING REMARKS

The goal of the project was to develop a prototype IVIS evaluation program in software format that would aid human factors engineers and designers. To help ensure the success of the program, several expert users from the human factors community aided in the design. Early in the program development, human factors design experts, who would ultimately be the program users, were brought on to review design ideas and provide feedback about the program. In addition, in order to solicit feedback from potential users, the prototype program was presented at six transportation/human factors-related conferences. From the advice of the expert user group, and the feedback received at the conferences, it appears that the final prototype program has the potential to be a useful IVIS evaluation tool for human factors engineers and designers. The FHWA is currently preparing to distribute the prototype version of the software to a limited number of IVIS designers in the summer of 2000. In exchange for access to the first version of the software, the recipients will provide feedback and comments for future improvement and validation.

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