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Development of Human Factors Guidelines for Advanced Traveler Information Systems (ATIS) and Commercial Vehicle Operations (CVO): Comparable Systems Analysis

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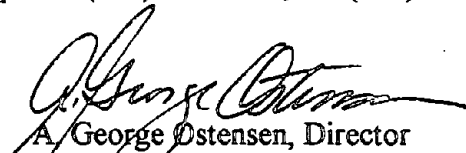
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FOREWORD

This report is one of a series of eight reports produced as part of a contract designed to develop precise, detailed human factors design guidelines for Advanced Traveler Information Systems (ATIS) and Commercial Vehicle Operations (CVO). Among the topics discussed in the series are a functional description of ATIS-CVO, comparable systems analysis, identification and exploration of driver acceptance, and definition and prioritization of research studies.

This report documents a comparable systems analysis of seven systems that represent ATIS/CVO features and functions. Those identified systems are analyzed with respect to identifying human factors issues, establishing lessons learned in the system design and evaluation, and developing human factors guidelines for future ATIS/CVO systems. Because this study examined accessible systems in the United States; the results reflected in this report do not represent all existing ATIS systems.

Copies of this report can be obtained through the National Technical Information Service, 5285 Port Royal Road, Springfield, Virginia 22161, telephone (703) 487-4650, fax (703) 321-8547.


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

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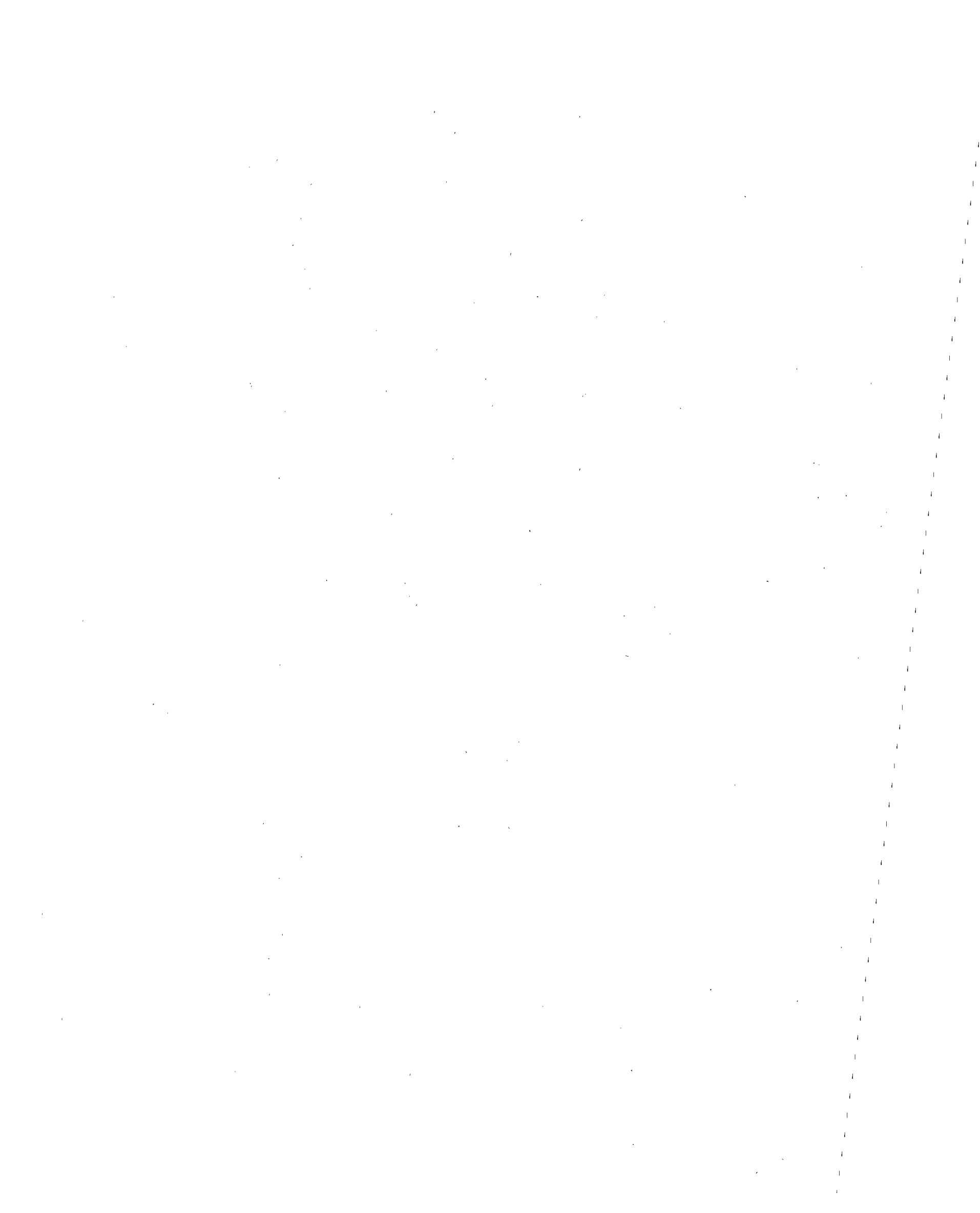
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16. Abstract A comparable systems analysis was performed on seven systems selected for their relevance to the features and functions of the Advanced Traveler Information Systems (ATIS) and Commercial Vehicle Operations (CVO) components of the Intelligent Transportation Systems (ITS) program. The seven systems were selected for their relevance to ATIS/CVO concepts, user time-sharing characteristics, technology level, dynamics of information flow, level of implementation, and accessibility. Five of the systems were highway transportation or CVO in-vehicle information systems, two were comparable systems featuring advanced navigation and decision aiding in Army aviation. Analyses of the seven systems resulted in human factors lessons learned. The lessons learned were compiled into preliminary human factors design guidelines for ATIS/CVO.					
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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

APPROXIMATE CONVERSIONS FROM SI UNITS

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

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

(Revised September 1993)

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LIST OF ACRONYMS

AAA	American Automobile Association
AATD	Aviation Advanced Technology Directorate
AI	Artificial Intelligence
ATIS	Advanced Traveler Information Systems
ATMS	Advanced Travel Management Systems
AVCS	Automated Vehicle Control Systems
AVL	Automatic Vehicle Location
CASE	Computer-Aided Software Engineering
CB	Citizens Band
CD	Compact Disc
CDAS	Cognitive Decision-Aiding Systems
CRT	Cathode Ray Tube
CSRDF	Crew Station Research and Development Facility
CVO	Commercial Vehicle Operations
D/NAPS	Day/Night Adverse Weather Pilotage Systems
DOD	Department of Defense
DOT	Department of Transportation
ES	Expert Systems
ETA	Estimated Time of Arrival
FHWA	Federal Highway Administration
GPS	Global Positioning Systems
HCI	Human-Computer Interaction
HFE	Human Factors Engineering
HMD	Helmet-Mounted Display
HUD	Head-Up Display
IMSIS	In-Vehicle Motorist Services Information Systems
IRANS	In-Vehicle Route and Navigation Systems
ISIS	In-Vehicle Signing Information Systems
ITS	Intelligent Transportation Systems
IVSAWS	In-Vehicle Safety and Warning Systems
LCD	Liquid Crystal Display
MCT	Mobile Communications Terminal
MP	Mission Planner
NMC	Network Management Center
NOE	Nap of Earth
O/D	Origin/Destination
PVI	Pilot-Vehicle Interface
REALM	Reactor Emergency Action Level Monitor
RF	Radio Frequency
RMPD	Right Multi-Purpose Display
RPA	Rotorcraft Pilot's Associate

LIST OF ACRONYMS
(continued)

SAE	Society of Automotive Engineers
SMD	Systems Management Display
SME	Subject Matter Expert
TISC	TravTek Information Services Center
TMC	Traffic Management Center
TMS	Traffic Management System
TSD	Tactical Situation Display

LIST OF CODES USED IN LESSONS LEARNED

CS	Crew Station Research and Development Facility (CSRDF)
NM	Navmate System
OM	OmniTRACS Mobile Communications Terminal
SK	Sikorsky Cognitive Decision-Aiding System
TP	TravelPilot System
TT	TravTek System
UM	University of Michigan Transportation Research Institute (UMTRI)

EXECUTIVE SUMMARY

Advanced Traveler Information Systems (ATIS) and Commercial Vehicle Operations (CVO) systems are important subsets of the Intelligent Transportation System (ITS) initiative of the U.S. Department of Transportation. ITS is intended to increase productivity and safety in future transportation systems through the application of advanced technology. The present study was one portion of a large-scale FHWA effort to develop human factors guidelines for ATIS and CVO systems. The objectives of this comparable systems analysis were to identify seven systems representative of ATIS/CVO features and functions, analyze those systems with respect to human factors issues, establish lessons learned in the design and evaluation of the systems, and derive human factors guidelines for future ATIS/CVO systems. Due to several constraints, this study targeted accessible systems in the United States and, therefore, the systems identified and analyzed were not representative of all existing ATIS systems.

A large list of potential candidate systems was compiled by combing the literature and by communicating with members of the ITS community. Seven systems were selected for the comparable systems analysis. The criteria used to select the systems included the following: relevance to ATIS/CVO concepts and features; similarity to specific ATIS subsystems (i.e., IRANS, IMSIS, ISIS, IVSAWS); advanced technology with interactive displays; dynamics of information flow; system complexity; implementation level; user population training level; user time-sharing requirements; and accessibility of the system for analysis. The seven systems selected for analysis were:

TravTek - This was an existing in-vehicle route guidance and navigation system that was undergoing the final phases of testing in Orlando, Florida.

UMTRI - An instrumented vehicle being used to conduct research on in-vehicle displays for navigational and routing purposes. The several years of research experience with navigation displays were expected to produce insightful lessons learned.

Navmate - This route guidance and navigation system was being tested by the manufacturer in rental cars in the San Jose, California area.

OmniTRACS - This system was a CVO-specific system and featured on-board two-way communication through the use of an in-vehicle unit currently installed in more than 50,000 trucks. The system was designed to facilitate the dispatcher-driver communication link with respect to shipment status and delivery, but also allowed route guidance and navigation information to be transmitted and received.

TravelPilot - This in-vehicle display system was installed in Seattle Fire Department trucks to provide two-way communication with a dispatch center. Real-time vehicle location and destination were the primary functions of the system.

Crew Station Research and Development Facility - This Army flight simulator for crew systems research includes several advanced technology features relevant to ATIS/CVO, such as a touchscreen digital map, out-the-window symbology (equivalent to a head-up display), voice interaction, and dynamic information flow with multi-tasking.

Army Helicopter Mission Replanning System - This system features a digital map that incorporated the output of a cognitive decision-aiding system to assist pilots in selecting alternate mission plans and routes.

To reveal as many lessons learned as possible, several methods of analyses were used. A thorough analysis of existing documentation (e.g., technical manuals, schematics, specifications, training videos/manuals, and user manuals) was performed for each system. Many of the lessons learned were derived from human factors heuristic evaluations in which human factors experts analyzed the systems while engaging in direct interaction with the equipment. This method was not possible for all the systems due to limited accessibility. When possible, volunteer target participants were asked to use the system following a structured set of tasks using a verbal protocol analysis wherein the participants were asked to describe their impressions, thoughts, and opinions of the system while they performed the specified tasks. Videotape records of this procedure were collected when possible. Interviews with design team members were intended to collect information about the rationale and criteria for the human factors design of the system. These interviews attempted to discover whether human factors guidelines were used in the design and, if so, were they helpful.

From the thorough data collection efforts, 177 lessons learned were identified. A chapter is dedicated to each system and the lessons derived from each system are listed at the end of each chapter. All the lessons learned were coded such that each could be linked back to the original system. The lessons learned were then grouped and categorized in a process aimed at developing human factors guidelines pertinent to each group. From this activity, 66 preliminary human factors guidelines for ATIS/CVO systems were generated and listed in a separate chapter. The preliminary guidelines produced from this comparable system analysis addressed a wide range of human factors issues, including some that are specific to ATIS/CVO systems, and some relevant to the use of human factors handbooks. Each guideline is accompanied by a list of system-specific codes of the lessons learned that contributed to that guideline. To facilitate use by ATIS and CVO designers and evaluation groups, the guidelines are grouped into 13 categories. The human factors categories and an example of a usability principle for that category identified in the survey of comparable systems are: In-Vehicle Display Design; Controls; User-System Interface; Driver Attention/World/Safety; Driver Information Requirements; Route Guidance/Planning/Navigation; Map Databases; Vehicle Location Accuracy; Driver Acceptance; Communication Between Driver and Dispatch/Help Center; Training Issues/Requirements; Handbooks and Guidelines; and Design Approaches.

The guidelines developed in this report should be considered preliminary. They are based on observation, expert judgment, user opinion, and other subjective analyses. However, the strength of the method used is that these preliminary guidelines were derived from actual ATIS/CVO systems. There is little doubt that preliminary guidelines, even when based on subjective analysis, are more likely to be applicable and relevant when they are derived from existing systems than from different application areas. Empirical validation of these preliminary guidelines is essential before considering them as actual guidelines for the human factors design of ATIS/CVO systems.

CHAPTER 1. INTRODUCTION AND OBJECTIVES

BACKGROUND

The fundamental premise underlying the U.S. Department of Transportation's initiative in ITS (Intelligent Transportation Systems) is that innovative application of advanced technology is vital to meeting the Nation's transportation requirements for the 21st century. Three major programs are currently under way to assess user requirements and human factors issues in the ITS subareas of Automated Highway Systems, Advanced Traffic Management Systems, and Advanced Traveler Information Systems/Commercial Vehicle Operations (ATIS/CVO). The present work is being performed under Task D of the ATIS/CVO contract. The objective of the comparable systems analysis was to glean "lessons learned" in the areas of in-vehicle information display and the effectiveness of existing guidelines for the design of ATIS/CVO user interfaces.

ATIS systems acquire, analyze, communicate, and present information to assist surface-transportation travelers in moving from an origin to their desired destination (IVHS America, 1992). The major objective of ATIS systems is to provide various types of information to the driver of a vehicle that would enhance his/her driving performance and safety. To accomplish this objective, several user services were identified and grouped into functional categories or subsystems. At the time Task D was performed, ATIS system user services were referred to as functions and were grouped into the four subsystems described in the next section.

ATIS SUBSYSTEMS

The proposed subsystems for the ATIS component were:

- (1) In-Vehicle Routing and Navigation Systems (IRANS).
- (2) In-Vehicle Motorist Services Information Systems (IMSIS).
- (3) In-Vehicle Signing Information Systems (ISIS).
- (4) In-Vehicle Safety Advisory and Warning Systems (IVSAWS).

The functional characteristics of these subsystems have been identified in Task C and are listed in table 1. Most of the ATIS functions are also applicable to CVO systems; however, an additional subset of functions is CVO-specific and is usually not addressed separately. The functional characteristics of these four subsystems, and those specific to CVO, are briefly described in the following paragraphs. For a detailed description of the functions, refer to Task C.

In-Vehicle Routing and Navigation Systems (IRANS)

This subsystem has received the most attention in ITS applications. IRANS provides drivers with information about how to get from one place to another, and may include information on traffic operations and recurrent and non-recurrent urban traffic congestion. Seven functional components have been identified that have applications in both ATIS and CVO. They are:

- (1) Trip planning.
- (2) Multi-mode travel coordination and planning.
- (3) Pre-drive route and destination selection.
- (4) Dynamic route selection.
- (5) Route guidance.
- (6) Route navigation.
- (7) Automated toll collection.

Two functional components were identified as CVO-specific:

- (1) Route scheduling.
- (2) Computer-aided dispatch.

These IRANS components are described in greater detail below:

Trip Planning

Trip planning is the route planning of long, multiple-destination journeys that may involve identifying scenic routes and historical sites, as well as coordinating hotel accommodations, restaurants, and vehicle services information.

Table 1. ATIS/CVO functional characteristics.

Subsystem	Function	Application
IRANS	Trip Planning	ATIS and CVO
	Multi-Mode Travel Coordination	ATIS and CVO
	Pre-Drive Route and Destination Selection	ATIS and CVO
	Dynamic Route Selection	ATIS and CVO
	Route Navigation	ATIS and CVO
	Route Guidance	ATIS and CVO
	Automated Toll Collection	ATIS and CVO
	Route Scheduling (CVO-Specific)	CVO
	Computer-Aided Dispatch (CVO-Specific)	CVO
IMSIS	Broadcast Services/Attractions	ATIS and CVO
	Services/Attractions Directory	ATIS and CVO
	Destination Coordination	ATIS and CVO
	Message Transfer	ATIS and CVO
ISIS	Roadway Sign—Guidance	ATIS and CVO
	Roadway Sign—Notification	ATIS and CVO
	Roadway Sign—Regulatory	ATIS and CVO
IVSAWS	Immediate Hazard Warning	ATIS and CVO
	Roadway Condition Information	ATIS and CVO
	Automatic Aid	ATIS and CVO
	Manual Aid Request	ATIS and CVO
	Vehicle Condition Monitoring	ATIS and CVO
	Cargo and Vehicle Monitoring (CVO-Specific)	CVO
CVO-Specific	Fleet Resource Management	CVO
	Dispatch	CVO
	Regulatory Administration	CVO
	Regulatory Enforcement	CVO

Multi-Mode Travel Coordination and Planning

Coordination information is provided to the driver on different modes of transportation (e.g., buses, trains, and subways) in conjunction with driving a vehicle. This information might include real-time updates of actual bus arrival times and anticipated travel times.

Pre-Drive Route and Destination Selection

This function allows the driver to select any destination and/or route before departure. The characteristics for the pre-drive selections include entering and selecting the destination, departure time, and route to the destination. System information might include real-time or historical congestion information, estimated travel time, and routes that optimize parameters such as time or distance.

Dynamic Route Selection

Dynamic route selection refers to any route selection system that operates while the vehicle is not in PARK. This capability includes the presentation of updated traffic and incident information that might affect the driver's route selection. In addition, the system would alert the driver if she or he makes an incorrect turn and leaves the planned route. Dynamic route selection can generate a new route that accommodates the driver's new position.

Route Guidance

This capability includes turn-by-turn and/or directional information. This information can be in the form of a highlighted route on an electronic map, icons indicating turn directions on a HUD, or voice guidance.

Route Navigation

Route navigation provides information to help the driver to a selected destination; however, it does not include route guidance. It might include presenting an in-vehicle electronic map with streets, direction orientation, current location of vehicle, destination location, and location of services or attractions. Route navigation provides information typically found on paper maps.

Automated Toll Collection

This system would allow a vehicle to travel through a toll roadway without the need to stop to pay tolls; tolls would be deducted automatically from the driver's account as the vehicle is driven past toll collection areas.

Route Scheduling (CVO-Specific)

Route scheduling offers coordination of numerous driver-entered destinations to minimize travel time or to accommodate delivery schedules.

Computer-Aided Dispatch (CVO-Specific)

This is a computer-aided system that assists the dispatcher in generating routes that coordinate multiple stops that are defined or entered by the dispatcher. This function may indicate which fleet vehicle is best suited for a particular destination based on information such as type of cargo, location of vehicle, and delivery/pick-up time.

In-Vehicle Motorist Services Information Systems (IMSIS)

IMSIS provides:

- (1) Broadcast information on services/attractions.
- (2) Access to a services/attractions directory.
- (3) Destination coordination.
- (4) Message transfer capability.

Broadcast Services/Attractions Information

Broadcast services/attractions information provides travelers with information that might otherwise be found on roadside signs. It may be very similar to the services and attractions information typically given on signs; but it will be displayed inside the moving vehicle.

Services/Attractions Directory

This capability provides information about motels; hotels; automobile fuel/repair; and emergency medical, entertainment, and recreational services. Using this capability, the driver can access relevant information concerning businesses or attractions.

Destination Coordination

The destination coordination function enables the driver to communicate and make arrangements for the final destination. This may include restaurant and hotel reservations.

Message Transfer

The message transfer capability allows drivers to communicate with others. Currently, this function is implemented by cellular telephones and CB radios. In the future, ATIS systems may improve upon this technology by automatically generating preset messages at the touch of a button and by receiving messages for future use. Message transfer might involve both text and voice messages.

In-Vehicle Signing Information Systems (ISIS)

ISIS provides in-vehicle displays of non-commercial routing, warning, regulatory, and advisory information that is currently depicted on external roadway signs.

Roadway Sign Guidance Information

ISIS guidance information includes street signs, interchange graphics, route markers, and mile posts. Traditionally found on signs outside the vehicle, this information will be displayed inside the vehicle.

Roadway Sign Notification Information

Roadside signs that currently notify drivers of potential hazards or changes in the roadway, such as merge signs, advisory speed limits, chevrons, and curve arrows, will be displayed in the vehicle.

Roadway Sign Regulatory Information

Regulation information, such as speed limits, stop signs, yield signs, turn prohibitions, and lane use, will be provided in-vehicle.

In-Vehicle Safety Advisory and Warning Systems (IVSAWS)

IVSAWS provides warnings on immediate hazard and road conditions/situations affecting the roadway ahead of the driver. It provides sufficient advanced warning to permit the driver to take remedial action (e.g., to slow down). This system does not encompass in-vehicle safety warning devices that provide warning of imminent danger requiring immediate action (e.g., lane change/blind spot warning devices, imminent collision warning devices, etc.). In addition, it provides for the capability of both automatic and manual aid requests.

Immediate Hazard Warning

IVSAWS may provide hazard proximity information to the driver by indicating the relative location of a hazard, the type of hazard, and the status of emergency vehicles in the area. Specifically, this might include notifying the driver of an approaching emergency vehicle or warning the driver of an accident immediately ahead.

Road Condition Information

This function provides information on road conditions, such as traction, congestion, or construction, within some predefined proximity to the vehicle or the driver's route.

Automatic Aid Request

The automatic aid request function provides a "mayday" signal in circumstances requiring emergency response where a manual aid request is not feasible and where immediate response is essential (e.g., severe accidents). The signal will provide location information and potential severity information to the emergency response personnel.

Manual Aid Request

The manual aid request function encompasses those services that are needed in an emergency (police, ambulance, towing, and fire department). It will allow the driver to have access from the vehicle without the need to locate a phone, know the appropriate phone number, or even know the current location. This function also may include feedback to notify the driver of the status of the response, such as the expected arrival time of service.

Vehicle Condition Monitoring

This function provides the driver with the capability to track the overall condition of the vehicle and notifies the driver of current problems, as well as potential problems. This function may be interactive, providing the driver with the capability of interrogating the system about problems and obtaining more details about the situation.

Cargo and Vehicle Monitoring (CVO-Specific)

This function is similar to vehicle condition monitoring, but more information may be conveyed to the driver (e.g., more precise indication of engine performance). Cargo-related conditions also can be monitored, providing the driver with information such as cargo temperature, humidity, and vibration. This function also may distribute this information to dispatch and company managers.

RATIONALE FOR A COMPARABLE SYSTEMS ANALYSIS

Although the ITS program is relatively new in the United States, several ATIS systems have been under development for nearly 10 years, particularly in Europe and Japan. Since some manufacturers, developers, and designers have already developed ATIS applications, they may have learned valuable lessons in the process. These discoveries can provide insight into the future development of this technology. The task of developing human factors design guidelines can benefit from investigating existing ATIS and related systems and learning from past mistakes and successes in the development, design, and deployment of those systems. The objective for performing this comparable systems analysis was to compile lessons learned from existing ATIS applications in the United States and to produce *preliminary* guidelines for the purpose of guiding empirical research to improve the design of future systems.

The contract Statement of Work (SOW) specified that at least five systems were to be analyzed as part of Task D, Comparable Systems Analysis. Two systems were mandatory—the TravTek system and the University of Michigan Transportation Research Institute (UMTRI) system. One Commercial Vehicle Operations (CVO) system also had to be included. It was further specified that at least two of the systems selected for analysis should represent application domains outside of highway transportation (e.g., aviation).

DEFINING LESSONS LEARNED

By performing a comparable systems analysis, we hoped to discover various types of lessons learned by designers, developers, manufacturers, and users of existing ATIS and CVO systems and related non-highway systems.

We anticipated that some of the lessons we would learn would involve unexpected or surprising applications or outcomes. These types of lessons would be very valuable in the guideline development process. However, we also included items that are confirmations of unsurprising, known human factors design principles. The reasons for including unsurprising "lessons" were that they may not be known by some readers and reconfirmation may be a positive contribution.

One of the objectives of Task D was to make as many field observations as possible. There are insufficient data in the literature on driver use of in-vehicle displays. Any insights, assumptions, and inferences made by various manufacturers were also important lessons to learn, for if they are erroneous, they can be corrected in future ATIS designs. Therefore, certain manufacturer's policies, user preferences, designer experience and opinions, and experimental results were also expected to foster important lessons learned.

At the end of each system analysis, statements of lessons learned from that analysis will be listed along with a brief background of each lesson. Implications for future ATIS/CVO system designs also will be provided if not explicitly evident from the statement and description.

TYPES OF LESSONS AND GUIDELINES SOUGHT

Whether the system was actually an ATIS system, or a comparable system (e.g., non-highway applications), this analysis looked for lessons learned in similar categories across the systems. Preliminary human factors guidelines also were expected to address these categories. The lessons that were focused on included the following categories and issues:

- Methods for displaying information in a vehicle (highway and non-highway vehicles).

- Visual and auditory interface design and usability.
 - Information content, format, and style.
- Methods for entering information.
 - Design of controls and procedures for entering information.
 - Driver safety and performance while operating equipment (e.g., pre-drive versus drive features).
- Methods for storing and retrieving information.
 - Technological advances in storing map databases, position data, and system response time.
 - Adverse transportation environment affecting hardware systems.
- Communication methods.
 - Obstacles in establishing a communications link between drivers and dispatchers (i.e., CVO applications) or between future drivers and ATMS traffic control centers.
- Methods/Approaches for designing ATIS and CVO systems.
 - The design team's approach to designing the particular system.

LEVELS OF ANALYSES PERFORMED

The candidate systems selected for this analysis (described in Chapter 2) varied considerably in application, level of implementation, and accessibility. To promote consistent analytic techniques, a structured set of surveys, checklist, worksheets, and interview items were created for each analyst performing the evaluation. In total, five analysts were involved in Task D.

Each analyst was instructed to perform the entire structured analysis, if possible. It was apparent that proprietary information, restricted accessibility, and lack of documentation could limit the level of analysis performed. For example, the usability of each system would be best evaluated by a targeted user, in a usability analysis. However, some systems were not available for such an evaluation. Furthermore, it was anticipated that analysts would not be able to interact personally with the non-highway and CVO systems.

The following outline describes the levels and procedures that were attempted in completing a full evaluation of selected ATIS/CVO units:

Documentation Analysis

System documentation was obtained and reviewed whenever possible. Examples included technical manuals, specifications, schematics, training videos/programs, and user manuals.

"Heuristic" Evaluation

This analysis was intended to apply the human factors expertise of the analyst to collect information regarding the performance and usability of the system. These data were to be based on the reviewer's observation of and experience with the system. The appropriateness of the various aspects of the system's interface was rated by the reviewer. Since this part of the evaluation involved the analyst's judgment based on personal "hands-on" experience with the unit being analyzed, we referred to this type of analysis as a Heuristic Evaluation (Jeffries and Desurvive, 1992).

Target User Evaluation

Whenever it was possible, volunteer participants were asked to use the system to perform tasks as instructed by the analyst. The user was asked to perform a verbal protocol while performing a defined list of pre-drive and en route (i.e., "drive") tasks that revolved around scenarios developed in Task C.

Design Team Member Interviews

The interviews were intended to collect information regarding the design team's rationale and criteria for the human factors design of the ATIS/CVO unit. This information was to be obtained through an interview session with system designers, developers, and/or evaluators. Specific items were developed so analysts would perform a structured interview and would make sure certain issues were addressed. The purpose was to discover the guidelines (human factors and other), design criteria, decision-making process, and design constraints involved in the design of the system being analyzed. If the analyst had personal experience with the functions of the system, he/she was instructed to use that knowledge to ask pertinent questions not listed in the interview items.

CHAPTER 2. SELECTION OF COMPARABLE SYSTEMS FOR ANALYSIS

SELECTING CANDIDATE SYSTEMS

The selection of the comparable systems was accomplished in two phases. The objective of the first phase was to compile a comprehensive list of existing ATIS/CVO-related systems. The list was compiled from several sources: *Proceedings of IVHS America Meeting 1993*; commercial presentations (booths) at the IVHS America Meetings of 1992 and 1993; ITS Clearinghouse on-line network; literature provided by *Task A—Literature Review* (Dingus, Hulse, Alves-Foss, Confer, Jahns, Rice, Roberts, Hanowski, and Sorenson, 1993); interviews conducted by Battelle in *Task B, Development of Objectives and Performance Requirements* (McCallum, Lee, Sanquist, and Wheeler, 1993); and telephone calls following up on prior leads.

In the second phase of the selection process, a total of seven systems were selected for the Comparable Systems Analysis. Two were mandated by the Statement of Work. The remaining five were selected based on the following criteria:

- Relevance to ATIS and CVO concepts and features.
- Similarity to specific ATIS subsystems (IRANS, IMSIS, ISIS, IVSAWS).
- Advanced technology with information display and user input capability.
- Dynamics of information flow.
 - The ideal candidate system would be two-way, real-time communication with either satellite systems, roadside beacons, or a Traffic Management Center (TMC).
- Complexity of the system.
 - The candidate system demonstrated a high level of system complexity, information content, and rate of user interaction.
- Implementation level.
 - The candidate system was at least at a prototype level of implementation, enabling detailed analysis and observation.

- User population training level.
 - The candidate system was designed for a population similar to the driving population for which ATIS systems are intended. More specialized user requirements were considered for CVO and non-highway systems.
- User time-sharing requirements.
 - The candidate system required users to reallocate their attentional resources from a primary task. Drivers must place priority on the driving task and share their attentional resources to interact with the in-vehicle device. Candidate systems demonstrated this "secondary task" requirement.
- Accessibility of the system for analysis.
 - For proprietary reasons, certain systems were not accessible. Foreign systems not available in the United States were eliminated due to travel cost constraints. Some of the systems selected still had restricted access and required a different level of analysis.

HIGHWAY TRANSPORTATION ATIS SYSTEMS

Two ATIS systems—TravTek and UMTRI—were required by the SOW. In addition, a similar system, Navmate, was selected.

The TravTek System

Travel Technology (TravTek) is an in-vehicle route planning and navigation system manufactured by General Motors.

The comparable systems analysis of TravTek was unique in that the TravTek operational field test was recently completed. Unlike the other ATIS systems, TravTek has been subjected to more than 1.6 million km of user testing. An in-depth field test on this system commenced in Orlando, Florida, in 1992, in which TravTek was installed in 100 cars (75 were rental cars) and participants were surveyed after they returned the rental cars. Twenty-five cars were used for research and development testing. The TravTek field test is the largest evaluation of an ATIS system to date in the United States. It was anticipated that the initial TravTek research, in addition to available knowledge about the TravTek design process, would provide the greatest number and most relevant ATIS lessons. Therefore, this section contains data not only on lessons learned in the design and development of TravTek, but on valuable lessons

learned from the initial results of the TravTek field tests (based on the participation of one of the authors in that evaluation).

The University of Michigan Transportation Research Institute (UMTRI)

Under the sponsorship of the FHWA, UMTRI has performed a series of laboratory and field studies over the past 4 years on the development of in-vehicle interfaces for driver information systems. The emphasis in Advanced Traveler Information Systems (ATIS) has been in the design of the controls and displays, the presentation logic, and the sequencing of information. Dr. Paul Green of the UMTRI Human Factors Division has directed much of this research, and approximately 16 reports are being submitted to FHWA. The objectives of the UMTRI program of research are to "develop a safe and easy-to-use in-car traffic information system and guidelines, and methods for their evaluation" (Paelke, Green, and Wen, 1993).

The Navmate System

Navmate is an in-vehicle route planning and guidance system designed and manufactured by Zexel Corporation. Plans for the first prototype began in 1989 and it was developed in 2 years. It was included as an additional ATIS system in this study because it was very accessible. Five Avis rental cars in San Jose, California, are currently instrumented with the Navmate system; this allows analysts to perform an informal usability study on the system. Navmate will be installed in another 95 rental vehicles in the next year to expand this data collection effort. This data will be used to evaluate the interface, features, and functions of the current prototype, and to improve the system in the next prototype.

HIGHWAY TRANSPORTATION CVO SYSTEMS

Two systems were selected to obtain lessons learned in the application of in-vehicle display systems to CVO. One system was selected directly from the commercial vehicle domain. The other was introduced because it applied ATIS technology to emergency service vehicles.

The OmniTRACS System

OmniTRACS is an on-board, two-way communication system developed by QUALCOMM. It was first installed in a commercial trucking fleet of 5,000 vehicles in 1988 and now exists in over 50,000 trucks. It is a two-way, satellite-based data link system between drivers and dispatchers. While it was not intended to be a route planning or navigation system, it does have that capability. This system enabled the analyst to learn lessons about methods for displaying, entering, and retrieving information with an in-cab system, as well as methods for storing and retrieving information for a large trucking fleet, and methods for communicating between a commercial vehicle and a control center (i.e., dispatcher).

The analysis of this CVO system provided insightful information and lessons learned in the design and development of driver-dispatcher communication systems in the trucking industry. Since this system has been available in the commercial market since 1988, additional lessons were discovered concerning the deployment of this system that will have to be addressed by future ATIS systems in order to penetrate the commercial market.

The TravelPilot System

The in-vehicle component of the TravelPilot system evolved from an earlier ETAK product named Navigator. Navigator was intended to provide information regarding the current position of a vehicle and a destination referenced to the road system. TravelPilot then evolved as a product for commercial applications that featured route selection and two-way communication to a dispatch center—functions that were not available in the consumer-targeted Navigator system. TravelPilot by ETAK is currently installed and used in trucks from the Seattle Fire Department. This on-board display system provides a communications link between emergency response vehicles (e.g., fire engines) and the Seattle Fire Department Dispatch Center.

The information on this system originated from the following levels of analysis: reviewing a chapter from the Seattle Fire Department Computer-Aided Dispatch System manual on the Automatic Vehicle Location Operations; on-site visit of the Seattle Fire Department Dispatch Center made by Battelle Seattle Research Center personnel in which the operation of the system was observed; and interviews with managers, dispatchers, and drivers.

NON-HIGHWAY TRANSPORTATION SYSTEMS

Two of the selected systems were required to be non-highway transportation systems. The selection of these systems also was based on the criteria described above to ensure that the systems would provide information relevant to ATIS/CVO applications. A number of major areas were investigated (e.g., maritime, aerospace, aviation, and nuclear power) to determine the feasibility of contributing to Task D objectives. The criteria of accessibility eliminated many potential systems that were either proprietary or still in the planning and research stages. In the end, the area of advanced rotorcraft navigation systems seemed to best fulfill the selection criteria.

Crew Station Research and Development Facility (CSRDF)

This advanced rotorcraft simulator at the NASA Ames Research Center includes a number of technological features, such as head-tracked helmet-mounted display, digital map, touchscreen technology, voice interaction, and dynamic information flow. The pilot-vehicle interface was designed by a team of human factors specialists working for the Army Aeroflightdynamics Directorate and the simulator facility was manufactured by CAE Electronics. This system

was accessible to analysts and fulfilled several of the selection criteria in terms of aided navigation using digital maps.

The Sikorsky Cognitive Decision-Aiding System

This system features a digital map that incorporates the output of a cognitive decision-aiding system to assist the rotorcraft pilot in selecting alternate mission plans and routes. This system incorporates advanced display technology and navigation decision aiding—features of direct relevance to ATIS/CVO.

COMMENTS ON SYSTEMS NOT SELECTED

The lessons learned and guidelines presented as a result of this analysis are based on a small sample of existing systems. Several other candidate systems may provide excellent material for lessons learned. To verify and extend the recommendations and lessons learned from this analysis, other systems could be investigated in greater detail. The ATIS-related systems that could be explored further include the following:

- Other existing domestic ATIS applications: Ali-Scout and Telepath.
- Foreign systems: Autoguide, CARIN, PROMETHEUS, Trafficscope.
- Personal navigation systems: Traxar, Driverguide.
- Corridors—Operational Traffic Management Tests (e.g., SmartRoute, Advantage I-75, HELP Crescent).

The "corridors" are undergoing operational testing and are composed of "intelligent highways" and Traffic Management Centers (TMC's). These systems involve monitoring traffic conditions (e.g., volume, vehicle flow, speed, congestion) from various highway and in-vehicle sensors, and highway videotape. Lessons regarding two-way, real-time information flow and corresponding effects on in-vehicle interface are worthy of detailed analysis to produce additional human-interface guidelines.

Other non-highway systems also could provide additional information. Some worthy candidates are:

- Glass-cockpit systems.
 - Many interface issues have been studied and implemented in aviation systems such as the Boeing 777, 747-400, and the A-320.

- Aerospace systems.
 - Mission Planning Systems and Shuttle Multipurpose Electronic Display System (MEDS) were investigated, but were not accessible.
 - Advanced air traffic control systems have some user-interface issues relevant to ATIS, but they are more applicable to Traffic Management Systems (TMS) [Kelly, Gerth, and West, 1993].
- Nuclear power systems.
 - The nuclear power industry has engaged in research and development on advanced display systems, primarily involving "system health monitoring." This concept is relevant to in-vehicle safety and hazard warnings. However, the operators are carefully selected and trained and the time-sharing requirements are different than those for drivers/pilots who must maintain an adequate level of performance on a primary task (i.e., driving) while interacting with in-vehicle ATIS/display system (a secondary task). Nevertheless, at least one nuclear system was identified as a potential candidate. Reactor Emergency Action Level Monitor (REALM) is an expert diagnostic and advisory system developed for the nuclear power industry to monitor high-risk conditions.

CHAPTER 3. THE TravTek SYSTEM

The following section describes and evaluates the TravTek system with respect to its interface design process. The design of the TravTek user interface was the responsibility of General Motors Research Laboratories. Many of the views expressed in this chapter are derived from published works and recollections of the authors on the process of designing TravTek. In addition, some of the descriptive material on TravTek and ATIS functionality is summarized from Task C and Task F working papers.

GENERAL SYSTEM DESCRIPTION AND OBJECTIVES

The TravTek demonstration project is the most comprehensive ATIS system fielded to date. As of the writing of this non-technical report (September 1993), the TravTek deployment and data collection phases have been completed, and the data analysis and reporting phases are ongoing. Limited empirical results are available for the TravTek study and will be cited in this section. These results provide unique insight into the usability and safety of the TravTek interface and the overall system effectiveness.

The TravTek system was composed of three primary components: the TravTek Information Services Center (TISC), the Traffic Management Center (TMC), and the TravTek vehicles. The TISC was managed by the American Automobile Association (AAA) of Florida during the deployment phase and provided help-line functions by means of a cellular telephone link. Supplemental travel, accommodation information, and emergency road service were available to TravTek users via this communications channel as requested. In addition, the TISC supplied local business and services data, a special events database, and selected listings from the Central Florida telephone book yellow pages for in-vehicle use. The TMC collected and fused traffic information from several sources. These included historical travel times as a function of time of day; and dynamic times from roadway loop detectors, police reports, city reports of maintenance and road closures, and probes of travel times from TravTek vehicles. In the TravTek vehicle, there was a computer and a color CRT with an infrared touch screen. The CRT was positioned high on the instrument panel and to the driver's right. The navigation system used a combination of dead-reckoning, map-matching, and Global Positioning System information to track the vehicle's position.

The TravTek Driver Interface has been created and developed to provide navigation, yellow pages, and roadway incident and traffic information to the driver (Fleischman, Carpenter, Dingus, Szczublewski, Krage, and Means, 1991). The design of this navigation system interface has as its primary objectives: (1) more effective driver navigation to save time and money, (2) easy access to valuable and convenient location information to alleviate stress and increase driving enjoyment, (3) maintenance of safe driving performance during system use and safety improvement facilitated by information for avoiding hazards and for emergency response, and (4) improvement of roadway efficiency to alleviate congestion.

Drivers who used the TravTek-equipped vehicles in Orlando, Florida, had access to an information-rich environment in the vehicle. Functions available in the vehicle included navigation information, route guidance, real-time traffic information, and information on local services and attractions. As shown on the main menu screen (figure 1), drivers could choose to enter a destination, browse through information about local services and attractions, browse through maps of the local area, request emergency services, go through tutorial instructions, or correct the location of their vehicle on the map display.

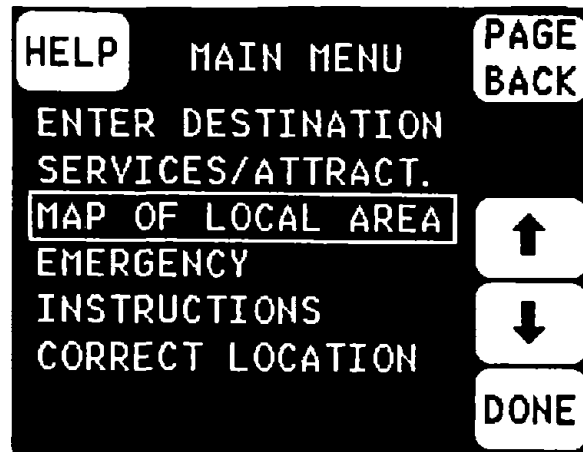


Figure 1. TravTek main menu.

The features provided by the TravTek system spanned at least some aspects of all four of the subsystems planned or anticipated for ATIS. Table 2 illustrates the functionality of the TravTek system in comparison to the functions proposed for ATIS/CVO. Note that 18 functions are addressed (to at least some extent) by the TravTek system.

Table 2. Comparison of TravTek functions with those from ATIS/CVO systems.

Subsystem	Function	TravTek
IRANS	Trip Planning	✓
	Multi-Mode Travel Coordination	✓
	Pre-Drive Route and Destination Selection	✓
	Dynamic Route Selection	✓
	Route Navigation	✓
	Route Guidance	✓
	Automated Toll Collection	✓
	Route Scheduling (CVO-Specific)	
	Computer-Aided Dispatch (CVO-Specific)	
IMISIS	Broadcast Services/Attractions	✓
	Services/Attractions Directory	✓
	Destination Coordination	✓
	Message Transfer	✓
ISIS	Roadway Sign—Guidance	✓
	Roadway Sign—Notification	✓
	Roadway Sign—Regulatory	✓
IVSAWS	Immediate Hazard Warning	✓
	Roadway Condition Information	✓
	Automatic Aid	✓
	Manual Aid Request	✓
	Vehicle Condition Monitoring	
	Cargo and Vehicle Monitoring (CVO-Specific)	
CVO-Specific	Fleet Resource Management	
	Dispatch	
	Regulatory Administration	
	Regulatory Enforcement	

The goals, as well as the anticipated users of ATIS, are well represented by the TravTek system. Business travelers, recreational travelers, and local inhabitants were recruited as part of the TravTek demonstration. Therefore, the "lessons learned" from this project may well provide the richest source of information on ATIS to date.

USER INTERFACE

It is important to note that the original TravTek interface had to be modified to match the constraints of the vehicle in which it was installed. The 1992 Oldsmobile Toronado was chosen since it already had an in-vehicle display and a cellular phone installed as options. Therefore, many of the physical aspects and specifications described below are indicative of the vehicle design and are not necessarily intended to be taken as part of the TravTek system.

General Description

The driver interface hardware consists of a 12-cm-diagonal color CRT with touchscreen overlay as shown in figure 2 and eight steering wheel buttons as shown in figure 3. The touchscreen provided a 5 x 5 matrix of touchscreen "keys" whose functionality changed with different screens. The touchscreen was only active when the car was in PARK (designated "PRE-DRIVE") or for selected functions when the car was in DRIVE but at zero speed. When the car was moving, only the steering wheel buttons were accessible to the driver. The system also had the capability of providing synthesized voice information to the driver upon request.

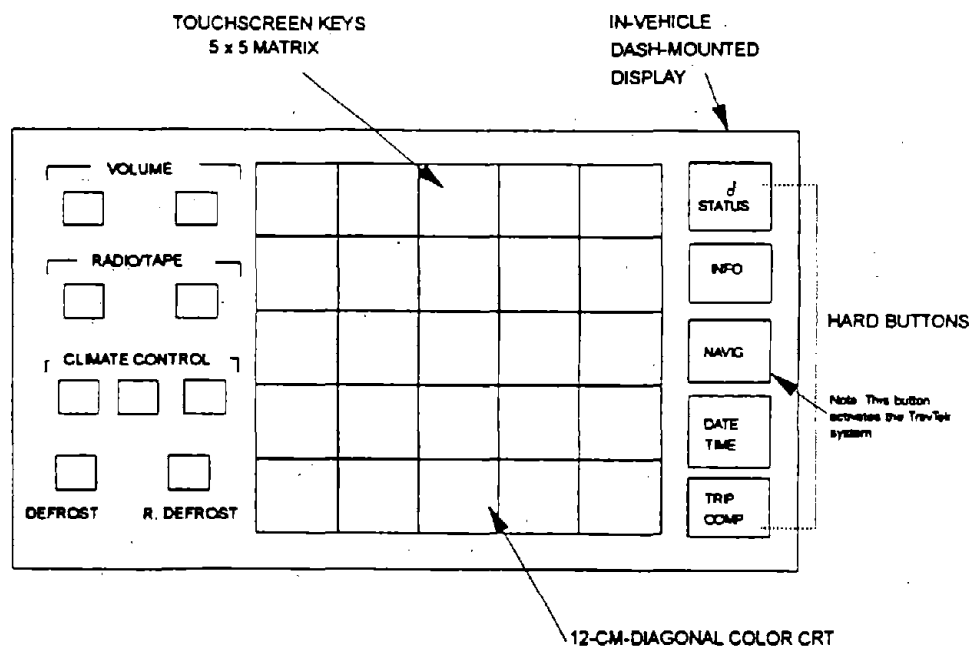


Figure 2. TravTek CRT screen.

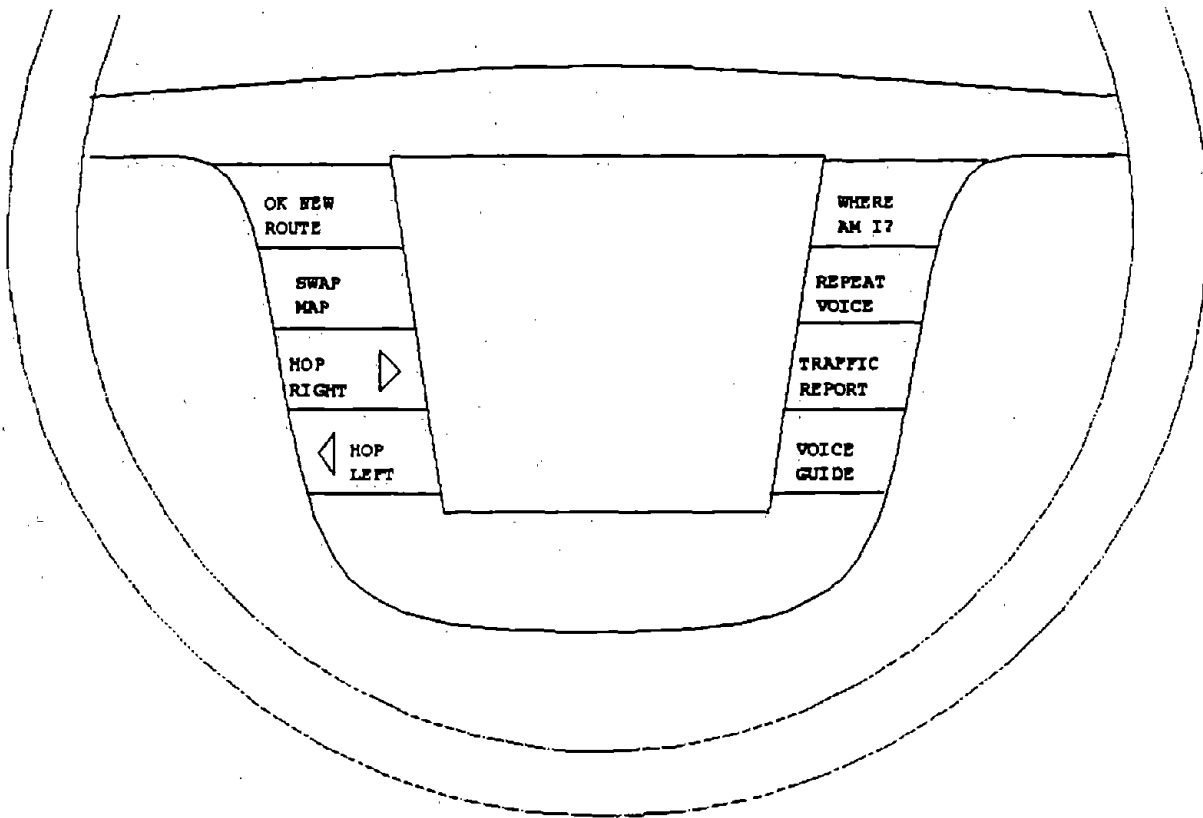


Figure 3. TravTek steering wheel with buttons.

Visual Information Display

All of the pre-drive and zero-speed functions, and the majority of the in-transit functions, are provided to the driver via the visual information display. A description of these functions is provided below.

Pre-Drive Functions

The pre-drive functions are wholly visual, and numerous touchscreen interactions with the system are available. The Enter Destination function allows the driver several choices of how to enter a desired destination (shown in figure 4). Like many of the other top-level menu screens, the driver scrolls a choice box to the desired menu item by touching the up or down arrow keys and then touching the DONE button.



Figure 4. Enter Destination menu.

Selection of a destination entry method, such as Saved Destinations, brings up another type of screen, as shown in figure 5, on which the driver can make a choice by touching a soft key adjacent to a two-line descriptor.

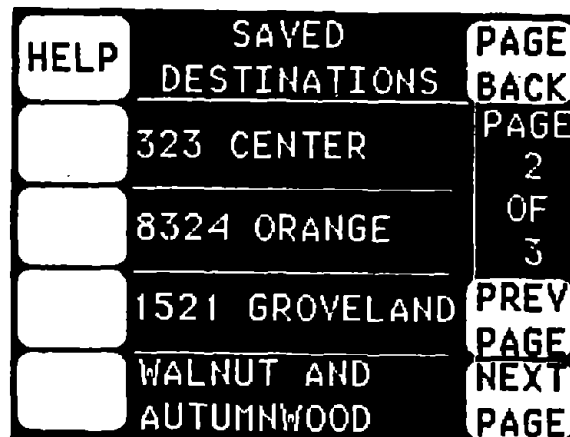


Figure 5. Saved Destinations screen.

Another pre-drive function allows the driver to browse through local services and attractions. The top-level menu for this function, shown in figure 6, allows the driver to select places to stay, including hotels/motels and campgrounds; things to see and do; places to eat; other services; and city facts.



Figure 6. Services/Attractions menu.

Once into the Services/Attractions menu, one can access a variety of detailed information. For example, by depressing the "WHERE TO STAY" key and selecting the "HYATT ORLANDO" from a scroll list, the driver would be presented the screen shown in figure 7. Note that information about the hotel is provided (including a AAA rating) and that the driver can show the location on a map, call the hotel with a single button press, or make this hotel the destination on the system.



Figure 7. Hotel Information screen.

Figure 8 shows another service provided within the Services/Attractions menu. The driver can access the location of Automatic Teller Machines through selection of a function on a menu. The driver can then depress a key to find a machine at a shorter distance and in a desired direction by selecting from among the choices provided.

HELP	AMERICAN EXPRESS ATM'S	PAGE BACK
5.5	SUNBANK ALAFAYA OFFICE	PAGE 6
6.3	SUNBANK AIRPORT OFFICE	OF 11
7.1	SUNBANK BAY HILL OFFICE	PREV PAGE
9.5	SUNBANK APOPKA OFFICE	NEXT PAGE

Figure 8. Automatic Teller Machine menu.

Another pre-drive function is browsing through maps of the local area. When this function is selected from the main menu, the screen displays a map showing the location of the car in a heading-up orientation, as shown in figure 9. Soft keys displayed on the screen allow the driver to change the scale (zoom level) of the map, pan the map from side to side or up and down, change the orientation of the map to North up, and display additional street names.

The driver is given two methods of obtaining emergency help. Emergency can be selected from the main menu. It is also one of the choices given in response to activating the Help soft key that is present on many of the pre-drive screens. The Emergency screen (figure 10) gives a choice of Police/Fire/Medical help, Road Service help, or Cancel Emergency request. If the Police/Fire/Medical choice is selected, the cellular phone is automatically dialed and a screen with pertinent information is presented (figure 11). When Road Service is selected, a similar screen is presented and AAA Road Service is dialed automatically.

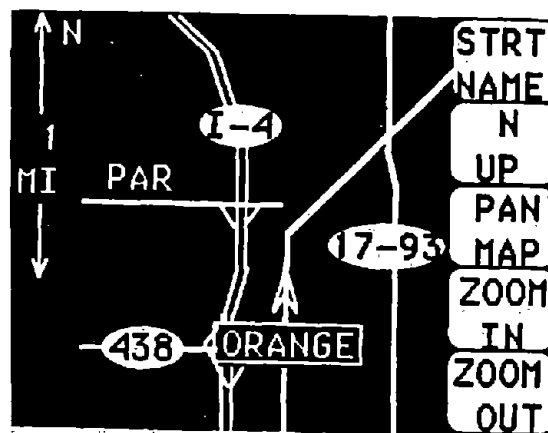


Figure 9. Map of local area display.

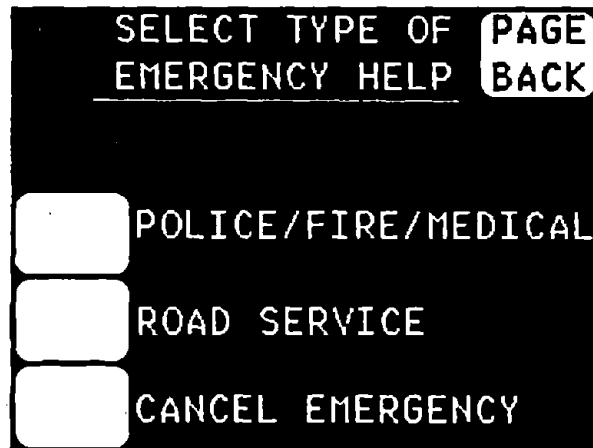


Figure 10. Emergency Help screen.

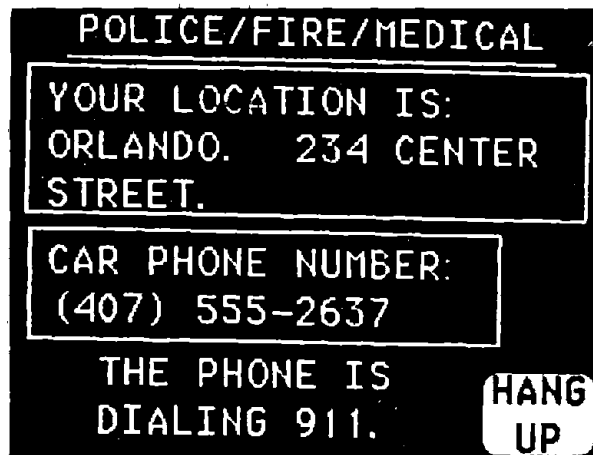


Figure 11. Police/Fire/Medical screen.

In-Transit Functions

The information provided by TravTek that is available while the car is in motion includes three types of map screens, as well as traffic information.

Information map. If the driver begins driving without inputting a destination, a map screen appears that is like the browse map screen, except that it has no soft keys superimposed on it (designated as an "Information Map"). The location of the car is shown on the map (see figure 12), along with the zoom level and the direction the car is heading. If the driver wants to change the orientation of the map to North up, pan the map, or see additional street names, the car must first be put in PARK. However, the zoom level can be changed when the car is at zero speed, such as when it is stopped at a traffic light. When the car is at

zero speed, the "Zoom-In" and "Zoom-Out" keys appear (as shown in figure 13) and can be activated to change the zoom level. The keys disappear when the car is again in motion. The position of the car is updated constantly because of the moving-map background.

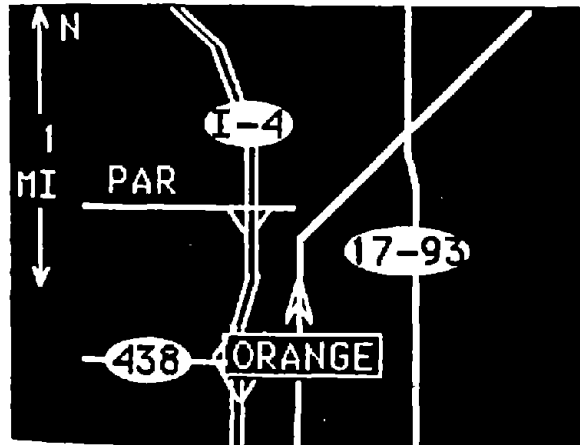


Figure 12. Information map when in motion.

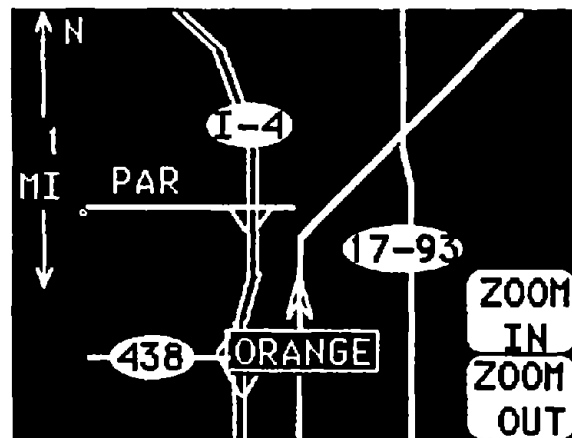


Figure 13. Information map at zero speed.

Guidance maps. When a driver has input a destination, the drive map that is displayed is a simplified turn map showing the next maneuver. These diagrammatic maneuver-by-maneuver guidance screens were designed to reduce demands on processing of visual information (Fleischman et al., 1991). As shown in figure 14, the symbolic guidance map, or turn-by-turn guidance screen, provides visual information about the next maneuver along the TravTek system's proposed route. Carpenter, Fleischman, Szczublewski, Dingus, Krage, and

Means (1991) and Rillings and Lewis (1991) describe this display more fully. The guidance display represents the TravTek vehicle's present position with an arrowhead. Guidance is in a heading-up format. The next maneuver along a pre-selected route and the relationship of the present position to that maneuver are displayed. Tic marks above the present position symbol represent tenths of a mile (0.16 km) to the maneuver point, and they are displayed when the vehicle is within 1.45 km of the maneuver point. A large solid arrow indicates the direction of the maneuver. The name of the road that the vehicle is on, the name of the road at the next maneuver, distance to the maneuver, distance to the destination, and estimated time to the destination are displayed in text. Drivers have the option of selecting the Route Map or Guidance screens via a "swap map" switch on the steering wheel. Should the TravTek navigation computer detect that the vehicle is off the planned route, the route map automatically displays a banner across the lower portion of the screen that reads "Off planned route.—OK new route?" This display enables the driver to either: (1) return to the originally planned route, (2) accept a new route, (3) correct the present position of the vehicle in the navigation system, or (4) ignore the route deviation (appropriate if the vehicle is on route, as the system may recover correct position without operator intervention). Once the system has switched to the route map display when off route, it automatically returns to the guidance display when it detects that the vehicle is again on the planned route.

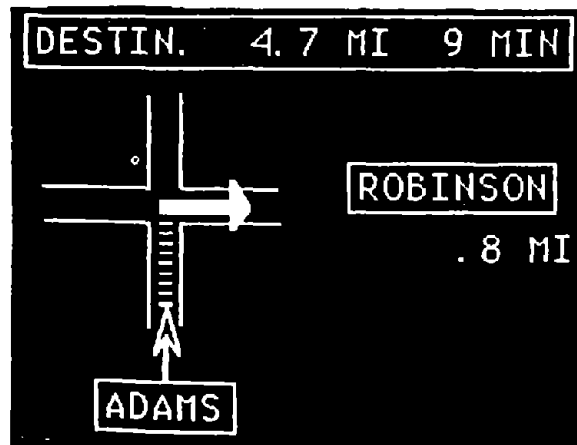


Figure 14. Guidance map display.

Route map. Because drivers may wish to see the total route displayed when they have input destinations, TravTek provided in-transit access to the route map via steering wheel button activation. The route map has the same appearance and function as the information map, with the addition of a destination symbol and a route line (shown in figure 15). Carpenter et al. (1991) and Rillings and Lewis (1991) describe the route map display. Present position of the TravTek vehicle is represented by an arrowhead. When the car is in PARK, the heading-up format can be changed to North up. When the vehicle is stopped (it may be in gear), zoom-in and zoom-out option buttons are available. The zoom-in, zoom-out, and North-up options are selected via buttons displayed on the touch-sensitive screen. If selected,

the North-up display automatically reverts to heading up when the car is taken out of park. Once selected, zoom scale remains the same until it is changed by the driver. Scales available with zoom are: 1/8 mile (0.20 km), 1/4 mile (0.40 km), 1/2 mile (0.80 km), 2 miles (3.22 km), 5 miles (8.05 km), 10 miles (16.09 km), 20 miles (32.19 km), and 40 miles (64.37 km). The map scale refers to the distance represented between the present position symbol and the top of the display. The present position symbol is approximately three-fourths of the distance from the top of the display.

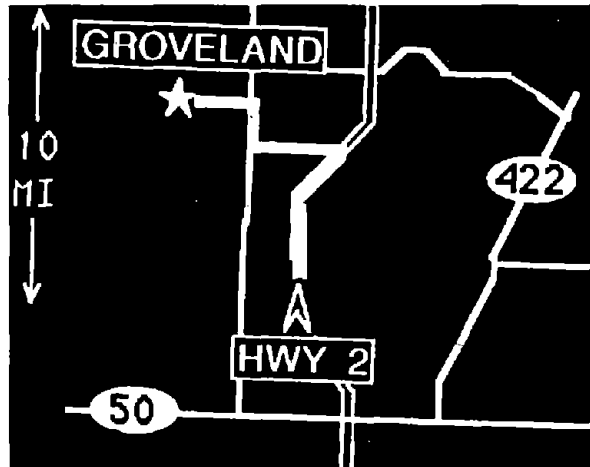


Figure 15. Route map display.

Traffic information. Traffic information that was radioed to the computer in the car from the Traffic Management Center during the demonstration was used to provide both visual and auditory information to the driver. The driver could turn the voice traffic reports on and off by operation of a steering wheel button. The traffic information was displayed visually on the different map screens. If a guidance map was displayed, a CAUTION AHEAD warning was superimposed on the screen when information was received about congestion or an incident ahead on the planned route. If the information map or route map was displayed, color-coded symbols were added to the map to show moderate congestion (hollow octagons), heavy congestion (filled octagons), road blocked (X's), or accidents/other incidents (large octagon with superimposed icon) (see figure 16).

avoid repeating messages in which the information content is extremely outdated. After the specified period, a button press of REPEAT VOICE produces the message "No recent message to repeat."

Traffic Report

The TRAFFIC REPORT function provides a verbal traffic advisory that reports known traffic problems. Traffic data are broadcast once per minute to the vehicles from the TravTek Traffic Management Center (TMC). Traffic data contain information on congestion problems within the TravTek map area, as well as details on incidents and construction when this information is known.

Onboard the vehicle, the traffic data are displayed on the map using incident and congestion icons. Traffic problems are filtered for relevance to the vehicle's location and route. With each new broadcast, a voice traffic message is formulated to describe each geographically relevant traffic problem. Voice traffic messages contain information on the location, cause, and severity of traffic problems. The set of relevant traffic messages constitutes the voice traffic report. When the TRAFFIC REPORT function is activated by a button press, the voice begins to state the current traffic report, with messages ordered by urgency and proximity to the vehicle. A subsequent button press will terminate the report. While the TRAFFIC REPORT function remains activated, all new, relevant traffic problems are presented as subsequent TMC broadcasts are received (Means et al., 1992).

At the outset of a trip, the TRAFFIC REPORT function defaults to OFF. Voice traffic reports are only presented if requested by the driver. When the TRAFFIC REPORT function is switched off, then back on, the full relevant, ordered set of traffic messages is repeated, allowing the driver to hear all traffic problems:

Voice Guide

The VOICE GUIDE button enables and disables voice route guidance instructions. Voice guidance messages describe upcoming route maneuvers, as well as indicating an off-route condition. Up to three voice messages may accompany each upcoming maneuver. If the distance to the maneuver is so great that the driver need not attend to it yet, the voice guidance message specifies only the distance to the maneuver, corresponding to a straight-ahead arrow on the visual display (e.g., "Ahead, next turn in three and four-tenths miles."). At a shorter distance to the maneuver, when the driver must get into the appropriate lane in anticipation of a turn, a "near turn" message is stated. The near-turn message contains the distance to the maneuver, as well as the name of the turn street and the type of maneuver (e.g., "make a hard left" or "bear right"). A typical near-turn message is "In eight-tenths miles, turn right onto the ramp to I-4 East." This corresponds to a change in the guidance display, which now depicts the geometry of the maneuver intersection and displays the name of the turn street. Just before the maneuver intersection, at a point where the driver can be expected to visually identify the turn street, voice guidance states an "at turn" message, which

contains the same information as the near-turn message, except for the distance. This informs the driver that the maneuver is imminent.

When an upcoming maneuver is followed by another maneuver in very close proximity, the message for the first maneuver alerts the driver to prepare for the second one. An example is "Bear left to follow the correct branch of Sand Lake Road, then prepare to turn right." This aids the driver in positioning himself or herself correctly after the first maneuver, in order to be able to execute the second one. When the VOICE GUIDE function is switched off and back on again, a distance-appropriate guidance message is presented. In this way, the driver always has the ability to force the system to present an instruction for the next maneuver. The VOICE GUIDE function is automatically enabled at the start of a trip, as voice guidance was intended to reduce glances at the visual guidance display.

User Input (Controls)

Driver input to the TravTek system is provided through three sets of controls. The TravTek functions are activated by a push button located adjacent and to the right of the CRT display. The push button is labeled "NAVIG" and was originally designed to activate the compass in the Oldsmobile Toronado. As described above, steering wheel buttons were also provided to access selected controls while the vehicle was in motion. Eight functions are available:

- (1) HOP LEFT allows correction of current vehicle location on the map.
- (2) HOP RIGHT also allows correction of current vehicle location on the map.
- (3) O.K. NEW ROUTE lets the driver accept a new route determined by the system to be faster.
- (4) WHERE AM I? provides current location and heading information.
- (5) TRAFFIC REPORT provides a report on current relevant traffic conditions.
- (6) VOICE GUIDE provides voice guidance information.
- (7) REPEAT VOICE replays the last voice message as long as it has relevance.
- (8) SWAP MAP allows the driver to switch between the guidance screens and the moving map displays.

In addition to the "hard" push buttons, a 25-key touchscreen overlay is an integral part of the CRT display. This touchscreen is described in detail in the Visual Information Display section above.

Communications Systems

The TravTek system has an integrated cellular telephone feature available to users. In addition to normally available cellular telephone features, the TravTek user could contact a 24-hour TravTek help desk with the press of a single touchscreen key, or the user could contact a variety of emergency services (including police/fire/ambulance and roadside service) by accessing the emergency services menu described above.

In addition to the cellular communications, the TravTek vehicles also received periodic traffic and incident reports and an events calendar. These were automatically integrated into the interface as described in the previous sections.

Cognitive Demands

The richness of information and multiplicity of functions that TravTek offers have the potential for causing information overload for the driver. Therefore, human factors engineering of the information displays and controls was a team priority from the early conceptual stages of the project (Carpenter et al., 1991). The intended users of the field-test system (travelers and local residents) had minimal opportunity for training. Throughout design and development, an overriding consideration was to make the system as easy to learn and easy to use as possible.

The cognitive demands, as determined by preliminary TravTek evaluation results, are discussed in detail in a subsequent section.

System Temporal Requirements

TravTek has a number of temporal requirements associated with its user interface. These include the timing of visual and aural cues while navigating, the prevention of auditory messages that are no longer current, and the updating of traffic and incident messages. Each of these requirements is discussed in the General Description section.

THE TravTek HUMAN FACTORS DESIGN PROCESS

Human Factors Design Guidelines

The TravTek design process was conducted under the same circumstances as many human factors designs for advanced systems. That is, some design support data were available from the human factors handbooks or guideline documents, but much of the data had to be generated from the review of empirical research, conduct of selected laboratory study, and review of selected on-road testing. The sources of information used to collect or generate the guidelines and information used to design TravTek are described below.

Application of Existing Principles and Guidelines to TravTek

Some of what is known from human/computer interaction research can be applied to drivers' interactions with automotive systems; however, driving is a complex combination of tasks that may be executed in potentially dangerous situations. In this sense, automotive human factors shares much with avionic human factors (Marshak, Kuperman, Ramsey and Wilson, 1987; Roscoe, 1980). However, the automobile user is quite different from the specially selected, highly trained population of pilots. So, it is generally necessary to develop laboratory and

simulator research, along with field studies, to better understand driving with advanced displays, as well as cognitively complex tasks such as way finding (Wetherell, 1979; Zwahlen and DeBald, 1986; Streeter, Vitello, and Wonsiewicz, 1985). A primary reason for this research requirement is that many differences among individual drivers and many different driving situations exist, making modeling and generalization difficult (Noy, 1990; Avolio, Kroeck, and Panek, 1985; Pauzie, Marin-Lamellet, and Trauchessec, 1989).

Although the task of driving must be carefully and accurately accounted for in the design of an advanced automotive system, one of the major challenges of the TravTek interface was the pre-drive function design. In essence, the design of the pre-drive interface constitutes nothing more than a human-computer interaction (HCI) design. For this process, two guideline documents were heavily utilized. These were Smith and Mosier's HCI guideline document and MIL-STD 1472D. These documents (Smith and Mosier, 1986) provided individual guidelines ranging from the use of color to menu design.

Some of the most important examples of principles applied from these documents included guidelines dictating high legibility and large character size because of the age range of the drivers and, in the pre-drive case, the need for them to quickly glance at and extract information from the screen. For example, the font size is specified as 19.7 arc-minutes. Information is presented on menu and pick screens, map and route guidance screens, and by auditory messages. Color is used conservatively, with low-saturation levels of colors selected from the middle of the spectrum. The principle of consistency was followed in the placement of information, the grouping of information, the use of nomenclature, and coding by shape and color. There is auditory feedback for all key presses so that the user can be sure that the computer has entered each selection.

A major human factors concern for navigation systems in general and for TravTek specifically (Rockwell, 1972; Dingus, Antin, Hulse, and Wierwille, 1988) is that the addition of visually displayed information, especially moving maps, may divert visual attention from primary visual tasks such as lane tracking and obstacle detection. Although drivers may often have spare attentional resources (Dingus et al., 1988), there may be situations in which processing and response demands exceed capacity. This may result in increased mental workload and errors.

In general, principles utilized in addressing these concerns for TravTek included limiting the information presented to the driver to that which was required for a given circumstance (as determined from task analyses) and use of the auditory mode to limit visual attention requirements. Specifically, this resulted in restricting the use of displays and controls that were accessible during driving, reducing the information density of visually presented information, and using auditory tones and messages to augment the visual displays.

Utilizing Previous Research: The ETAK Navigator Studies

The ETAK Navigator (Dingus, Antin, Hulse, and Wierwille, 1986; Antin, Dingus, Hulse, and Wierwille, 1990; Wierwille, Hulse, Fisher, and Dingus, 1989) was comprehensively evaluated

in several human factors studies that addressed the attentional demands imposed by the ETAK upon the driver, the effectiveness and efficiency of the navigation system, and driver adaptation behavior to the navigation system. Each of these studies was performed on-road, utilizing an instrumented camera car. These studies revealed that several of the ETAK functions required a high degree of attentional demand compared to other automotive tasks. Despite this fact, the ETAK was found to be a usable and somewhat useful device that could potentially be improved by conceptual and design changes. On the basis of the ETAK studies' results, the investigators recommended several modifications to the driver interface for future systems. The recommended modifications included: automated route selection, simplified information displays, and a path feature for route planning. Each of these recommendations was included as part of the initial TravTek concept.

Preliminary TravTek Research Used to Generate and Validate Guidelines

Recommended modifications of the ETAK Navigator and additional navigation system designs and studies (e.g., Catling and Belcher, 1989) were considered in a preliminary conceptual design of TravTek. This early conceptual design was subjected to several laboratory usability tests (Dingus and Hulse, 1990).

Testing of the "pre-drive" functions revealed that manual route selection and browse map/area traffic scanning were difficult to use. It was the opinion of the investigators that because these functions were of marginal value to the overall system, the functions could be effectively eliminated. Pre-drive testing also revealed that system labeling, nomenclature, and messaging should be allotted substantial testing in order to minimize errors of confusion and/or required instruction. Furthermore, a larger control/display screen was recommended. Or, in cases where a small screen is the only option, a system with somewhat limited function was recommended. For the TravTek system, an automatic route selection feature was included for driver convenience. In addition, the TravTek nomenclature and labeling were subjected to comprehensive usability testing.

Evaluation of the "drive" functions included testing of the visual attention demand requirements. The inclusion of a turn-by-turn guidance map was strongly recommended for future systems as a lower attention demand option. Additional results included: (1) directly providing critical information (e.g., next-turn distance), (2) increasing the salience of critical roadway names through highlighting, and (3) the elimination of street names of secondary importance and/or increasing the lettering size. Each of the above recommendations was included as part of the TravTek driver interface.

Following refinement of the TravTek interface prototype, a series of design studies using naive subjects drawn from the general population were performed to arrive at display screens that were as self-teaching as possible (Carpenter et al., 1991). The display screen designs resulting from these comprehension tests were intended to facilitate user understanding of what to do and what would happen when soft keys were activated. To enhance driver understanding of how to operate TravTek, a Help key was provided on almost all of the pre-drive screens. In addition to using the Help key, the driver could also request an on-screen

tutorial or connection to the Help Line at the TravTek Information and Services Center (TISC) via the cellular phone. The operator at the TISC had a system similar to the one in the car and could guide the driver through the process.

The design study process described above was also extensively used in the development of the on-screen tutorial. This tutorial was accessed by selecting "Instructions" from the main menu and was divided into lessons covering all major functions. The driver had the capability of proceeding through the entire tutorial or viewing lessons selectively. The extensive help screens, tutorial instructions, and the TISC Help Line were intended to obviate the need for extensive training sessions and bulky manuals.

Modification of Human Factors Guidelines: Fitting the System to the Constraints

Early design concepts visualized a display screen and controls tailored to the characteristics of the information to be displayed and actions to be input by the driver. However, since TravTek was to be a limited edition system for operational fieldtest purposes and not a mass-produced production system, economic considerations dictated that an existing display and touchscreen system already integrated into the vehicle instrument panel be used as the major driver interface. The 1992 Oldsmobile Toronado included such a system as an option and was therefore selected as the vehicle for the operational field test (Carpenter et al., 1991).

While human factors were considered relatively early in the conceptual design process, there were already a number of system and user constraints. The TravTek functions make use of a color CRT with hard keys and touchscreen controls located in the dashboard section of the car usually reserved for the radio. The TravTek system shares the "vehicle information center" with the radio, climate controls, vehicle status indicators, and Yellow Pages Directory. So the CRT placement and screen size, the color palette, and the number and spacing of soft key controls were fixed. A set of hard keys located on the steering wheel were made available, and an auditory message system was added to augment the visual display. Due to the number and variety of messages to be presented by the system, it became necessary to use synthesized, rather than digitized, natural voice.

Display of map information, and especially of route guidance information, constituted the biggest design challenge. Most prior research points out what **not** to do, rather than what to do, for map displays. For the driving mode, it is important to reduce the density and distraction quotient to minimize eyes-away-from-the-road time. Because of character size and the touchscreen characteristics, labels on the soft keys could contain no more than two rows of four characters each, and menu items also had space restrictions. A series of studies identified labels that were understandable to untrained users, given the size constraints. Multiple ways of displaying traffic information visually were investigated to arrive at a set of symbols that were clear and did not conflict with each other (Carpenter et al., 1991).

Although there is no consensus on the use of maps and touchscreens while driving, the TravTek philosophy was to proceed with caution. This conservative approach led to the

distinction between functions available to the driver only in a pre-drive mode (while the car is in PARK) and functions available while driving.

In addition, to reduce the necessity for the driver to look at the display screen while driving, auditory displays using coded tones and synthesized voice messages were added to the design to supplement the visual information. The decision was made early in the design process to eliminate the use of touchscreen keys while the car is in motion, and to allow the driver to make system inputs only through activation of steering wheel buttons while driving.

Constraints Imposed by the User Population

TravTek users were mostly rental car customers, although there were also some local residents. The age range of these drivers was approximately 25 to 65 years old. Their level of education varied from high school to college with limited computer experience to highly experienced computer users. The opportunity for training was minimal. Therefore, in addition to constraints imposed by a multi-task environment, special emphasis had to be given to making the system as easy to use as possible.

Guidelines Used in the Design of the TravTek Auditory Interface

From the outset of the TravTek project, the design of the synthesized voice interface was given a top priority. The TravTek team felt that the auditory mode, if implemented effectively, had great potential as a means of imparting complex information to the driver while allowing eyes to remain on the road. In addition, voice messages also draw the driver's attention to the fact that new information is available, so the driver need not glance at the visual display frequently to check for an update. However, unlike some ATIS systems, voice was designed for TravTek to provide a supplement to the visual display, which could also be used as a stand-alone system if desired.

The TravTek driver interface design team strived to make the application of voice to an ATIS system a desirable and useful feature to the driver (Means et al., 1992). The guiding principles that were applied to the design of the auditory interface to achieve this goal included:

- (1) Minimizing voice "chattering" and "nagging."
- (2) Maximizing voice intelligibility.
- (3) Providing timely, useful information through voice.
- (4) Allowing significant driver control of voice functions.

The use of voice in the automotive industry will typically meet with resistance due to the belief that "people do not like talking cars." This belief has apparently arisen from negative reactions to vehicles that use voice to warn drivers of open doors or unbuckled seatbelts. An examination of the use of voice for such purposes reveals violations of some of the TravTek principles mentioned above.

Drivers may not be receptive to the use of voice for a system warning unless the condition is urgent (e.g., collision warning). In the case of an open door, a non-verbal auditory signal or a telltale on the instrument panel is probably sufficient to alert the driver to the problem. The use of voice in this instance may be perceived by the driver as "nagging," as it is more analogous to an interfering passenger than it is to a machine warning. Drivers may have various reasons for wanting to suppress a voice system at times, and these wishes must be accommodated by giving the driver control over volume as well as activation of voice functions.

Clutter

As anthropomorphism is inevitable in a talking car, the TravTek design team chose a conservative approach to the sort of "personality" that may be attributed to the ATIS system. Anthropomorphism can be lessened by designing voice systems that are more machine-like than human-like in their expression. ATIS systems with excessively long voice messages, or messages that exceed strict bounds of usefulness, may be accused of "chattering" or "nagging" (Means et al., 1992). "Auditory clutter" is the term used by Stokes, Wickens, and Kite (1990) to describe the overuse of the auditory channel, resulting in potential distraction from the driving task. To minimize auditory clutter, voice feedback was avoided for correct maneuvers, driving speed, and system status (uses that are advocated by Davis, 1989). Initial road tests of the TravTek driver interface convinced the TravTek design team to further reduce the length and number of voice messages.

Voice Intelligibility

Computer-generated speech for ATIS systems may be either synthesized or digitized. Digitized speech has the significant advantage of intelligibility and naturalness, along with the disadvantage of prohibitive limitations in recording and storing large amounts of text. In TravTek, synthesized voice has enabled the use of a large variety of message text in an implementation that achieves an acceptable level of intelligibility.

Although the TravTek voice sounds male, this should not be interpreted as a deliberate design decision. The selection of a speech synthesis product was based on hardware requirements for durability in an automotive application. There was little choice regarding voice characteristics, and it was necessary to settle for the voice available in a product that satisfied the constraints. Although a synthesizer does allow for programmer control over voice attributes such as rate of speech, pitch, and voice gain, it did not provide a choice between a male and a female voice. It did, however, offer a choice of three voices—differentiated as "a large person," "a medium-sized person," and "a small person." The male-sounding TravTek voice is the "medium-sized person" (the other two voices are mostly unintelligible).

Regarding the issue of the intelligibility of synthesized and digitized speech, synthesized speech is decidedly less intelligible than digitized speech. The reduced intelligibility has been demonstrated to stem from the absence of many prosodic features that are found in natural human speech (Allen, 1976). The prosodic element of speech is what gives natural speech its

rhythm. A state-of-the-art voice synthesizer applies some reasoning to the insertion of pauses and variations in pitch and stress; however, the inability of the system to interpret the input text severely limits the prosodic results. Many commercially available voice synthesizers provide a means of inserting prosodic markers in text, giving the programmer some control over the intonational pattern of a synthesized utterance (Means et al., 1992).

Similarly, a speech synthesizer typically contains a large dictionary of stored pronunciations for known words, as well as a program that creates a pronunciation for an unknown word based on its spelling. In English, spelling is not a good predictive measure of pronunciation, and no known algorithms will produce consistently accurate results in pronouncing unknown English words. For the TravTek voice messages, the prosody was carefully selected by a linguistic specialist to enhance intelligibility. As part of this process, the linguistic expert listened to voice synthesizer pronunciation for all words that were spoken by the system, including over 12,000 Orlando, Florida, street names, storing corrected pronunciations as needed. This effort resulted in large improvements in intelligibility, and the TravTek design team considers this preprocessing to be essential for public acceptance of synthesized voice.

Other strategies are also effective in increasing intelligibility of synthesized speech. It was found that in TravTek route guidance and traffic messages, the street names are the least intelligible part of the utterance. To aid in the comprehension of street names, it is useful to speak the street name suffix (e.g., "Colonial Drive" as opposed to simply "Colonial"). Alerting prefaces are thought to be effective in attracting the listener's attention to an impending voice message. Various experimenters have found a reduced response time for prefaced messages, despite the increased length of the message due to the preface (Bucher, Karl, Voorhees, and Werner, 1984; and Simpson and Williams, 1980).

The mechanical-sounding characteristic of synthesized speech may have some advantage over digitized voice in automotive applications. Because the voice does not sound human, it is easily and immediately distinguishable from other voices in the automobile environment. In this way, the perceptual contact makes the voice somewhat self-alerting; it is obvious that the car is speaking. The machine-like voice also reduces the tendency toward anthropomorphism, as mentioned above.

Usefulness of Information

Useful TravTek information was defined as that which enabled the driver to optimize performance of the driving task. Route guidance instructions are useful if they enable the driver to follow a route safely and without error. Traffic information is useful if it enables a driver to avoid congestion, minimize traffic time, and drive safely in the vicinity of unavoidable traffic congestion. There are many open questions as to the appropriate information content of guidance and traffic messages in an ATIS system.

Route Guidance

People typically include the names of turn streets in route guidance instructions. Are street names a useful piece of information in a maneuver instruction? The TravTek design team believed that they were, given the difficulty in timing turn messages accurately enough to prevent erroneous turns in areas with closely spaced cross streets. Street names also aid in driver orientation in unfamiliar territory.

At an intersection where two streets cross at right angles, the instruction describing the maneuver is easily formulated: "turn right" or "turn left." Complex intersections entail maneuvers that are more difficult to describe clearly. While this is another justification for the use of street names, it is important to note that street signs are not always easily visible. For this reason, voice guidance, graphical representation of the maneuver intersection, and error recovery strategies for driver mistakes are all important elements of route guidance. Combined into a coherent system, they work effectively to keep the driver on the planned route.

Another aspect of route guidance is that it is useful for drivers to know how far they are from their next maneuver. Individual drivers, however, differ in their ability to reason about distance. Davis (1989) and Streeter et al. (1985) have discussed the potential ambiguity of measures of distance. For instance, "in two blocks" may be ambiguous when the next cross street does not intersect the driven street on both sides; does it delimit a block? Upon hearing an instruction such as "turn left at the third light," will the driver count the light at the intersection he is passing through when the message is spoken? The conclusion is that distance expressed unambiguously (e.g., in fractions of a mile) is more likely to help drivers who can gauge it than it is to confuse drivers who cannot do so.

Navigation Assistance

The WHERE AM I? function was designed primarily to provide assistance when the driver is navigating along a self-planned route. It helps the driver to identify the intended turn street and to orient himself or herself when uncertain of his or her current location and heading. WHERE AM I? can be a useful supplement to route guidance as well, identifying turn streets at intersections where street signs are missing or when visibility is obscured. It also provides an indication of navigation system accuracy without reference to the map display.

An example of a WHERE AM I? message is "Approaching Lee Road. Headed North on Orlando Avenue." At first glance, it may seem counter-intuitive to answer the question of "Where am I?" by first stating what you are near, then where you are. It was decided to word the message in this way to impart the presumably more urgent piece of information first. Cross-street information is considered to be more urgent, as it may identify the location of the intended maneuver. The WHERE AM I? function is self-interrupting, i.e., it aborts its current message and restarts itself when the button is pressed during WHERE AM I? output. Repeated quick button presses will result in a series of cross-street notifications with the location information clipped. This function enables the driver to use WHERE AM I? to listen

to names of cross streets in quick succession while proceeding down the road. The terseness of the WHERE AM I? message further serves this purpose (Means et al., 1992).

Research Issues in Traffic Advisories

There is not a good understanding of which pieces of information about a traffic problem are necessary and useful to drivers. Specifically, it is not clear whether knowing about lane closures or the cause of a congestion problem will cause drivers to modify their behavior. Perhaps it is beneficial to suppress clarification of a spectacular incident such as a fire, as it could encourage gawkers to travel to the scene. On the other hand, it also alerts drivers to the possibility of emergency vehicles in the area.

There are a variety of ways to express the severity of a congestion problem. Terms such as "heavy traffic," "sluggish traffic," "a 1-minute delay," "bumper to bumper," "stop and go," "slow and go," and "merging delays" are used in traffic reports broadcast by radio stations. Radio traffic reports also occasionally provide an estimate of the length of a congestion queue. More research is needed, however, to determine how drivers use an estimate of a backup queue; whether it can be reliably estimated; and how best to describe it to drivers (in miles, or number of traffic signals, or from street X to street Y.) The word "congestion" itself may be ambiguous. Do drivers interpret it consistently as slow traffic, or can congestion also refer to a heavy volume of traffic moving at the posted speed?

The location of a traffic problem can also be expressed in various ways. Can the relevance of the problem be assessed more easily by the driver if its location is described relative to the vehicle or in absolute terms?

Onboard computer-generated traffic advisories can provide information on demand that is filtered for relevance to a given vehicle location/route. Some issues that arise in relevance filtering include the criteria that are applied to determine relevance; the upper limit on the amount of information that should constitute an on-demand traffic report; and the possibility of giving drivers the ability to tailor traffic reports to their own needs and interests (Means et al., 1992).

The TravTek Approach to Traffic Reporting

TravTek traffic advisories report lane closures and the cause of an incident when known. Congestion is characterized as "heavy" or "moderate," depending on the degree to which travel time on the affected road varies from free-flow travel time (Dudeck and Huchingson, 1986). The locational description of a traffic problem differs according to whether the vehicle is on the planned route and whether the traffic problem is an incident or a non-incident-related congestion problem. The location of an incident (e.g., an accident, disabled vehicle, malfunctioning signal, construction, etc.) can be pinpointed, whereas congestion is so volatile that we cannot delimit it precisely and reliably. When the vehicle is on a planned route, only problems that are ahead of the vehicle on the route are reported. If an on-route problem is an incident, its location is described as "[distance] ahead on [street name]," where

distance is expressed in miles. A non-incident congestion problem on the route is specified as "ahead on [street X] between [street Y] and [street Z]." The visual display indicates incidents and congestion with icons placed on the local area map, thus clarifying the location of problems reported by the voice traffic report.

The collection, dissemination, and in-vehicle use of traffic data is a process whose design is subject to many interdependencies. The TravTek solution to on-vehicle presentation of traffic data was largely driven by outside constraints imposed by the organization of the TravTek Traffic Management Center (TMC). The design of the TMC itself is constrained by local availability of information sources. In future ATIS systems, it would be preferable to base the information content of traffic advisories on solid research on the usefulness of the information, constrained by the general feasibility of data collection in most large urban areas.

Driver Control of Voice Features

It is essential that drivers be allowed to select functions for which they receive voice output, control the volume of the voice, and suppress all voice messages. In the TravTek system, when a voice message is about to be spoken, the radio is muted for the duration of the voice output. Activation of the radio volume button during voice output adjusts the volume of voice messages; to adjust radio volume, the driver uses the volume control during radio output. This enables differing volume levels for radio broadcasts and for TravTek voice functions (Means et al., 1992).

In initial testing, it was found that voice messages for TravTek functions were generally welcome when the driver was not listening to the radio or conversing with a passenger. Because the voice synthesizer suppresses radio output and tends to interrupt conversations, drivers may occasionally want to turn off some or all voice functions. Separate controls for voice guidance, traffic reports, and WHERE AM I? function allow the driver to reduce the amount of voice selectively, as opposed to having only a single voice on/off control.

While a driver's attention is occupied by the driving task and competing thought processes, he may not immediately attend to a voice message that is issued automatically. Because the auditory display is inherently ephemeral, the REPEAT VOICE function provides a necessary mechanism to recapture information that may not be initially comprehended.

Non-Verbal Auditory Signals

Considerable research has been done in the use of non-verbal auditory warnings in aircraft cockpits (see Patterson, 1982, for a comprehensive discussion). Some of the knowledge that has accrued from aircraft research may pertain to passenger vehicles (e.g., appropriate volumes and temporal characteristics for auditory tones). However, principles guiding the use of auditory systems in aircraft must not be applied indiscriminately to passenger vehicles. It is important to bear in mind the essential differences between highly trained cockpit personnel and automobile drivers who vary greatly in age, driving ability, physical condition, etc.

When ATIS systems become so commonplace as to be available to untrained drivers, the meaning of auditory signals must be easily learned and retrained, with minimal potential for confusion. In the TravTek system, three nonverbal auditory signals were used. Two were tied directly to driver actions: a feedback signal for touchscreen key presses, and an error tone for inappropriate steering wheel button presses (for instance, pressing ROUTE GUIDE when no destination has been entered).

The third signal must be taught. When the VOICE GUIDE function is turned off, a glance-at-the-screen tone is sounded to prompt the user to look at the visual display when new information is presented—when the next maneuver is first depicted, or when the driver must be informed that the car has left its route. The glance-at-the-screen signal was selected to be soft and unobtrusive; with the goals of not startling drivers or disrupting conversations.

TravTek EVALUATION METHODOLOGY

Given that selected evaluation data are available from the TravTek demonstration project, the majority of the lessons learned have come from the wealth of available evaluation data. To fully understand the value of this data for establishing design guidelines, one must first understand the magnitude of the TravTek evaluation program.

As previously stated, the TravTek evaluation program currently is in the data analysis and reporting stages. The TravTek evaluation is an extensive program to test various aspects of the TravTek system, from performance of the technology to safety and human factors issues. As such, much of the data generated will be of great use to the development of ATIS guidelines. Some of the preliminary data are summarized in the following sections in a "lessons learned" format. However, much of the data presented are descriptive only and have not been subjected to inferential statistics. Therefore, the results should be interpreted with caution.

To provide a full understanding of the scope of the TravTek evaluation in the context of the data presented in the following section, a description of the evaluation studies of interest to the human factors community (from Fleischman, 1991) is presented below.

The TravTek evaluation was designed to address several levels of analysis. At the most macro level of analysis is the traffic network as conceived by many traffic managers and traffic researchers. The flow traffic within the network can be directed around stoppages or distributed over more of the network. However, in the case of an advanced driver information system such as TravTek, network efficiency is not improved by managing the flow of traffic in a direct way. Rather, the traffic is composed of drivers with different states of knowledge about possible routes, cyclical traffic patterns, and incidents. The hypothesis is that drivers who have the more precise, current information will use it to plan trips and to navigate more efficiently. If the system functions properly, the vehicle information system will calculate and inform drivers of routes that are more direct and/or that bypass traffic

incidents. So, in a mature system with enough vehicles equipped with route and traffic information, the result should be a redistribution of traffic. The proposed benefits to the equipped drivers include improved trip times, avoidance of traffic congestion, and easier navigation to chosen destinations. The proposed benefit to non-equipped drivers is the increased flow through a traffic network relieved by the redistribution of equipped vehicles (Fleischman, 1991).

At a micro level of analysis, the driver is an information processor and decision maker in a control loop with the vehicle that is nested in the TravTek system. The success of the system at the macro level depends on many assumptions about the system at the micro level (e.g., the driver and vehicle level of analysis). The following assumptions have been called out as hypotheses to be tested as part of the TravTek research (Fleischman, 1991):

- (1) The driver will be able to extract navigation and traffic information from displays without a degradation in basic driving performance. There has been much speculation and some research on the potential for distraction and information overload (Fleischman, Carpenter, Dingus, Szczublewski, Krage, and Means, 1991): (a) Some suggest that the presentation of navigation information to the driver will reduce the need to scan the roadway for signs, which can itself detract from driving performance. Others, particularly those in the human factors community, contend that some visual information displays may impose an unacceptable attentional demand on the driver. (b) There is evidence that attentional demand may be a function of display type, that moving-map displays may require drivers to glance more than would simple graphic depiction's of the next maneuver or auditory messages. (c) As drivers have more experience with the system, there may be a shift from novice behavior of glancing at displays inappropriately to more appropriate division of attentional resources.
- (2) The drivers will behave as system designers and traffic researchers predict. However, this may depend on the utility of the information to the drivers, the human factors of the driver interface, and the willingness of drivers to comply by driving routes selected by the system and accepting better routes while in transit.
- (3) If drivers use the system, they will navigate better. That is, drivers will spend less time and drive fewer miles because they will not get lost. They will drive to destinations more efficiently, and they will potentially perform fewer unsafe maneuvers to correct navigation errors.
- (4) There is a relationship between observed measures of time savings, congestion avoidance, and navigation improvement and the perception of these benefits by drivers. The salience of improvements as experienced by the drivers may affect the utility of the system.

- (5) Drivers will want to equip their cars and use the system regularly. A TravTek-type system will require a critical level of market penetration and system use to effect network efficiency.
- (6) There will be indirect safety benefits due to: (a) routing drivers around potentially dangerous traffic conditions and (b) reduction of navigational waste. Each of these aspects is being addressed in the TravTek evaluation program in one or more of the following studies (Fleischman, 1991):

Field Study With Rental Users

The participants in this study were recruited by the American Automobile Association from club members who traveled to the Greater Orlando area. They rented TravTek vehicles through special arrangements with Avis. Seventy-five vehicles were used in the field study throughout the year of data collection. Each traveler participated for their normal planned length of stay in Orlando. All drivers participated in a questionnaire study and some were interviewed.

Participants were divided into three groups: (1) Drivers in the "Navigator Plus" group had access to all of the navigation functions, real-time data communicated by the TMC, and service functions. Service functions are the maps and the services and attractions directory that are available only when the vehicles are in PARK and, also, the cellular telephone. (2) Drivers assigned to the "Navigator" group had access to all autonomous navigation and service functions, but no real-time data. (3) Drivers in the "Service" group had service functions only. This is the control group against which the others are compared. The control group vehicles were equipped with a TravTek in-vehicle navigation and data logging system, but it was to be transparent to the users. Data such as vehicle position, heading, speed, and stops were automatically time-stamped and logged.

This division allowed the manipulation of the level-of-information variable and, therefore, an evaluation of TravTek benefits and costs by comparing data produced by driving "high-tech" vehicles with and without navigation or traffic information. The Navigator Plus and Navigator groups are needed to evaluate the incremental benefits associated with providing real-time data.

Driver interaction with the TravTek system, such as key presses, were logged in the vehicle and are being sorted and analyzed to reveal which functions drivers used. The data can be sorted by subject and traffic factors by merging the vehicle log data with the TMC and User Profile log data. For example, how many drivers used route guidance? When they used route guidance, did they use the maneuver-by-maneuver screens, route maps, or voice? What did they use during peak versus off-peak traffic conditions? Did drivers of different ages make different choices?

Field Study With Local Users

The field study with local users shares many of the aims of the rental car study, but it sampled a population of people who are familiar with the geography of the Orlando area.

Two groups of drivers used Navigator Plus and Navigator vehicles for approximately 2 months. They were asked to assess the benefits of having the system functions compared with their usual means of negotiating the Orlando traffic network. This study was comparatively small, with 10 to 25 drivers at a time.

An analysis of system use compared with the rental car study should reveal a more complete picture of how trip planning, navigation, and traffic information systems might be used by people purchasing the system for their own use and how that use may change with experience. All local users completed questionnaires (Fleischman, 1991).

Yoked Driving Study

The Yoked Driving Study is a method of specifically testing the trip time savings and network efficiency objectives by studying the effects of TravTek on trip times and congestion avoidance.

Hired drivers were assigned to Control, Navigator, and Navigator Plus groups. They were instructed to drive a series of origin-destination pairs. To control for weather and traffic conditions, a member from each group drove simultaneously from origin to destination.

To facilitate the mapping of this study onto the Field Studies, origin-destination pairs were chosen to correspond to routes most likely to be traveled in the Field Studies. Additional pairs were also chosen to accommodate traffic/environmental variables (Fleischman, 1991).

Orlando Test Network Study

The purpose of this experimental approach was twofold: (1) to learn if people do navigate more efficiently with the in-vehicle navigation information provided by TravTek, and (2) to test navigation performance and preferences as a function of navigation information display type.

The Test Network was a network of possible routes between origin-destination (O/D) pairs. These routes encompassed a variety of highway types and conditions. They passed through system sensors and overlapped, to the greatest extent possible, with O/D pairs defined in the Field Studies and Yoked Driving Study. Navigation display types that were tested include: (1) hard-copy map, (2) maneuver-by-maneuver route guidance map, (3) moving map with route overlay, (4) moving information map, and (5) voice guidance. In addition, interactions with driver age, sex, and light conditions were studied (Fleischman, 1991).

Camera Car Study

A Camera Car Study provided detailed evaluations of: (1) how using the in-vehicle navigation displays affect driving performance (safety and navigation behavior) and (2) how easy the system is to use and to learn (human factors).

A TravTek vehicle was equipped with video cameras focused on the driver, the driving scene, the display and controls, and the outside lane line. This instrumentation, along with the vehicle data log, experimenter observations, and driver debriefing, provided a rich array of driver attention, vehicle control, and usability and learning measures.

Hired participants varied with respect to age, sex, and education level attained. The participants performed a series of tasks using the pre-drive functions available only in PARK, such as entering a destination; using the functions available while driving; and using the navigation functions. The drive tasks were performed while navigating the Orlando Test Network. Each driver used: (1) a hard-copy map, (2) a paper directions list, (3) a moving map with route guidance overlay, (4) a maneuver-by-maneuver guidance map, (5) voice guidance in combination with (3) above, and (6) voice guidance in combination with (4) above. The results of this study will help establish the relationship between eye glance measures and driving performance measures such as speed variance and lane excursions (Fleischman et al., 1991).

Questionnaire Study

Subjective and attitudinal data were gathered by means of a single questionnaire distributed to all participants in the Field Studies with Rental and Local Users. Questions addressed most TravTek objectives and research questions. People rated attributes of the TravTek system, such as system reliability, display readability and color quality, accuracy and usefulness of traffic information, overall user friendliness, usefulness for navigation, perceived safety benefits or costs, perceived time savings, and congestion avoidance. In addition, they answered market research questions about their willingness to buy a system with TravTek functions such as navigation, traffic reports, and services/attractions directory; under what circumstances, and for what price.

Debriefing and Interviews

Detailed driver preference, perception, and marketing data were collected through person-to-person interviews. A subset of participants in the Field Studies with Rental and Local Users were interviewed, and hired participants in the Yoked, Orlando Network, Camera Car, and TMC/Traffic Probe Studies were debriefed after their experimental drives.

Modeling and Analyses

Data collected during the year of operation of TravTek are being analyzed to project the resulting effects to a mature system. Traffic simulation modeling that builds on the work of

Van Aerde (Van Aerde and Krage, 1991) and market penetration modeling are being used to predict the consequences of a TravTek-like system for traffic network performance at several levels of market penetration. Potential environmental, economic, and community impact are being derived from the collected data. Analyses are being performed to investigate the implications of a TravTek-type system on safety (Burgett, 1991).

Global Evaluation

The Global Evaluation integrates the results of all individual TravTek Studies to provide evidence that TravTek met or did not meet its objectives. This is a macro evaluation that interprets the research results in the context of TravTek's stated claims and constraints. The global evaluation relates the results to those of similar ITS projects, such as Pathfinder (Farradyne Systems and Associates, 1989). The other purpose of the global evaluation is to assess TravTek as a cooperative project with public and private sector partners.

DATA FROM THE TravTek EVALUATION

A questionnaire item included in the TravTek post-experiment questionnaire was an overall rating from poor to excellent. Poor was designated as a "1" on the questionnaire and excellent was rated as a "6". Poor and Excellent were the only two anchor points provided. The mean response to this item was 5.2, indicating that overall, subjects found TravTek to be a very positive experience.

Usability

Usability of the TravTek system was addressed in a series of questionnaire items as depicted in figure 17. In general, the usability of the system as represented by ease of learning, ease of understanding, and way finding were rated quite positively. In addition, other factors related to usability, including driving interference and proper function, were also positively rated.

Figures 18, 19, and 20 highlight differences in trip planning time, travel time, and number of wrong turns while navigating for the Orlando Test Network Study (Inman, Fleischman, Dingus, and Lee, in press). Six conditions were utilized for this study, including turn-by-turn guidance and route map with and without voice, voice alone, and a control condition consisting of a paper map. Trip planning time and travel times were higher for the paper map condition when compared to any of the TravTek conditions.

Note, however, as shown in figure 20, that more turning errors occurred for the route map condition without voice as compared to any other condition. In contrast, the route map with voice had the lowest turn error rate, but it was not a great deal lower than the voice alone or guidance screen without voice conditions.

Safety

Accident statistics associated with the TravTek evaluation program were quite positive. Even using the most conservative comparison groups (i.e., non-visitors, non-rental car users, national averages), a statistical difference (or even an approach to significance) in accident rate does not exist between the TravTek users and any comparison group (Perez and Van Aerde, personal communication, 1993). Even though the TravTek users drove more than 1.6 million km, accident rates require extremely large exposures to be reliable. Still, these results are encouraging with respect to the safety of ATIS systems.

Overall, the TravTek system:

	Was Easy to Learn						Was Easy to Understand						Helped Me Find My Way					
	Strongly Disagree			Strongly Agree			Strongly Disagree			Strongly Agree			Strongly Disagree			Strongly Agree		
	1	2	3	4	5	6	1	2	3	4	5	6	1	2	3	4	5	6
Primary Driver																		
Secondary Driver																		
	Helped Me Pay More Attention to My Driving						Interfered with My Driving						Functioned Properly					
	Strongly Disagree			Strongly Agree			Strongly Disagree			Strongly Agree			None of the Time			All of the Time		
	1	2	3	4	5	6	1	2	3	4	5	6	1	2	3	4	5	6
Primary Driver																		
Secondary Driver																		

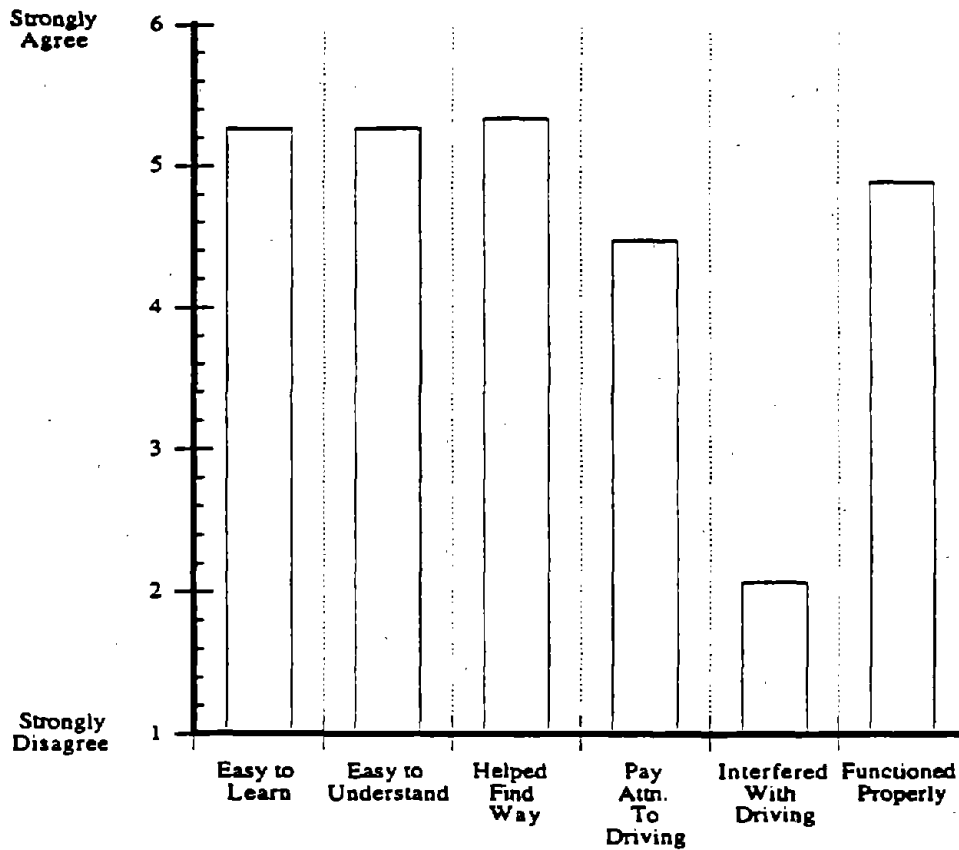


Figure 17. Global TravTek usability questionnaire responses.

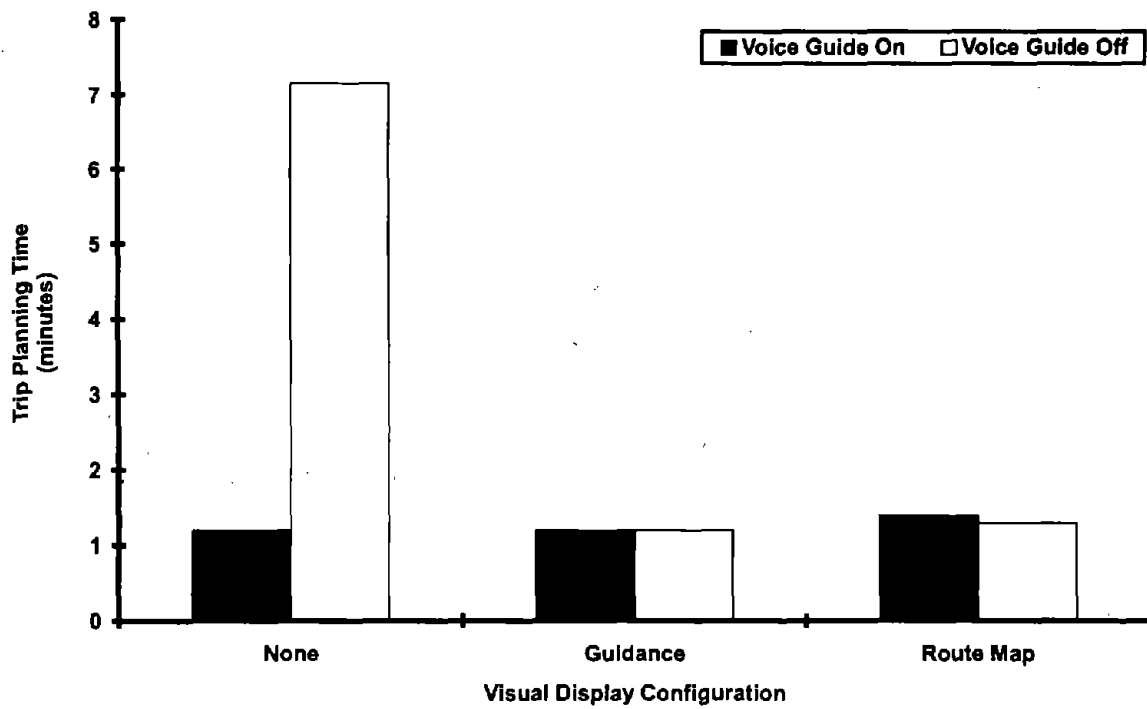


Figure 18. Mean trip planning time as a function of display configuration.

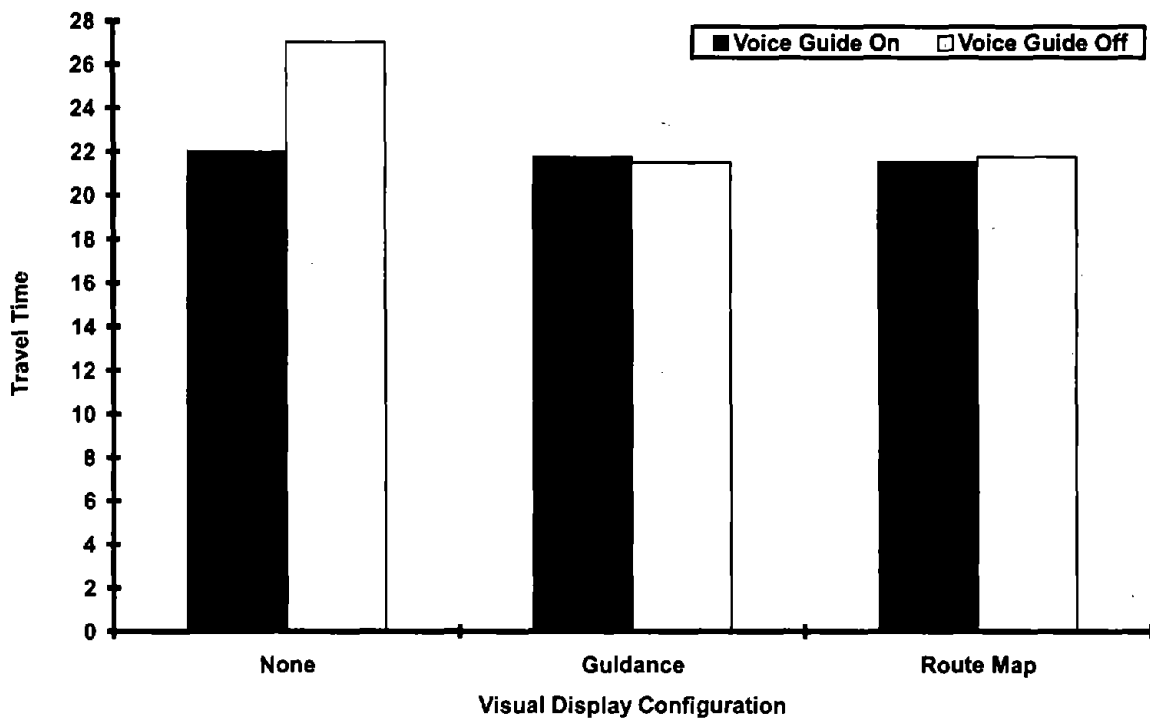


Figure 19. Mean travel time as a function of display configuration.

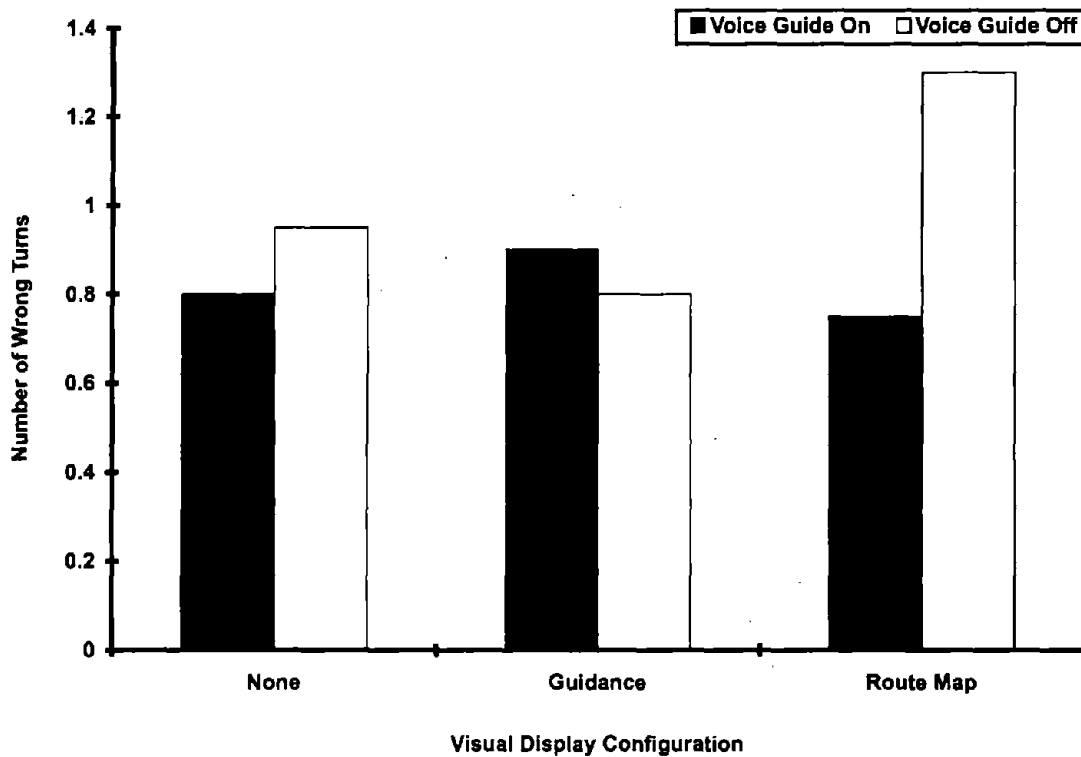


Figure 20. Mean number of wrong turns as a function of display configuration.

In addition to accident rates, near misses were analyzed in the Camera Car Study and as an item in the post-experiment questionnaire. The Camera Car Study found a surprising lack of near-miss data (Dingus, to be published). In detailed frame-by-frame analysis of 90 hours of video tape, only a handful of what could truly be considered close calls were identified. Of those identified, no more were found (in general) under the TravTek conditions than under the control conditions (paper map and paper directions list). For the question, How many times did you experience "close calls" (or near accidents) while driving the vehicle?, the mean response was approximately 1.3 on a 1 = never to 6 = frequently scale.

The questionnaire also asked a general safety question about the TravTek system—Do you think that TravTek helped you drive more safely in Orlando? The response to this question was a slightly positive 4.4 on a 1 = "Didn't help me drive safely" to 6 = "Helped me drive safely" scale.

The initial results described above indicate that safety does not necessarily degrade with the use of ATIS systems such as TravTek, particularly in comparison to other existing means of navigation. Additional analyses aimed at assessing the safety benefits of TravTek will be forthcoming as the analysis and reporting process continues.

Displaying Information in a Vehicle

General

A question in the TravTek post-experiment questionnaire assessed the general usability of the TravTek visual displays. The mean question responses are shown in figure 21. As shown, subjects rated the usability of the TravTek visual displays quite positively.

Route Guidance

Two of the primary issues addressed by the TravTek evaluation were the performance and preference of subjects using the various display configurations. As was discussed in the usability section above (see figures 18, 19, and 20), navigation performance didn't vary much among the TravTek configurations, with the exception of turn errors committed while using the route map without voice.

Subjects' perceptions regarding the value and usability of the maps and screens, as measured by questionnaire responses, are shown for the route map in figure 22, and for the guidance screen in figure 23. As shown in the figures, both maps were highly rated by the subjects. In fact, very few differences between comparable questions were found. A more informative finding with respect to the relative value of the route guidance screens is depicted in figure 24. This figure represents an objective and unobtrusive assessment (through data telemetry from the vehicles) of what the drivers actually used for the Navigator and Navigator Plus conditions.

Visiting drivers chose to use the guidance screen more than 85 percent of the time that TravTek was activated. Local drivers chose to use the guidance screen more than 70 percent of the time. Although the initial route guidance system default state was the guidance screen, the drivers had the capability to "swap maps" at the press of a steering wheel button at any time. It is clear from these results that the majority of drivers preferred the turn-by-turn guidance screen over the full-route moving map. However, it is also clear that some drivers in some circumstances found the route map more useful. In addition, there are a number of cases, including when the driver is off-route for either a planned or unplanned reason, for which a moving map may be the only way to effectively display required information. Therefore, the TravTek strategy of allowing the driver to access both types of maps appears to have been the most effective choice. This interpretation is supported by the questionnaire responses evaluating the "swap map" feature on the steering wheel (figure 25). As shown, the swap map feature was rated highly in general and as an aid to way finding in particular.

Overall, how would you rate the TravTek system's *Visual Displays* (e.g., TravTek Maps, TravTek Menus, TravTek Screen Instructions):

	Did Not Use	I Could Easily Read the Text						I Could Understand the Information						I Liked the Screen Colors					
		Strongly Disagree			Strongly Agree			Strongly Disagree			Strongly Agree			Strongly Disagree			Strongly Agree		
Primary Driver	0	1	2	3	4	5	6	1	2	3	4	5	6	1	2	3	4	5	6
Secondary Driver	0	1	2	3	4	5	6	1	2	3	4	5	6	1	2	3	4	5	6

	The Screen was Distracting at Night						Functioned Properly					
	Strongly Disagree			Strongly Agree			None of the Time			All of the Time		
Primary Driver	1	2	3	4	5	6	1	2	3	4	5	6
Secondary Driver	1	2	3	4	5	6	1	2	3	4	5	6

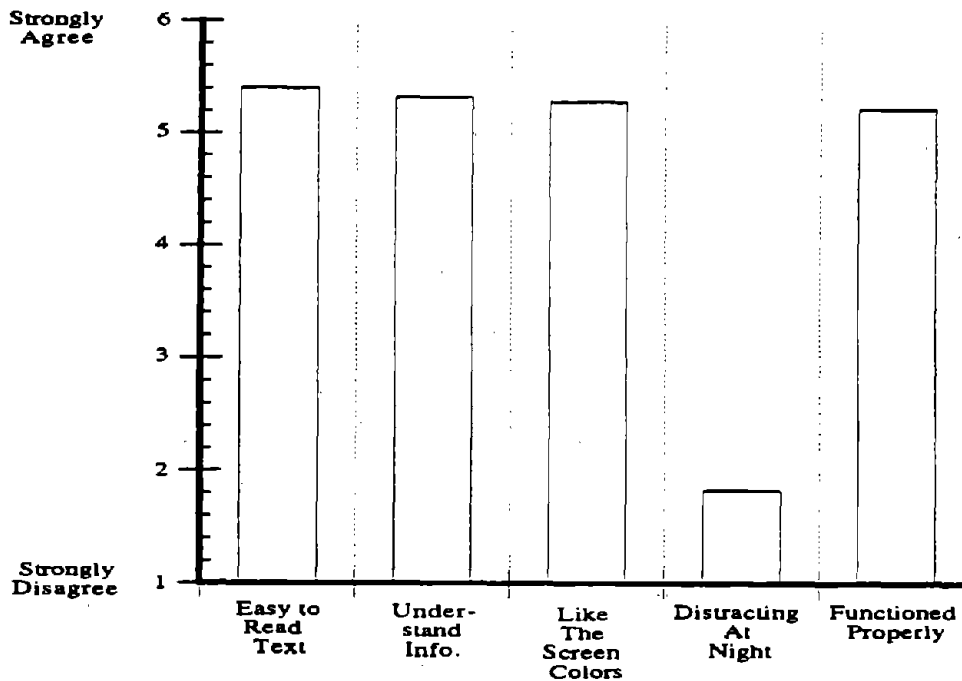
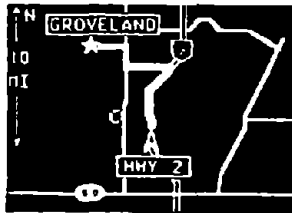


Figure 21. Questionnaire ratings of the usability of the TravTek visual displays.



The TravTek system's Route Map:

	Did Not Use	Was Easy to Learn		Was Easy to Use		Showed Sufficient Detail		Helped Me Find My Way	
		Strongly Disagree	Strongly Agree	Strongly Disagree	Strongly Agree	Strongly Disagree	Strongly Agree	Strongly Disagree	Strongly Agree
Primary Driver	0	1 2 3 4 5 6		1 2 3 4 5 6		1 2 3 4 5 6		1 2 3 4 5 6	
Secondary Driver	0	1 2 3 4 5 6		1 2 3 4 5 6		1 2 3 4 5 6		1 2 3 4 5 6	
		Helped Me Pay More Attention To My Driving		Interfered With My Driving		Functioned Properly			
		Strongly Disagree	Strongly Agree	Strongly Disagree	Strongly Agree	None of the Time	All of the Time		
Primary Driver		1 2 3 4 5 6		1 2 3 4 5 6		1 2 3 4 5 6			
Secondary Driver		1 2 3 4 5 6		1 2 3 4 5 6		1 2 3 4 5 6			

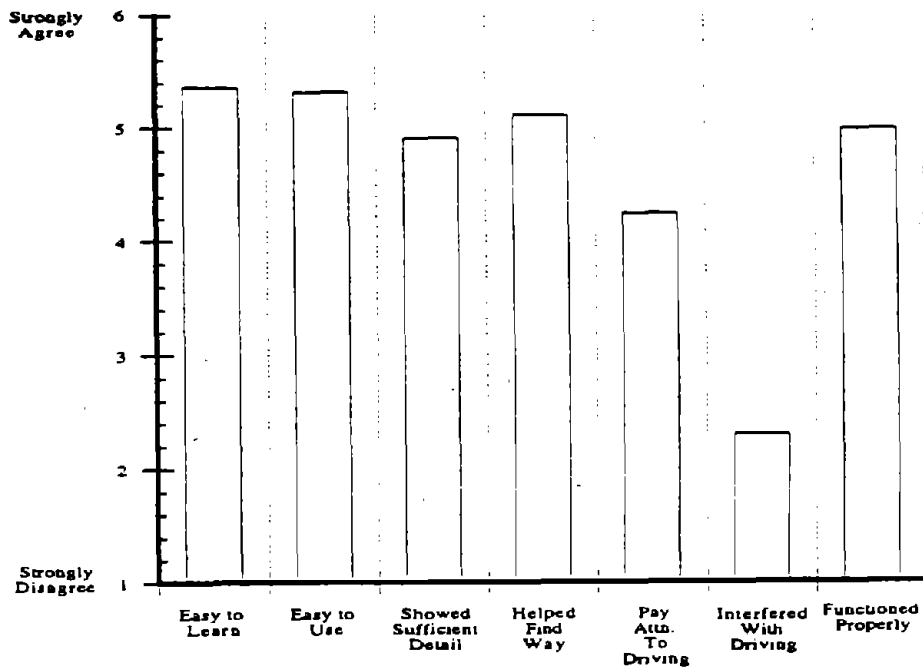
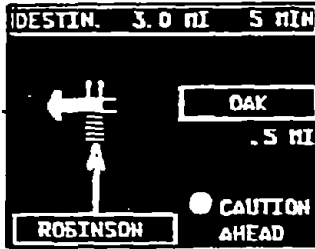


Figure 22. Questionnaire ratings of the usability of the TravTek route map.



The TravTek system's Guidance Display:

	Did Not Use	Was Easy to Learn		Was Easy to Use		Helped Me Find My Way		Helped Me Pay More Attention To My Driving	
		Strongly Disagree	Strongly Agree	Strongly Disagree	Strongly Agree	Strongly Disagree	Strongly Agree	Strongly Disagree	Strongly Agree
Primary Driver	0	1 2 3 4 5 6		1 2 3 4 5 6		1 2 3 4 5 6		1 2 3 4 5 6	
Secondary Driver	0	1 2 3 4 5 6		1 2 3 4 5 6		1 2 3 4 5 6		1 2 3 4 5 6	
		Interfered With My Driving		Provided Timely Information		Functioned Properly			
		Strongly Disagree	Strongly Agree	Strongly Disagree	Strongly Agree	None of the Time	All of the Time		
Primary Driver		1 2 3 4 5 6		1 2 3 4 5 6		1 2 3 4 5 6			
Secondary Driver		1 2 3 4 5 6		1 2 3 4 5 6		1 2 3 4 5 6			

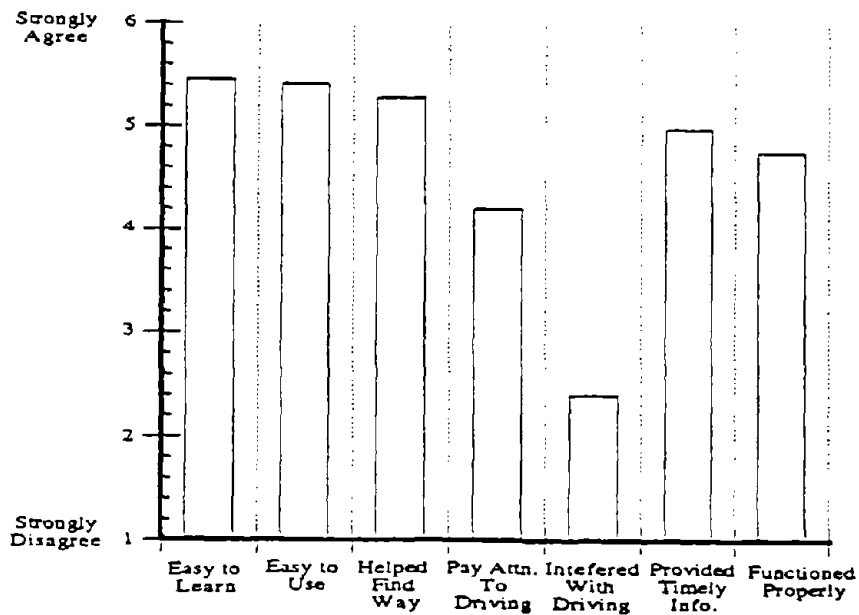


Figure 23. Questionnaire ratings of the usability of the TravTek guidance display.

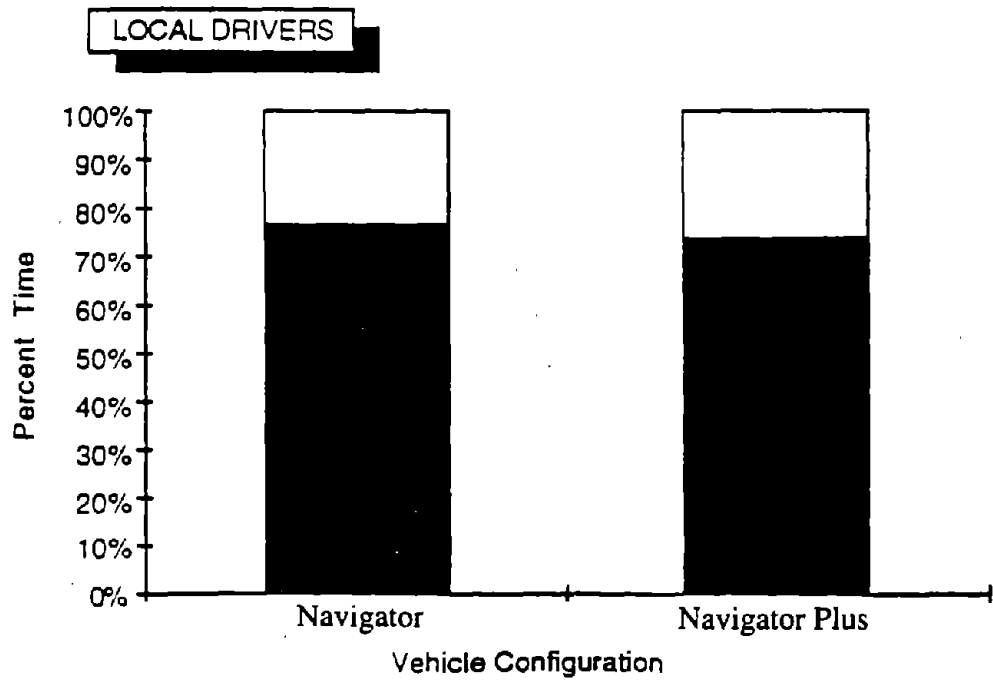
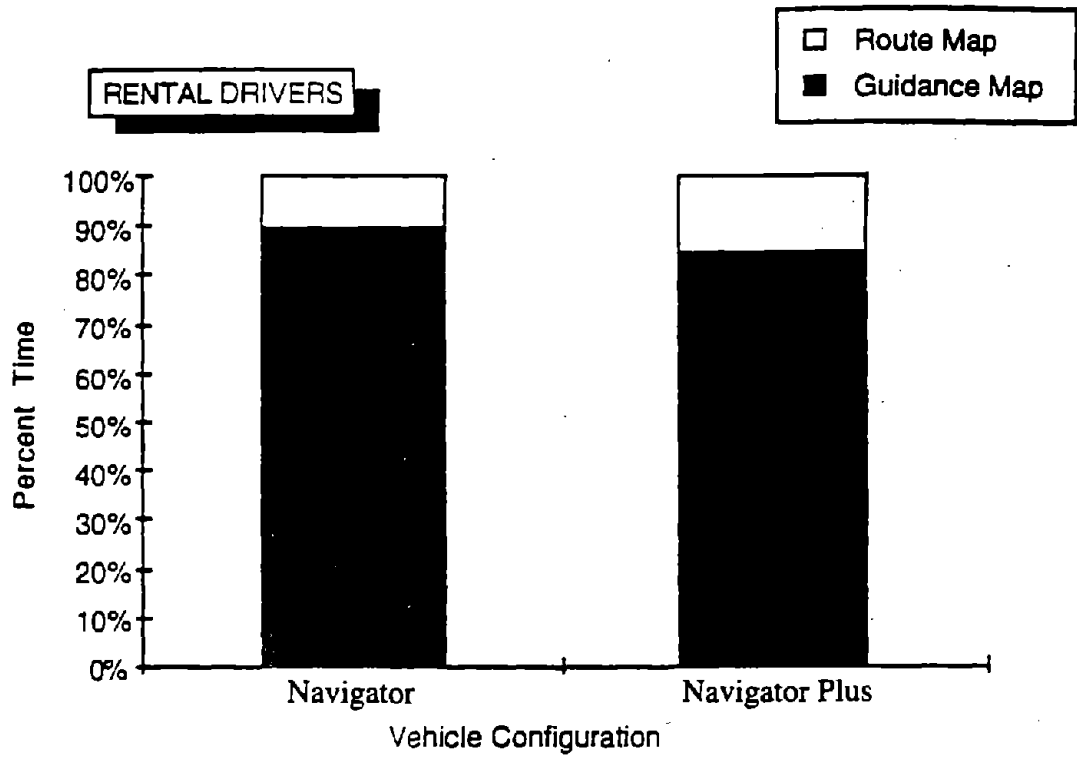
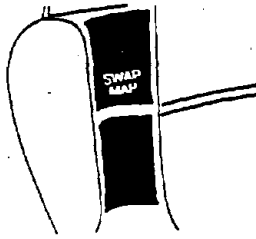


Figure 24. Relative use of TravTek visual route guidance displays (from Fleischman, Thelen, and Denard, in press).



The TravTek system's "Swap Map" Feature (located on steering wheel):

	Did Not Use	Was Easy to Learn					Was Easy to Use					Helped Me Find My Way											
		Strongly Disagree	1	2	3	4	5	6	Strongly Disagree	1	2	3	4	5	6	Strongly Disagree	1	2	3	4	5	6	
Primary Driver	0	1	2	3	4	5	6	1	2	3	4	5	6	1	2	3	4	5	6				
Secondary Driver	0	1	2	3	4	5	6	1	2	3	4	5	6	1	2	3	4	5	6				
		Helped Me Pay More Attention To My Driving					Interfered With My Driving					Functioned Properly											
		Strongly Disagree	1	2	3	4	5	6	Strongly Disagree	1	2	3	4	5	6	None of the Time	1	2	3	4	5	6	All of the Time
Primary Driver		1	2	3	4	5	6	1	2	3	4	5	6	1	2	3	4	5	6				
Secondary Driver		1	2	3	4	5	6	1	2	3	4	5	6	1	2	3	4	5	6				

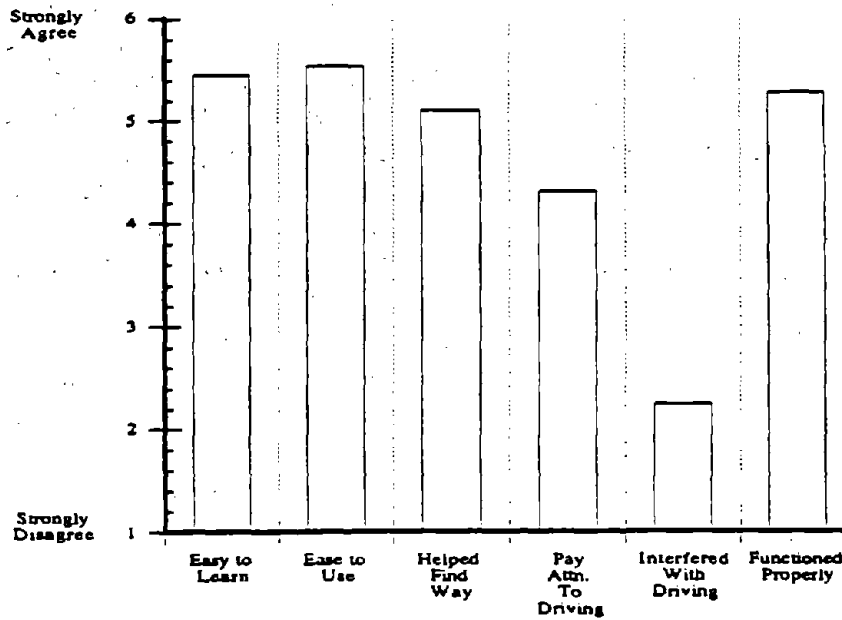


Figure 25. Questionnaire rating of the "swap map" feature.

The use of voice to provide route guidance information turned out to be quite successful in the TravTek system. As previously shown in figures 18, 19, and 20, the addition of the voice generally provided improved navigation performance. Another informative result regarding voice is shown in figure 26. Rental drivers chose to have the voice activated while using TravTek more than 90 percent of the time. Note that drivers could deactivate the voice at any time by pressing a steering wheel button. Figure 27 shows that the local users used the voice more than 65 percent of the time. One lesson learned from this result is that voice is perceived as being valuable, particularly by drivers who are unfamiliar with an area. Perhaps a more surprising finding is that the local users continued to use the voice at a fairly high rate. Note that the local users drove TravTek cars daily for 2 months. Therefore, apparently voice is still considered to have value to users who are both familiar with the area *and* familiar with the vehicle and system.

A global rating of the TravTek voice intelligibility is shown in figure 28. Although the voice clarity, message understandability, and function were rated positively by subjects, these ratings are not as high as many of the other ratings. The "lesson learned" from this finding may be that the state-of-the-art in low-cost synthesized speech still leaves something to be desired. However, as previously described, the TravTek voice messages would have to be highly modified and would contain less information in order to use digitized speech, so the digitized vs. synthesized trade-off is still somewhat in question. Note, however, that the TravTek voice design and implementation was successful as indicated by these results and that technological advances will continue to improve the quality of synthesized speech at an ever-lowering cost.

Figure 29 summarizes the preferences for the various TravTek display options. As shown, preferences for the route map and guidance screen were almost identical. Note that consistent with the voice data described in the preceding paragraph, voice was preferred *in conjunction with* either visual display. This is in contrast to the rating of voice alone, which was still positively rated, but not as highly. Figure 29 provides a good summary of the "lessons learned" for route guidance. Drivers prefer to have the option in type of visual display as well as a voice feature. Another route guidance feature provided by the TravTek system was to offer a faster route if one became available while in transit due to changing traffic conditions. An item, If the TravTek system offered you new routes due to traffic conditions, how often did you accept the new routes?, was included in the post-experiment questionnaire to assess driver willingness to change routes to save time. The response to this item was 4.3 on a 1 = "None of the time" to 6 = "All of the time" scale. This result indicates that many drivers are willing to change routes to save time while en route.

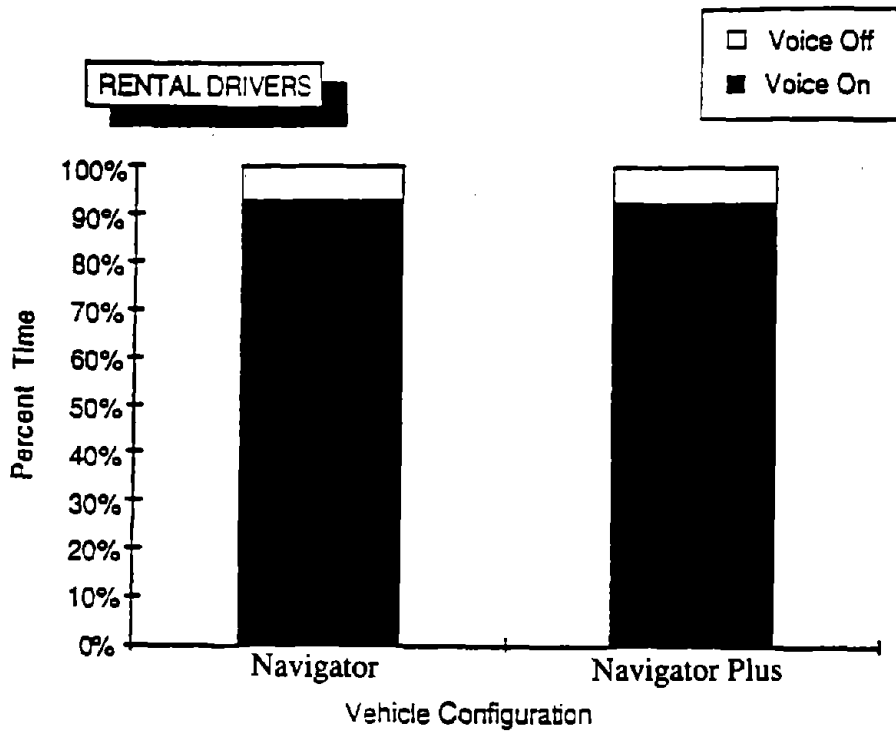


Figure 26. Use of the voice feature by rental drivers (from Fleischman, Thelen, and Denard, in press).

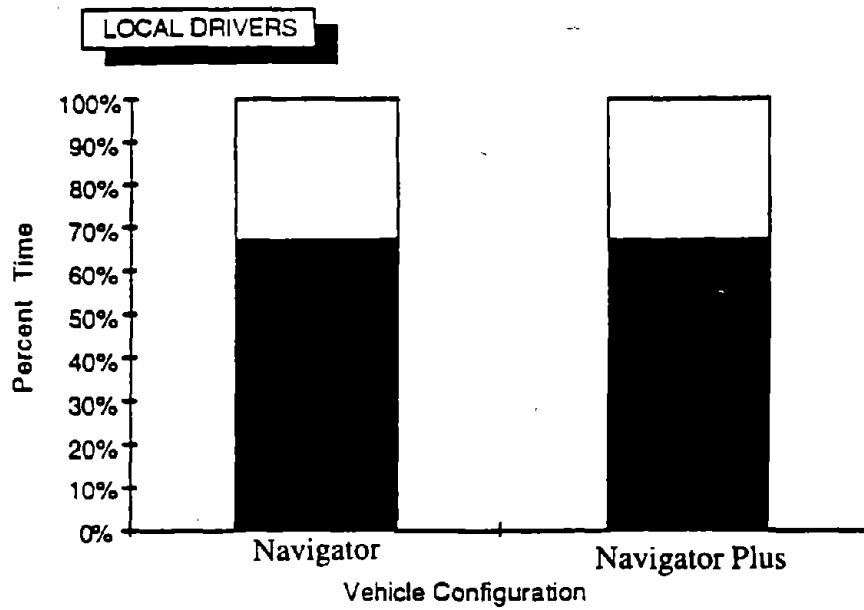


Figure 27. Use of the voice feature by local drivers (from Fleischman, Thelen, and Denard, in press).

How would you rate the TravTek system's *Voice Presentation* (e.g., *Voice Guide, Where Am I, Traffic Report, and Repeat Voice*)?

	Voice Tone was Clear						Message was Understandable						Functioned Properly					
	Strongly Disagree			Strongly Agree			Strongly Disagree			Strongly Agree			None of the Time			All of the Time		
Primary Driver	1	2	3	4	5	6	1	2	3	4	5	6	1	2	3	4	5	6
Secondary Driver	1	2	3	4	5	6	1	2	3	4	5	6	1	2	3	4	5	6

Comments: _____

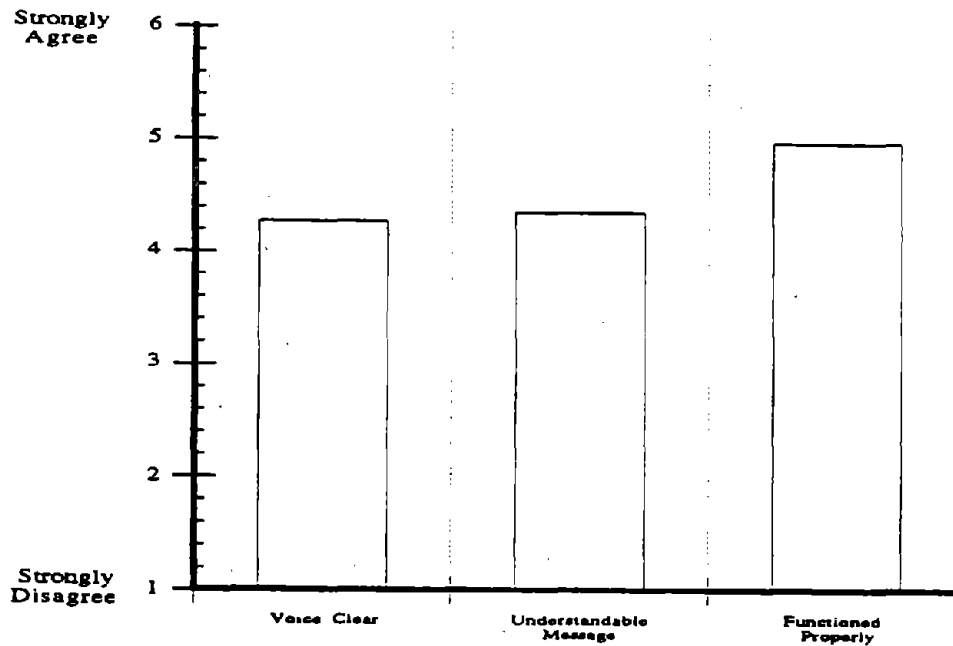


Figure 28. Questionnaire rating of the TravTek voice presentation.

How well did you like the following TravTek modes of operation?

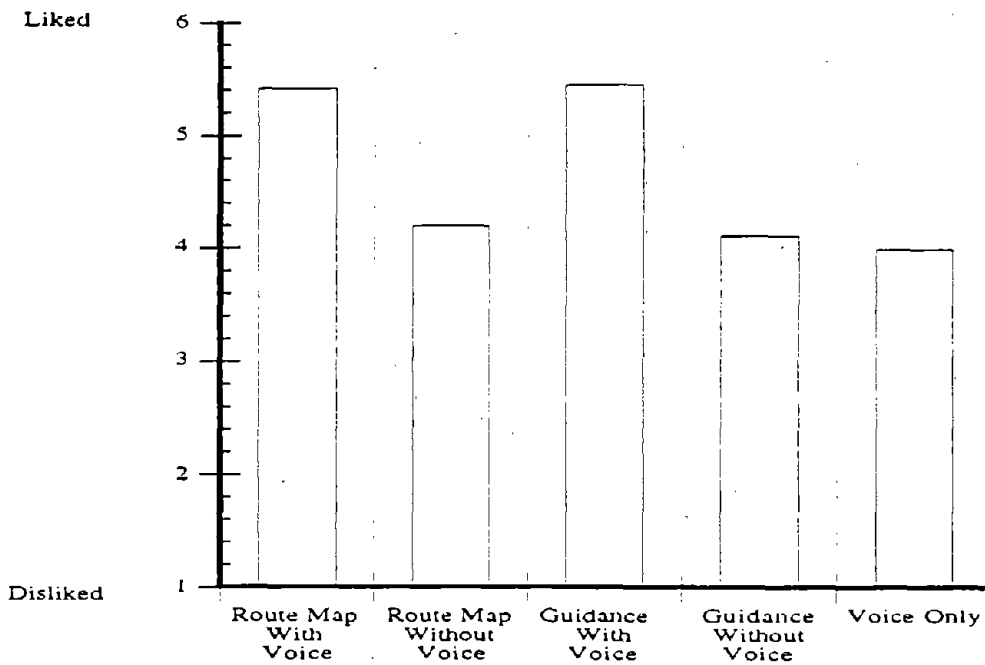
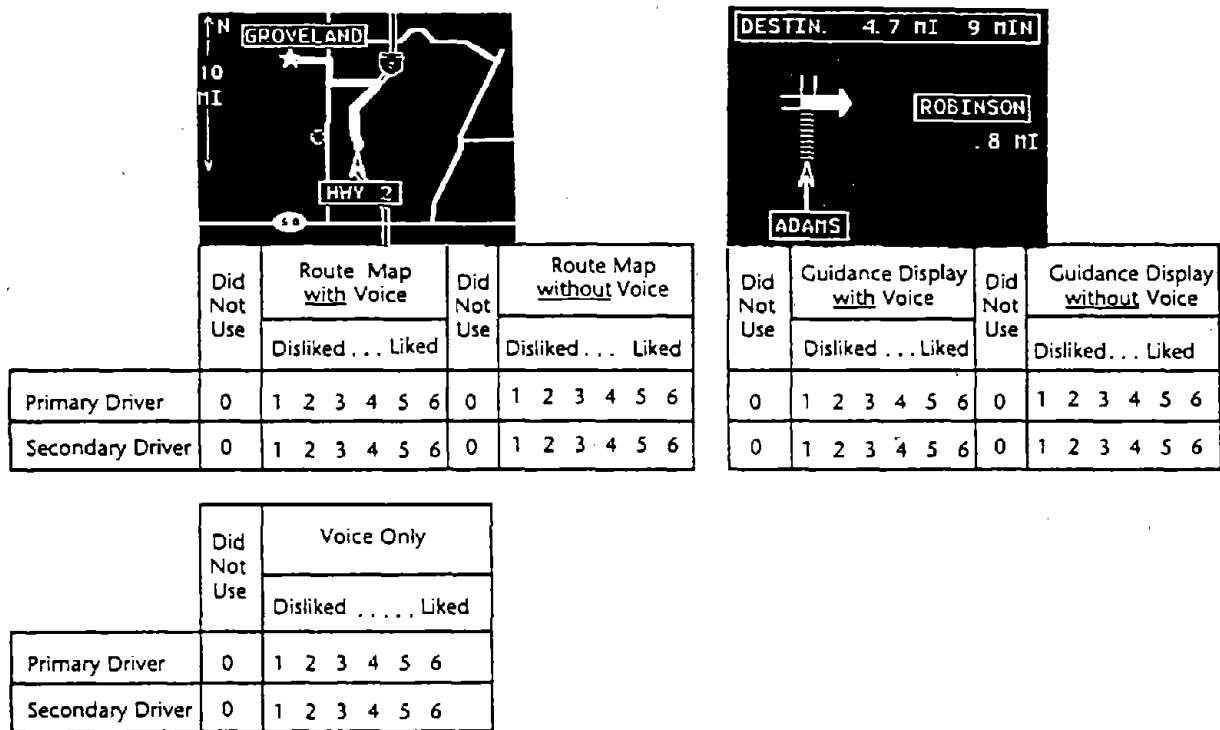


Figure 29. Questionnaire comparison of the TravTek route guidance modes.

Navigation Assistance

The TravTek system allowed access to a moving map even when a destination was not entered. This screen, called an "information map," allowed the driver to get proximal orientation and navigation information, as well as traffic congestion and incident information, without entering a destination. The perceived usability of this screen was addressed with an item in the post-experiment questionnaire. The subjects' responses to this item are shown in figure 30. As with the other visual display responses, subjects' opinions of this display were positive. The "lesson learned" from this finding is that providing drivers who are perhaps somewhat familiar with an area and their destination with supplemental orientation and traffic information is viewed as a positive feature.

Services Information

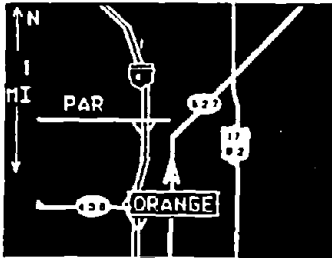
The services provided by the TravTek system are described in detail in the System Description section. In addition to the features associated with route guidance and navigation, such as entering a destination, the major services consisted of a services and attractions menu (including a "yellow pages" database of selected Orlando businesses), emergency services, and on-line system tutorial.

The subjects' ratings of the services and attractions directory are shown in figure 31. As shown, the features of the directory were rated positively by the TravTek users. There are similar results for the emergency services feature shown in figure 32. Although these ratings are quite positive, questions regarding the timeliness of the emergency services response were rated somewhat lower. These data may provide insight on features and aspects that have the most room for improvement in future ATIS systems.

The perceived effectiveness of the on-screen instructions is shown in figure 33. As with the other services features, this instruction technique was rated positively by the subjects.

Cautions and Warnings of Hazards

The TravTek system provided warnings about congestion or an incident ahead on either visual route guidance display configuration. Figure 34 shows the questionnaire responses to the display of this information on a route map. As shown, several of the items received essentially neutral responses—some of the lowest ratings received by the system. Of particular interest are the categories "Provided Believable Information" and "Provided Timely Information." A number of subjects apparently questioned the reliability and timeliness of the traffic information provided by the TMC. In future production systems, it is apparent that such information will have to be accurate in order to optimize driver acceptance and route-changing behavior.



The TravTek system's technique of displaying a Local Map for Driving Without a Pre-Selected Destination:

	Did Not Use	Was Easy to Learn		Was Easy to Use		Was Useful		Helped Me Find My Way	
		Strongly Disagree	Strongly Agree	Strongly Disagree	Strongly Agree	Strongly Disagree	Strongly Agree	Strongly Disagree	Strongly Agree
Primary Driver	0	1 2 3 4 5 6	1 2 3 4 5 6	1 2 3 4 5 6	1 2 3 4 5 6	1 2 3 4 5 6	1 2 3 4 5 6	1 2 3 4 5 6	1 2 3 4 5 6
Secondary Driver	0	1 2 3 4 5 6	1 2 3 4 5 6	1 2 3 4 5 6	1 2 3 4 5 6	1 2 3 4 5 6	1 2 3 4 5 6	1 2 3 4 5 6	1 2 3 4 5 6
		Helped Me Pay More Attention to My Driving		Interfered with My Driving		Functioned Properly			
		Strongly Disagree	Strongly Agree	Strongly Disagree	Strongly Agree	None of the Time	All of the Time		
Primary Driver		1 2 3 4 5 6	1 2 3 4 5 6	1 2 3 4 5 6	1 2 3 4 5 6	1 2 3 4 5 6	1 2 3 4 5 6		
Secondary Driver		1 2 3 4 5 6	1 2 3 4 5 6	1 2 3 4 5 6	1 2 3 4 5 6	1 2 3 4 5 6	1 2 3 4 5 6		

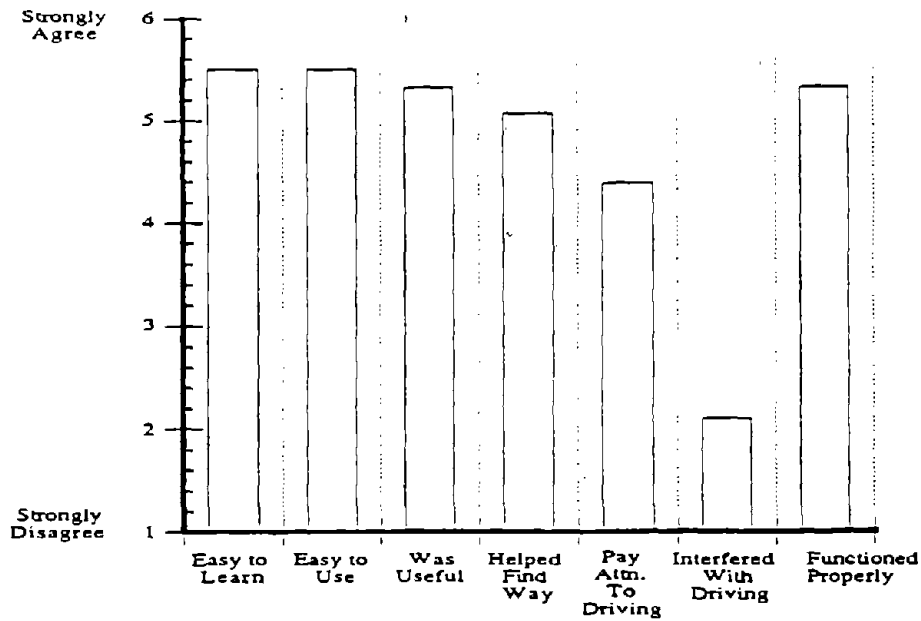


Figure 30. Questionnaire rating of the TravTek information map.

HELP SERVICES/ ATTRACTIONS **PAGE BACK**
 WHERE TO STAY **MAIN**
 THINGS TO SEE & DO **MENU**
 WHERE TO EAT
 OTHER SERVICES
 CITY FACTS

↓
DONE

The TravTek system's *Services/Attractions Directory*:

	Did Not Use	Was Easy to Use					Helped Me Plan My Trip					Was Useful							
		Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree			
Primary Driver	0	1	2	3	4	5	6	1	2	3	4	5	6	1	2	3	4	5	6
Secondary Driver	0	1	2	3	4	5	6	1	2	3	4	5	6	1	2	3	4	5	6
		Contained Orlando Destinations I needed					Contained Destinations in Expected Categories					Functioned Properly							
		Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree	None of the Time	Some of the Time	Most of the Time	All of the Time				
Primary Driver		1	2	3	4	5	6	1	2	3	4	5	6	1	2	3	4	5	6
Secondary Driver		1	2	3	4	5	6	1	2	3	4	5	6	1	2	3	4	5	6

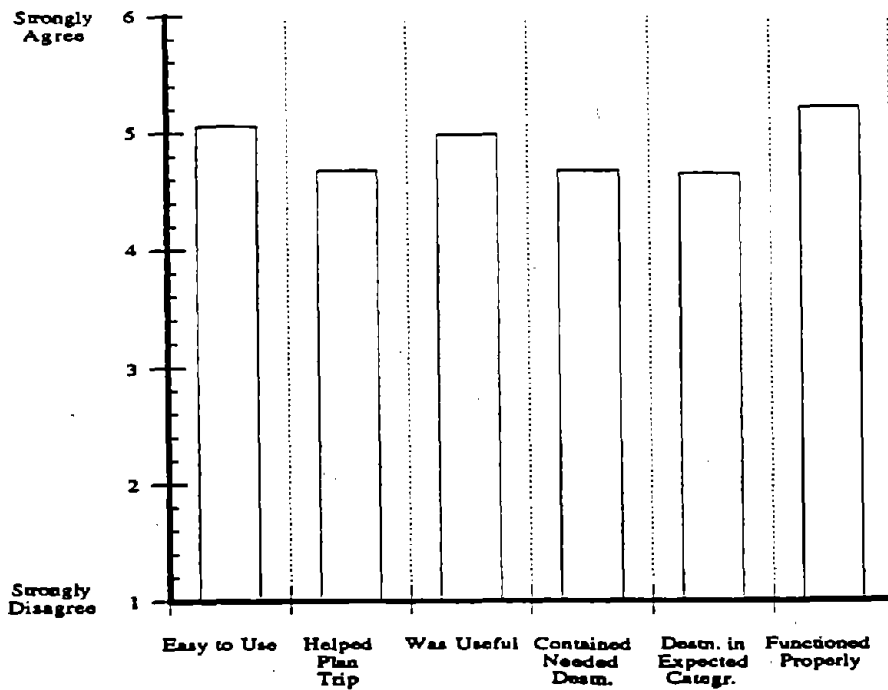


Figure 31. Questionnaire rating of the TravTek services/attractions directory.

SELECT TYPE OF EMERGENCY HELP	PAGE BACK
<input type="checkbox"/> POLICE/FIRE/MEDICAL	
<input type="checkbox"/> ROAD SERVICE	
<input type="checkbox"/> CANCEL EMERGENCY	

The TravTek system's *Emergency Services Feature*:

	Did Not Use	Was Easy to Learn					Was Easy to Use					Was Useful					Offered Timely Assistance					Functioned Properly															
		Strongly Disagree	1	2	3	4	5	6	Strongly Disagree	1	2	3	4	5	6	Strongly Disagree	1	2	3	4	5	6	Strongly Disagree	1	2	3	4	5	6	None of the Time	1	2	3	4	5	6	All of the Time
Primary Driver	0	1	2	3	4	5	6	1	2	3	4	5	6	1	2	3	4	5	6	1	2	3	4	5	6	1	2	3	4	5	6	1	2	3	4	5	6
Secondary Driver	0	1	2	3	4	5	6	1	2	3	4	5	6	1	2	3	4	5	6	1	2	3	4	5	6	1	2	3	4	5	6	1	2	3	4	5	6

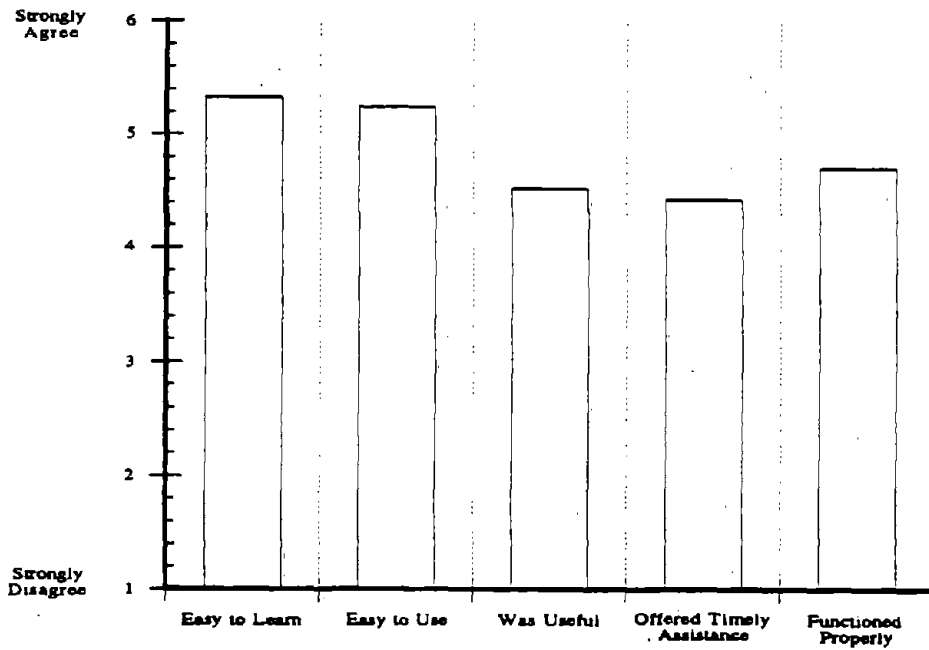


Figure 32. Questionnaire rating of the TravTek emergency services feature.

SCREEN INSTRUCTIONS
 SELECT YOUR CHOICE BY
 TOUCHING THE KEY NEXT
 TO IT. IF A "NEXT
 PAGE" OR "PREV PAGE"
 KEY IS SHOWN, USE IT
 TO SEE MORE CHOICES.

NEXT **QUIT**

The TravTek system's On-Screen Instructions:

	Did Not Use	Were Easy to Learn					Were Easy to Use					Were Useful					Functioned Properly										
		Strongly Disagree	1	2	3	4	5	6	Strongly Disagree	1	2	3	4	5	6	None of the Time	1	2	3	4	5	6	None of the Time	1	2	3	4
Primary Driver	0	1	2	3	4	5	6	1	2	3	4	5	6	1	2	3	4	5	6	1	2	3	4	5	6		
Secondary Driver	0	1	2	3	4	5	6	1	2	3	4	5	6	1	2	3	4	5	6	1	2	3	4	5	6		

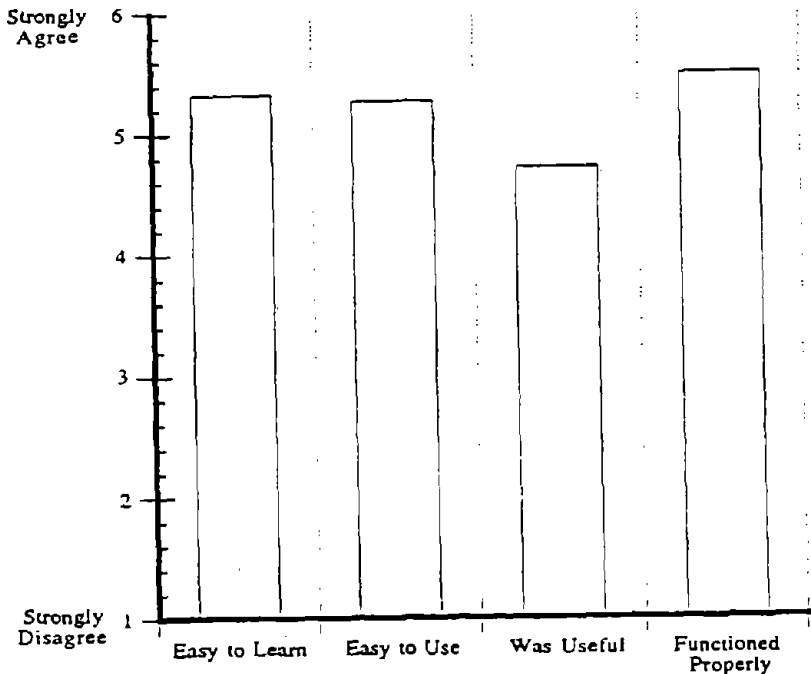


Figure 33. Questionnaire rating of the TravTek on-screen instructions.

In contrast to the somewhat lower ratings of traffic and incident information provided on the route map, the traffic information provided on the guidance screen was highly rated (figure 35). Note that the information provided for the route map and the guidance screen came from the same source—the TMC. Therefore, the reliability of the information was not different. The higher rating for the guidance screen may have occurred since less information was presented that could be evaluated by the subjects.

Entering Information

Pre-Drive Information

Pre-drive information was entered via the touchscreen menu system. A questionnaire rating of the usability of the TravTek main menu is shown in figure 36. As shown, the menu was rated quite positively by users. A touchscreen keypad (figure 37) was utilized to create a saved destination list and to input destinations by street, intersection, or complete address. As shown in the figure, this keypad had multiple letters per soft key, and required two button presses for each letter. This design was necessitated by the constraints of the existing 25-key keypad arrangement. As shown in the figure, ease of use was rated somewhat lower (although still positively) in comparison to many of the TravTek functions and features. Although this arrangement was usable, clearly a single-letter-per-key keypad would be even more so.

In-Transit Information

While in-transit, only the steering wheel buttons were accessible to the driver. The questionnaire rating of the usability of these controls appears as figure 38. As shown, the steering wheel buttons were rated higher than most other functions and features, and quite highly overall. Previous research has shown the value of steering wheel buttons for ease of use and relatively low attention demand. It is apparent that these results generalize to ATIS applications.

Communication Between Drivers and the TravTek Help Desk

Drivers had the capability to communicate with the TravTek help desk via the cellular phone if they had any problems or questions about the system. This could be directly accessed via the "help" menu (figure 39). As shown, the overall help feature was positively rated, although the usefulness was rated somewhat lower. However, the help desk feature by itself (figure 40) had ratings that were uniformly very high. The lesson learned in this case is that for a complex ATIS system, a variety of help features in general and communications with a help desk in particular are valuable features.

Findings From the TravTek Design Methodology

The TravTek design process was an iterative blend of design and testing that is depicted in figure 41 (Fleischman et al., 1991). The process itself provides lessons learned about the design of an ATIS system. Some of these lessons are summarized below:

The use of a team of human factors and systems engineering experts throughout the design process facilitates design. The TravTek interface was quite complex, and often required that design be constrained by driver, vehicle, and cost factors. As such, there were many design changes and iterations that required close scrutiny. Each member of the team (three human factors experts on a part-time, but ongoing basis; a linguistics expert; and two systems engineers) made significant contributions throughout this process.

The use of "standard" human factors design techniques was critical. These included task analysis, function allocation, and somewhat informal trade-study analyses.

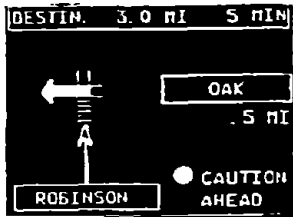
Laboratory usability testing early in the system design process that used rapid prototyping and testing in a dual-task environment was helpful. Design decisions generated or supported by this process included conservative use of "moving maps" (i.e., only when necessary, as a secondary choice to turn-by-turn guidance screens, and in conjunction with voice guidance).

Testing of labeling and nomenclature used in the system proved to be very valuable. TravTek was essentially a computer interface for the computer illiterate. Effective nomenclature proved to be somewhat critical for navigation within the menu system and for understanding of the functions. It is very difficult for even an experienced human factors designer to anticipate or analyze the optimum use of labeling and nomenclature.

Users, in general, can adapt behavior in a driving dual-task environment and drive safely. This is not to say that a driver has unlimited resources to effectively use a poorly designed system; however, drivers seem to be able to utilize ATIS systems such as TravTek at least as effectively and safely as existing means (e.g., paper maps) for performing the same functions.

Despite the above statement, there is insufficient driving research available to accurately predict and model driving performance using an ATIS system without significant user interface testing. Thus, conservative loading of the driver is still warranted. Conservative features of the TravTek system that led to system success included: no access to touchscreen functions while the vehicle was in motion, the use of a guidance screen instead of a moving map as the primary guidance display, and the supplementary use of voice in conjunction with the visual display.

Even with the most carefully designed interface, some opportunity for orientation and training is necessary and very useful. For TravTek, a video and demonstration procedure was utilized that took approximately 30 minutes.



The TravTek system's technique of displaying Updated Traffic Messages on the Guidance Display:

	Did Not Use	Was Easy to Learn		Was Easy to Use		Was Useful		Helped Me Find My Way	
		Strongly Disagree	Strongly Agree	Strongly Disagree	Strongly Agree	Strongly Disagree	Strongly Agree	Strongly Disagree	Strongly Agree
Primary Driver	0	1 2 3 4 5 6		1 2 3 4 5 6		1 2 3 4 5 6		1 2 3 4 5 6	
Secondary Driver	0	1 2 3 4 5 6		1 2 3 4 5 6		1 2 3 4 5 6		1 2 3 4 5 6	
		Helped Me Pay More Attention to My Driving		Interfered with My Driving		Functioned Properly			
		Strongly Disagree	Strongly Agree	Strongly Disagree	Strongly Agree	None of the Time	All of the Time		
Primary Driver		1 2 3 4 5 6		1 2 3 4 5 6		1 2 3 4 5 6		1 2 3 4 5 6	
Secondary Driver		1 2 3 4 5 6		1 2 3 4 5 6		1 2 3 4 5 6		1 2 3 4 5 6	

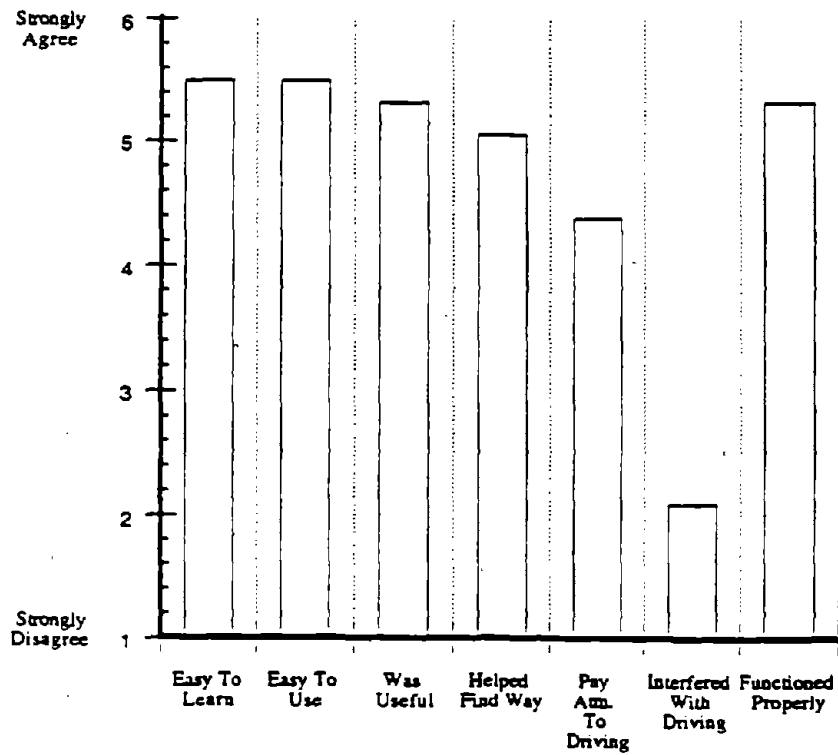


Figure 35. Questionnaire rating of the guidance screen traffic condition/incidence information.

HELP MAIN MENU PAGE BACK
 ENTER DESTINATION
 SERVICES/ATTRACT.
 MAP OF LOCAL AREA
 EMERGENCY
 INSTRUCTIONS
 CORRECT LOCATION
 ↓
 DONE

The TravTek system's Main Menu:

	Did Not Use	Was Easy to Learn					Was Easy to Use					Functioned Properly													
		Strongly Disagree	1	2	3	4	5	6	Strongly Disagree	1	2	3	4	5	6	None of the Time	1	2	3	4	5	6	All of the Time		
Primary Driver	0	1	2	3	4	5	6	1	2	3	4	5	6	1	2	3	4	5	6	1	2	3	4	5	6
Secondary Driver	0	1	2	3	4	5	6	1	2	3	4	5	6	1	2	3	4	5	6	1	2	3	4	5	6

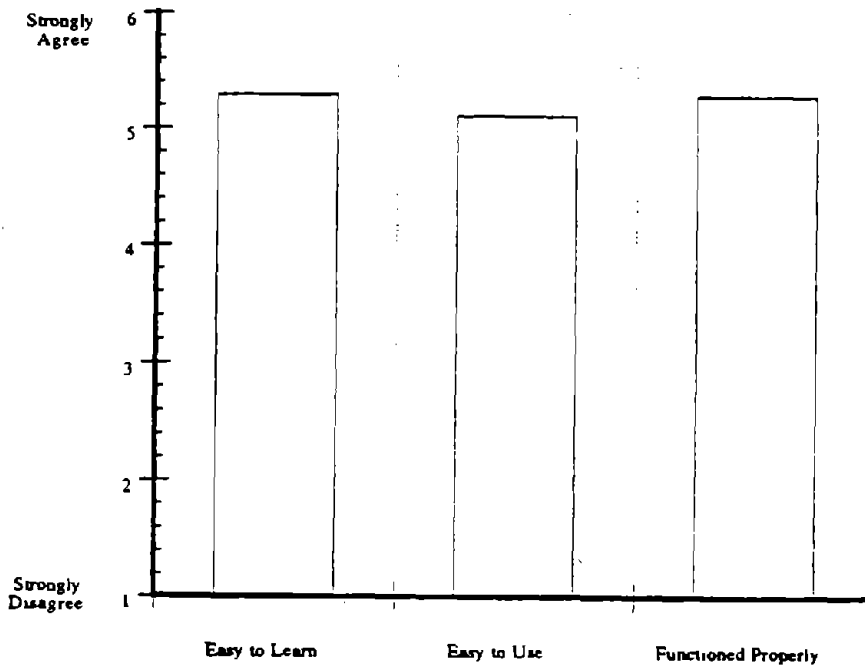


Figure 36. Questionnaire rating of the TravTek main menu.



The TravTek system's On-Screen Keyboard:

	Did Not Use	Was Easy to Learn		Was Easy to Use		Functioned Properly	
		Strongly Disagree	Strongly Agree	Strongly Disagree	Strongly Agree	None of the Time	All of the Time
Primary Driver	0	1 2 3 4 5 6		1 2 3 4 5 6		1 2 3 4 5 6	
Secondary Driver	0	1 2 3 4 5 6		1 2 3 4 5 6		1 2 3 4 5 6	

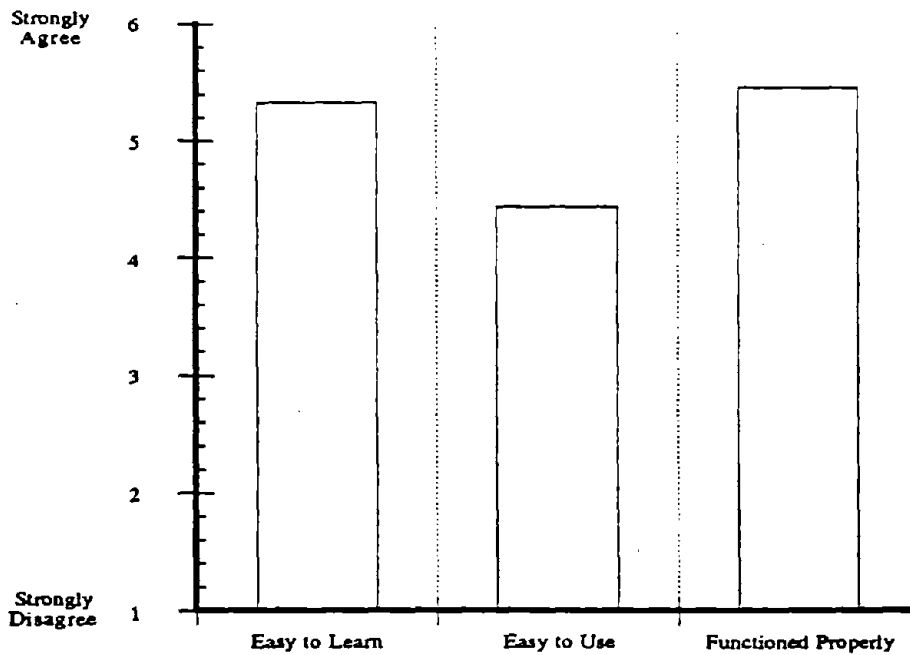


Figure 37. Questionnaire rating of the TravTek on-screen keyboard.

Overall, the steering wheel buttons:

	Were Easy to Use		Were Easy to Learn		Were Easy to Find		Were Useful																	
	Strongly Disagree	Strongly Agree	Strongly Disagree	Strongly Agree	Strongly Disagree	Strongly Agree	Strongly Disagree	Strongly Agree																
Primary Driver	1	2	3	4	5	6	1	2	3	4	5	6	1	2	3	4	5	6	1	2	3	4	5	6
Secondary Driver	1	2	3	4	5	6	1	2	3	4	5	6	1	2	3	4	5	6	1	2	3	4	5	6
	Helped Me Find My way		Helped Me Pay More Attention to My Driving		Interfered with My Driving		Functioned Properly																	
	Strongly Disagree	Strongly Agree	Strongly Disagree	Strongly Agree	Strongly Disagree	Strongly Agree	None of the Time	All of the Time																
Primary Driver	1	2	3	4	5	6	1	2	3	4	5	6	1	2	3	4	5	6	1	2	3	4	5	6
Secondary Driver	1	2	3	4	5	6	1	2	3	4	5	6	1	2	3	4	5	6	1	2	3	4	5	6

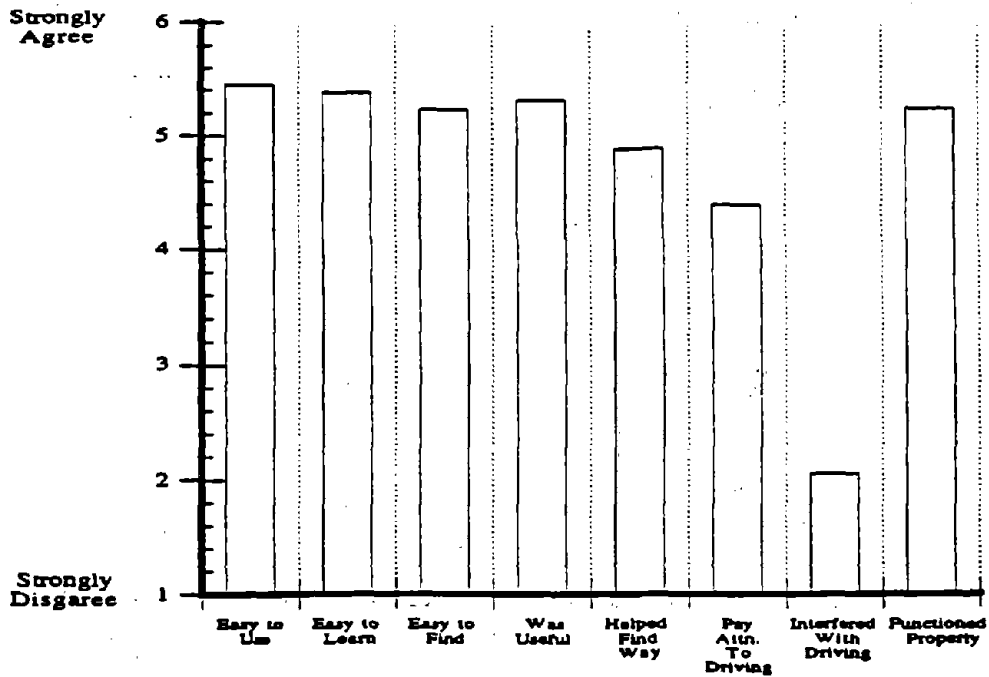


Figure 38. Questionnaire rating of the TravTek steering wheel buttons.

SELECT TYPE OF HELP
 SCREEN INSTRUCTIONS
 EMERGENCY HELP
 PHONE TO HELP DESK
 HANG UP THE PHONE

The TravTek system's Help Feature:

	Did Not Use	Was Easy to Learn		Was Easy to Use		Was Useful		Functioned Property	
		Strongly Disagree	Strongly Agree	Strongly Disagree	Strongly Agree	None of the Time	All of the Time	None of the Time	All of the Time
Primary Driver	0	1 2 3 4 5 6		1 2 3 4 5 6		1 2 3 4 5 6		1 2 3 4 5 6	
Secondary Driver	0	1 2 3 4 5 6		1 2 3 4 5 6		1 2 3 4 5 6		1 2 3 4 5 6	

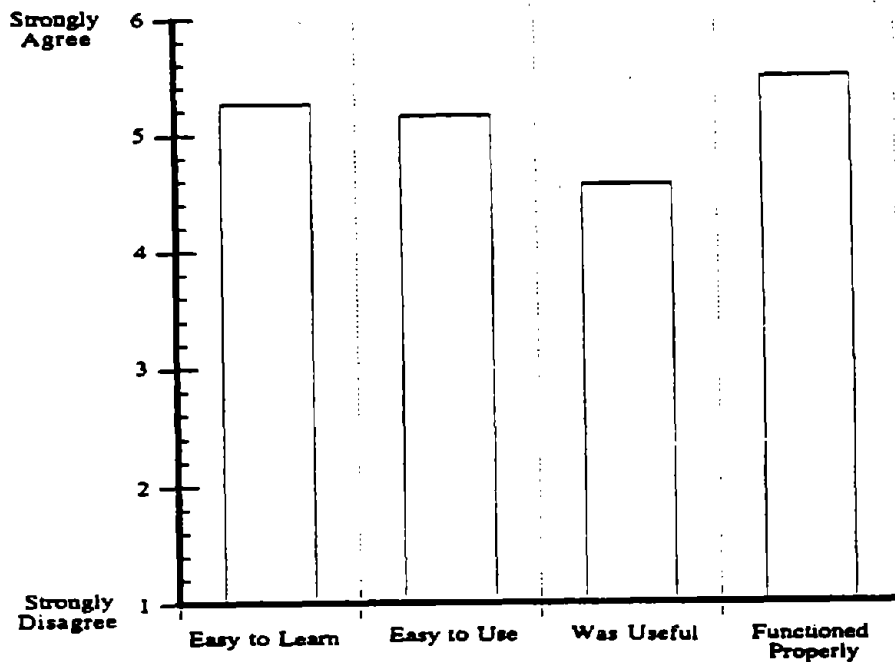


Figure 39. Questionnaire rating of the TravTek help features.



The TravTek system's Help Desk:

	Did Not Use	Was Available		Was Easy to Use		Was Useful		Correctly Answered Questions in a Timely Manner	
		Strongly Disagree	Strongly Agree	Strongly Disagree	Strongly Agree	Strongly Disagree	Strongly Agree	None of the Time	All of the Time
Primary Driver	0	1 2 3 4 5 6		1 2 3 4 5 6		1 2 3 4 5 6		1 2 3 4 5 6	
Secondary Driver	0	1 2 3 4 5 6		1 2 3 4 5 6		1 2 3 4 5 6		1 2 3 4 5 6	

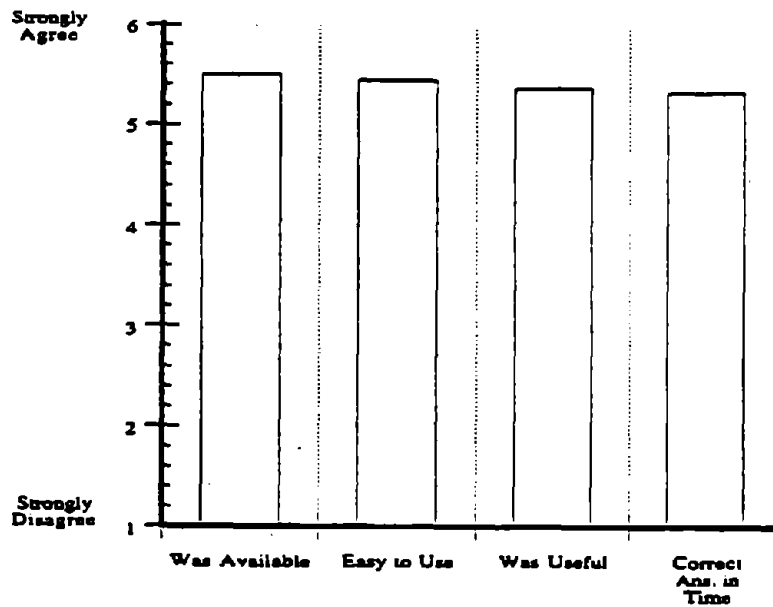


Figure 40. Questionnaire rating of the TravTek help desk.

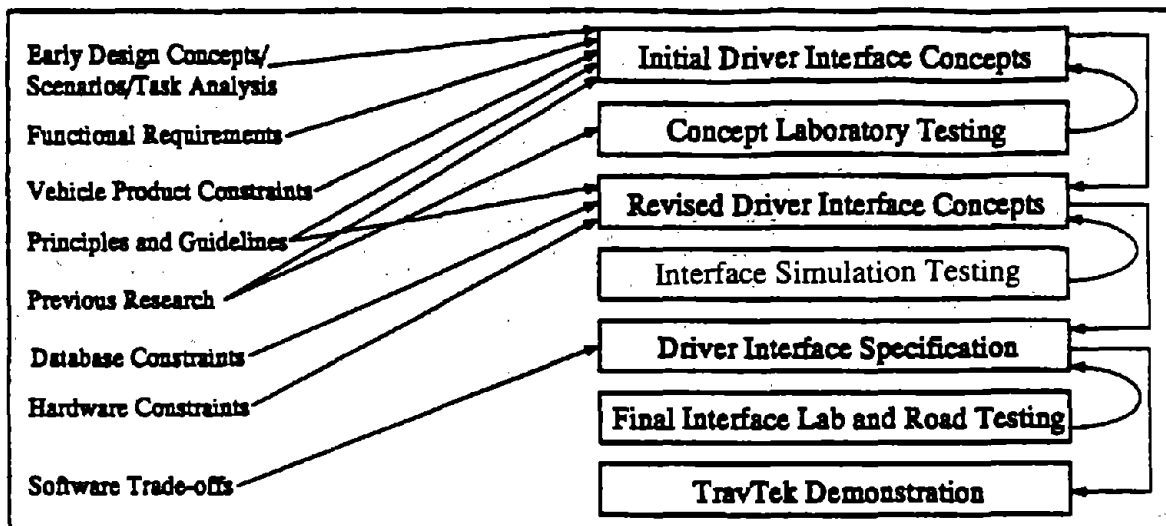


Figure 41. TravTek design process (from Fleischman et al., 1991).

LESSONS LEARNED

[TT 01] USER ACCEPTANCE OF TravTek SYSTEM WAS POSITIVE

- Overall, subjects found the TravTek interface and system to be a very positive experience.
- Given the amount of data collected, the comprehensiveness of the TravTek system analysis, and the positive outcome of the study, ATIS system designers should consider TravTek a model prototype design.

[TT 02] PAPER MAPS REQUIRED MORE TIME COMPARED TO THE TravTek SYSTEM

- Trip planning time and travel times were higher for the paper map condition compared to the TravTek conditions.
- ATIS systems seem to be more effective than relying on paper maps.

[TT 03] ROUTE MAP WITHOUT VOICE LED TO GREATER TURNING ERRORS

- More turning errors occurred for the route map condition without voice as compared to any other condition. In contrast, the route map with voice had the lowest turn-error rate. This is not a surprising result considering that the visual information load increases as drivers near turning maneuvers. Voice feedback provides continuous information while the driver's eyes are fixed on the roadway.

- ATIS systems should provide voice messages to supplement route map display information, especially during turning maneuvers.

[TT 04] *TravTek USE DID NOT LEAD TO INCREASED ACCIDENT RATES*

- Accident statistics associated with the TravTek evaluation program were quite positive. Even using the most conservative comparison groups (i.e., non-visitors, non-rental car users, national averages), a statistical difference in accident rates did not exist between the TravTek users and any comparison group (Perez and Van Aerde, personal communication, 1993).
- Even though the TravTek users drove more than 1.6 million km, accident rates require extremely large exposure to be reliable. Still, these results are encouraging with respect to the safety of ATIS systems.

[TT 05] *TravTek USE DID NOT LEAD TO AN INCREASE IN "NEAR MISSES"*

- Near misses were analyzed in the Camera Car Study and a surprising lack of near-miss data was found. No more near misses were found (in general) under the TravTek conditions than under the control conditions (paper map and paper directions list).
- These data support the safety of ATIS systems relative to the existing behavior of using paper maps and written directions while driving.

[TT 06] *TravTek USE DID NOT LOWER DRIVERS' PERCEPTIONS OF SAFETY*

- The questionnaire also asked a general safety question about the TravTek system—Do you think that TravTek helped you drive more safely in Orlando? The response to this question was a slightly positive 4.4 on a 1 = "Didn't help me drive safely" to 6 = "Helped me drive safely" scale.
- These data support the perceived safety of ATIS systems by drivers compared to their previous driving experiences.

[TT 07] *DISPLAY MODE DID NOT AFFECT NAVIGATION PERFORMANCE*

- Navigation performance did not vary among the TravTek configurations (with the exception of turn errors committed while using the route map without voice).

[TT 08] *BOTH ROUTE MAP AND GUIDANCE SCREEN WERE VALUED*

- Both types of maps were highly rated by the participants. In addition, objective data indicated that visiting drivers (i.e., rentals) chose to use the guidance screen more than 85 percent of the time that TravTek was activated. Local drivers chose to use the guidance screen more than 70 percent of the time. The majority of drivers preferred the turn-by-turn guidance screen over

the full-route moving map. However, it is also clear that some drivers in some circumstances found the route map more useful. There are a number of cases, including when the driver is off-route for either a planned or unplanned reason, in which a moving map may be the only way to effectively display required information.

- The TravTek strategy of allowing the driver to access both types of maps appears to have been the most effective choice.

[TT 09] VOICE GUIDANCE IS PERCEIVED AS VALUABLE

- Voice guidance information was quite successful in the TravTek system. Voice generally provided improved navigation performance when compared to visual display only. Rental drivers chose to have the voice guidance mode activated more than 90 percent of the time. Local users activated the voice guidance mode more than 65 percent of the time.
- Voice guidance is perceived as being valuable, particularly by drivers who are unfamiliar with an area. Apparently, voice *also* is considered to have value to local users who are both familiar with the area and familiar with the vehicle and the system.

[TT 10] SYNTHESIZED SPEECH IS SOMETIMES MISUNDERSTOOD

- Drivers' ratings of voice clarity, message understandability, and function were positive, but not as high as other ratings.
- The state-of-the-art in low-cost synthesized speech still leaves something to be desired. The digitized versus synthesized trade-off (intelligibility vs. storage requirements) is still in question.

[TT 11] VOICE AND DISPLAY FEEDBACK PREFERRED

- Voice was preferred in conjunction with either the route guidance or the map display. This is in contrast to the rating of voice alone, which was still positively rated, but not as highly.
- Voice is perceived as a valuable complementary feature to visual displays in ATIS systems.

[TT 12] DRIVERS ARE WILLING TO USE ALTERNATIVE ROUTES

- Questionnaire results indicate that many drivers are willing to change routes to save time while en route. This is valuable data to support alternative route functions.
- ATIS systems should provide drivers with alternative routes.

[TT 13] MAP DISPLAYS ARE USEFUL EVEN WITHOUT DESTINATION-SPECIFIC ROUTING INFORMATION

- The TravTek system allowed access to a moving map even when a destination was not entered. This "information map" allowed the driver to get proximal orientation and navigation information, as well as traffic congestion and incident information.
- Destination selection should not be mandatory in the use of ATIS system map displays.

[TT 14] MOTORIST SERVICES INFORMATION WAS HIGHLY RATED

- The features provided by the services directory were rated positively by the TravTek users.
- ATIS systems should contain motorist services features (i.e., yellow pages) to assist in destination selection.

[TT 15] HAZARD AND CONGESTION WARNINGS GET TEPID RESPONSE

- Warnings of congestion or an incident ahead received essentially neutral ratings—some of the lowest ratings received by the system. A number of subjects apparently questioned the reliability and timeliness of the traffic information provided by the TMC.
- Hazard and incident information must be timely and accurate to receive driver acceptance.

[TT 16] ESCHEW TWO-PRESS TOUCHSCREENS

- Pre-drive information was entered via the touchscreen menu system. The keypad had multiple letters per soft key, and required two button presses for each letter. Ease of use was rated somewhat lower (although still positively) in comparison to many of the TravTek functions and features.
- A single-letter-per-key input device is recommended over a two-letter-per-key input device.

[TT 17] STEERING WHEEL BUTTONS WERE HIGHLY RATED

- While in transit, only the steering wheel buttons were accessible to the driver. The steering wheel buttons were rated higher than most other functions and features, and quite highly overall. Previous research has shown the value of steering wheel buttons for ease of use and relatively low attention demand. It is apparent that these results generalize to ATIS applications.
- ATIS system primary controls should be placed on the steering wheel.

[TT 18] *HELP DESK WAS HIGHLY RATED*

- Drivers highly rated the capability to communicate with the TravTek help desk via the cellular phone if they had any problems or questions about the system.
- A variety of help features is recommended in ATIS system design and rapid communication with a help desk is a particularly valuable feature.

[TT 19] *HUMAN FACTORS AND SYSTEMS ENGINEERING TEAMS PLAYED A CRUCIAL ROLE IN TravTek's DESIGN*

- The use of a team of human factors and systems engineering experts was advocated throughout the design process. The TravTek interface was quite complex, and often required designs constrained by driver, vehicle, and cost factors. As such, there were many design changes and iterations that required close scrutiny. Each member of the team (three human factors experts on a part-time ongoing basis, a linguistics expert, and two systems engineers) made significant contributions throughout this process.
- Incorporating human factors early in the design of ATIS systems can enhance system performance, promote user acceptance, and reduce the need for later design changes.

[TT 20] *HUMAN FACTORS DESIGN TECHNIQUES WERE USEFUL*

- The use of "standard" human factors design techniques was essential. These included task analysis, function allocation, and somewhat informal trade-study analyses.

[TT 21] *RAPID PROTOTYPING AND USABILITY TESTING WERE MOST USEFUL IN THE DESIGN PROCESS*

- Laboratory usability testing early in the system design process using rapid prototyping and testing in a dual-task environment was invaluable. Design decisions generated or supported by this process included conservative use of "moving maps" (i.e., only when necessary, as an alternative to turn-by-turn guidance screens, and in conjunction with voice guidance).
- Laboratory usability testing should be introduced early in the system design process and implemented iteratively throughout system development.

[TT 22] *TESTING THE SEMANTICS OF LABELS WAS VALUABLE*

- Testing of labeling and nomenclature used in the system proved to be very valuable. TravTek was essentially a computer interface for the computer illiterate. Effective nomenclature proved to be critical for navigation within the menu system and understanding of functions. It is very difficult for even an

experienced human factors designer to anticipate or analyze the optimum use of labeling and nomenclature.

- Laboratory usability testing should be performed on all labels and nomenclature used in the ATIS interface.

[TT 23] RESEARCH IS NEEDED ON DRIVER ATTENTION AND PERFORMANCE

- Despite the minimal incidence of accidents or close calls, there is insufficient driving research available to accurately predict and model driving performance utilizing an ATIS system. Thus, conservative cognitive loading of the driver is still warranted.
- Conservative features should be considered for ATIS system design, such as no access to touchscreen functions while the vehicle is in motion; the use of a guidance screen instead of a moving map as the primary guidance display; and the supplementary use of voice in conjunction with the visual display.

[TT 24] USER TRAINING WAS NEEDED TO SUPPLEMENT SYSTEM DESIGN

- TravTek users participated in a video and demonstration of approximately 30 minutes in duration.
- Even with the most carefully designed interface, some opportunity for orientation and training is necessary and needs to be provided.

[TT 25] DESIGN GUIDELINES WERE UTILIZED IN THE DESIGN PROCESS

- ATIS-specific guidelines were used in the development of the TravTek system, although not from guideline documents per se. Specifically, interface ideas and specifications were gleaned from a variety of articles describing driving research and other ATIS systems. In addition, basic human factors guidelines proved useful, particularly MIL-STD 1472D for legibility considerations, and human-computer interaction (HCI) standards for the design of the pre-drive functions.
- ATIS system designers need to be aware that some human factors guidelines exist and can be integrated easily into the design process.

[TT 26] CHARACTER SIZE GUIDELINES WERE USED

- Human factors guidelines were used for determining legibility and character size. Font size used was 19.7 arc-min.



CHAPTER 4. UNIVERSITY OF MICHIGAN TRANSPORTATION RESEARCH INSTITUTE (UMTRI)

GENERAL SYSTEM DESCRIPTION AND OBJECTIVES

In accordance with the Task D SOW for the current contract, UMTRI was designated as one of the comparable systems to be analyzed. Information about the UMTRI research program was obtained primarily in a meeting with Dr. Paul Green at the UMTRI Human Factors Division and in subsequent telephone interviews.

A variety of techniques have been used in the UMTRI research program, including literature review, focus groups, identification of functions and features of driver information systems, analysis of methods for assessing safety and usability, laboratory development of prototype in-vehicle displays, and on-the-road testing in an instrumented vehicle. After the literature review, focus groups with drivers, and human factors evaluations in the laboratory, UMTRI identified five categories of information for further study:

- Navigation/Route Guidance.
- Traffic Information.
- Vehicle Monitoring.
- Cellular Phones.
- In-Vehicle Safety and Warnings Systems (IVSAWS).

Various information display methods and formats were developed and evaluated using rapid prototyping techniques. Analyses using the Goals, Operator, Method, and Selection (GOMS) model addressed the effectiveness of the various displays (Card, Moran, and Newell, 1983). Usability studies were conducted on various types of interface designs and the best features were incorporated into a field study investigating the navigation and route guidance aspects of ATIS systems.

The culmination of the UMTRI effort was the on-the-road test of this IRANS system. (See table 3 for the ATIS functional characteristics that apply to the on-the-road system.) That system will be emphasized in the present report, since the authors were able to gain direct experience with the system while acting as pseudo-subjects in the test procedure. Three members of the Battelle team drove the test vehicle with the simulated route guidance system.

Table 3. Comparison of UMTRI functions with those from ATIS/CVO systems.

Subsystem	Function	UMTRI
IRANS	Trip Planning	
	Multi-Mode Travel Coordination	
	Pre-Drive Route and Destination Selection	✓
	Dynamic Route Selection	
	Route Navigation	✓
	Route Guidance	✓
	Automated Toll Collection	
	Route Scheduling (CVO-Specific)	
	Computer-Aided Dispatch (CVO-Specific)	
IMSYS	Broadcast Services/Attractions	
	Services/Attractions Directory	
	Destination Coordination	
	Message Transfer	
ISIS	Roadway Sign—Guidance	
	Roadway Sign—Notification	
	Roadway Sign—Regulatory	
IVSAWS	Immediate Hazard Warning	✓
	Roadway Condition Information	✓
	Automatic Aid	
	Manual Aid Request	
	Vehicle Condition Monitoring	
	Cargo and Vehicle Monitoring (CVO-Specific)	
CVO-Specific	Fleet Resource Management	
	Dispatch	
	Regulatory Administration	
	Regulatory Enforcement	

The test vehicle is an instrumented Honda station wagon. It has a lane tracker built into the left side mirror and collects data from the steering wheel, brake, gas pedal, and turn signals. A microphone and two video cameras captured the driver's face and the front view from the car. In previous studies, UMTRI emulated a head-up display (HUD) by using a small mirror attached to the windshield that enabled the driver to view a reversed-video, 23-cm CRT mounted between the front seats. The HUD was not implemented for this study. The UMTRI Research Assistant sat in the back seat on the passenger's side. She had two keyboards available to control the pages displayed by the route guidance system. In effect, she was using the "Wizard of Oz" technique to replace global positioning systems (GPS) or other navigation data sources to control the display of route guidance information. The technique was very effective in achieving the look and feel of a dynamic in-vehicle display of route guidance, given the constraint that the route was predetermined. The Wizard of Oz technique was entirely successful in emulating a fully functional in-vehicle navigation system.

The test route was approximately a 25-minute drive and included a variety of driving conditions, with semi-rural, residential, multi-lane business, and interstate roadway segments.

USER INTERFACE

Visual Information Display

The in-vehicle display was a 13-cm LCD, located on top of and in the middle of the dashboard. A rudimentary road map was displayed, showing the route to be followed, with an arrow representing heading direction (figure 42).

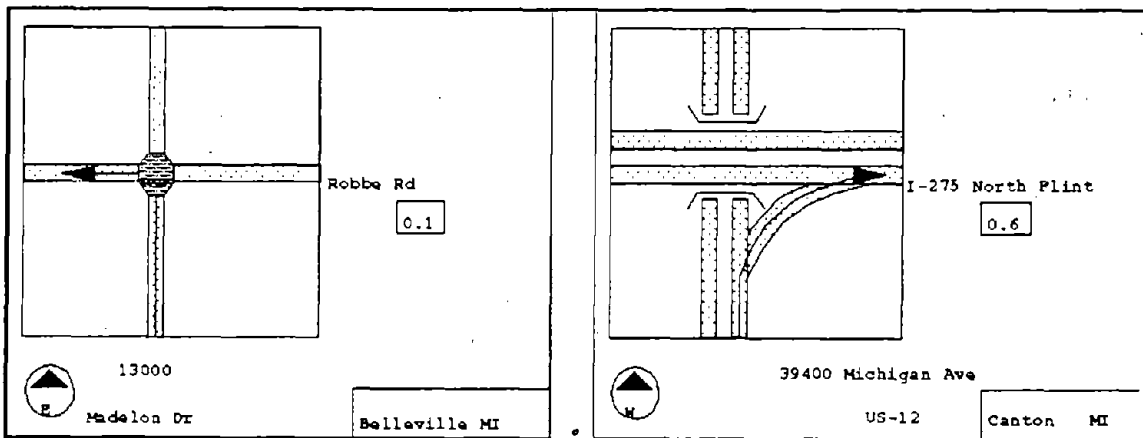


Figure 42. Schematic of UMTRI display.

The display also indicated the name of the current street, name of the next turn street, and distance to the turn in tenths of a mile. The display was presented in a heading-up mode. The system did not incorporate voice output.

The display was helpful in route guidance and it was easy to interpret next-turn information. It seemed very similar to the Navmate (Chapter 5) route guidance display, without the auditory information.

Auditory Information Display

No auditory information was given in this on-road study. Prior laboratory work at UMTRI included the development of auditory display for route guidance. The system was developed after analysis of the TravTek auditory information.

A given maneuver, such as a turn, was communicated to the driver in three stages: Early, Prepare, and Final. In all the stages, a similar format or syntax was used:

- Distance.
- Landmark.
- Location.
- Action.

Early communication was given soon after completion of the prior maneuver. An example of an early communication is:

"In 2 miles at Pine Street, turn right."

The early communication omits the "landmark" feature and gives distance, location, and action.

The middle or "Prepare" communication was given 1.6 km prior to the action. An example is:

"Prepare in 1 mile, at the Shell Station at Pine Street, to turn right."

The final communication used the word "approaching" to indicate that the action is required soon. Normally, it was given 0.16 km in advance. An example is:

"Approaching the Shell Station at Pine Street, turn right."

The UMTRI research indicated the importance of using a term such as "approaching" to indicate that the action is imminent, but not necessarily immediate. One or more right turns might exist before Pine Street, so a communication such as "turn right now" would not necessarily be correct. The landmark gives the driver a visual cue to supplement street signs, which are sometimes difficult to locate or are poorly illuminated at night.

The UMTRI work on auditory displays was done first in the laboratory, then it was tested on the road. In the road test, the error rate (e.g., failure to make the correct turn) was less than 5 percent with the auditory route guidance. This is an excellent success rate for auditory guidance only, using no visual display.

User Input (Controls)

The UMTRI research did not include work on driver input or control actions related to an in-vehicle display system.

Communications Systems

The UMTRI research did not include work on driver communications with a Traffic Management Center or dispatcher.

Cognitive Demands

Eye-fixation data were obtained in the UMTRI instrumented vehicle during road tests. These data provide a foundation for the analysis of driver time-sharing behavior and they supplement more direct measures of driving performance such as lane tracking and speed variance. However, these data have not been analyzed to date.

At UMTRI, the prevailing design philosophy with respect to attention and workload seems to be that drivers may become overloaded if they attempt to interact with an in-vehicle system while driving. Therefore, the favored concept is to allow the driver to interact with the system only in the pre-drive phase, while the vehicle is in PARK.

System Temporal Requirements

The temporal requirements of the system were circumvented in this test by the Wizard of Oz technique. The human operator (research assistant) could account for computer lags or other temporal factors in presentation of the display pages.

DESIGN GUIDELINES USED

According to Dr. Green, no human factors or other guidelines were used as reference documents in the development of the ATIS displays at UMTRI. He suggested that traditional human factors guidelines usually are developed either for human-computer interaction (e.g., Smith and Mosier, 1988) or for military systems (e.g., MIL-STD 1472) and are not helpful for the design of in-vehicle displays for ATIS systems. He suggests that the preferred method is to develop in-vehicle displays using a pragmatic approach of iterative designing and testing. This technique was used, for example, to decide on the typeface and character size used in the UMTRI in-vehicle display.

LESSONS LEARNED

[UM 01] PRAGMATIC, ITERATIVE DESIGN METHODS ARE EFFECTIVE IN DEVELOPING CRITICAL DESIGN FEATURES

- This is a methodological lesson learned that supplements typical approaches to interface design. UMTRI suggested that the best method for developing human factors interfaces for a particular ATIS application is neither to refer to guidelines nor to do empirical research. This method uses a "quick-and-dirty" iterative design in which rapid prototyping is used to represent design alternatives. With this approach, a very small sample of typical (i.e., non-human factors experts) drivers is used to judge the design alternatives. Their performance and subjective opinions are used to choose among alternatives and to identify critical design features. Several iterations of this process can be done in a laboratory-type setting with rapid prototypes. As the design progresses, it can be tested more formally in a real vehicle as a working prototype.
- Repeated and frequent iterative usability testing and evaluations should be incorporated into the ATIS system development cycle.

[UM 02] INTERFACE CONSISTENCY IS ESSENTIAL

- Software architecture consisting of several menus and screens containing various symbology located in different display layouts may lead to driver confusion and increased scan time.
- Driver interfaces must be consistent. Information communicated to the driver in visual displays should be consistently located within the display. Vocabulary used in auditory speech displays should use consistent syntax and sequence of information.

[UM 03] DISPLAY CHARACTER SIZE SHOULD BE LEGIBLE FROM NORMAL DRIVING POSITION

- The size of all display characters should be large enough to be legible from a normal driving position and for varying degrees of driver visual abilities (e.g., low visual acuity in the elderly).
- Character size for in-vehicle displays should be not less than 64 mm. This recommendation stems from UMTRI research on the legibility of digital speedometers as well as prototype development for the ITS in-vehicle display. This character height can be expressed as a visual angle of approximately 0.45 degrees, assuming the distance from the driver's eye point to the display is approximately 80 cm.

[UM 04] DRIVER INPUT REQUIREMENTS MAY DISTRACT THE DRIVER FROM THE DRIVING TASK

- Driver control inputs to an in-vehicle route guidance system should be minimal because interacting with the unit may distract the driver from the primary driving task. This lesson learned is based on anecdote rather than data, but nonetheless is of critical importance. UMTRI suggested that a well-designed system should anticipate the driver's needs as much as possible, reducing the need for manual input. This position is pertinent for route guidance, but not for route planning. The selection of destination and route planning can be done while the vehicle is stationary. This allows the driver to interact with the system without being distracted from driving.
- The UMTRI research program on in-vehicle display systems circumvented this problem by not allowing the selection of destinations or routes. That option is not available for an operational system, which must allow users to select destinations and routes.

[UM 05] VERBAL INFORMATION ON VEHICLE STATUS IS BETTER THAN "MIMIC" OR ICON

- A common technique for communicating information about system status, such as a door open or trunk lid open, is to display a small mimic or replica of the car with the corresponding door open in the color red.
- The UMTRI program of research indicated that this type of information is communicated better by verbal cautions such as "Driver's door is open."

[UM 06] THE LOCATION OF HAZARDS SHOULD BE STATED VERBALLY FROM THE DRIVER'S PERSPECTIVE

- Auditory messages conveying the location of hazards should be delivered using the method that is most intuitive for the driver.
- After testing 10 designs for communicating the location of proximate hazards, such as an emergency vehicle, the UMTRI research program found that a simple verbal message giving the nature of the hazard, followed by its location, worked best. An example is "Ambulance to the left." This wording was more effective than options such as "Ambulance at 10 o'clock." (Hoekstra, Williams, and Green, 1993)

[UM 07] DRIVER INFORMATION REQUIREMENTS FOR ATIS SHOULD INCLUDE ROADWAY HAZARDS AND TRAFFIC CONGESTION INFORMATION

- UMTRI studies of driver information needs found the two most highly rated features to be information about roadway hazards (crash site, construction,

railroad crossing) and information about traffic congestion (Serafin, Williams, Paelke, and Green, 1991).

[UM 08] KNOWLEDGE OF HOW DRIVERS USE PAPER MAPS SHOULD BE USED AS BASELINE FOR ATIS DESIGN

- An extensive survey of map use and automobile navigation (Cross and McGrath, 1977) is relevant to the design of electronic maps. The design of new technologies normally is based on new methods for meeting the needs of users. Extensive knowledge of how motorists currently perform navigation tasks is an important foundation for the design of electronic navigation aids. One item from the Cross and McGrath study that is directly relevant to ATIS systems was that at any given time, 6 percent of motorists are either lost or uncertain of where they are.
- Green (1992) states that "For determining the information available and desired by drivers, Cross and McGrath (1977) is the most valuable source in the published literature and should be required reading for those defining system functionality. It contains a wealth of data indicating type of information desired and presentation problems with paper maps."

[UM 09] DRIVER INFORMATION NEEDS DEPEND UPON THE DRIVING TASK

- In the guidance mode, several types of information can be provided to drivers, including simple information about what to do next, when turns are not required for a period of time (e.g., a *continue* instruction), and lane information. Each type of information is contingent on a particular driving task and should be displayed during that task.
- To display the most useful information to the driver, it is necessary to identify the various types of tasks and intentions of drivers across phases of travel (e.g., trip planning, route guidance, or navigation).

[UM 10] TRAFFIC CONGESTION IS BETTER CODED WITH COLOR THAN WITH DIFFERENTIAL LINE WIDTH

- Color coding demonstrated higher discriminative qualities when compared to other graphical coding schemes. Specifically, differences in line width are more difficult to discern than color coding.

[UM 11] USE A DIGITAL SPEED INDICATOR RATHER THAN MOVING GRAPHIC ELEMENTS (e.g., DASHED LINES) FOR DISPLAYING TRAFFIC SPEED INFORMATION

- The relative speed of moving pixels is more difficult to judge than a direct digital read-out of traffic speed.

[UM 12] MAP ORIENTATION DEPENDS ON ATIS MODE

- Adeyemi (1982) found that geographic orientation and map interpretation were considerably better when the map and the map user were oriented in the same direction. Furthermore, maps with eight compass points rather than one (North) led to better performance. These data argue for aligning maps with the direction a person is facing (heading up) and providing multiple direction markers, not just North.
- For trip planning, electronic maps should be shown North up; for route guidance, they should be shown heading up. (See Green, 1992.)

[UM 13] ROUTE GUIDANCE DISPLAYS SHOULD AVOID DETAIL

- Simple arrow displays are preferred. Each additional street shown adds almost 0.4 seconds to search time (Stilitz and Yitzhaky, 1979).

[UM 14] LANDMARKS SHOULD BE SHOWN ON NAVIGATION DISPLAYS

- Landmarks (underpasses, bridges, stoplights, stop signs, etc.) and buildings (gas stations, restaurants, etc.) are used by motorists as keys to location and driving actions (e.g., "Turn right just past the McDonalds").
- Electronic maps should take advantage of a driver's propensity to use landmarks.

[UM 15] APPROPRIATE MEASURES OF DRIVER AND SYSTEM PERFORMANCE FOR EVALUATING IN-VEHICLE DISPLAYS MUST BE DEVELOPED AND USED

- Research has been done under laboratory, simulator, and on-the-road conditions using a variety of measures, including eye movement, heart rate, response time, lane tracking, speed tracking, navigation error, trip time, average speed, and, of course, driver opinion. There is no simple set of "correct" measures.
- Establishing valid measures of driver performance is not a trivial problem; it needs considerable deliberation and research.

[UM 16] SEVERAL ATIS-USER RESEARCH ISSUES NEED TO BE ADDRESSED

- The use of electronic navigation systems has not been studied sufficiently for use by older drivers, novice drivers, and under difficult conditions (such as at night) and requires further study.

CHAPTER 5. THE NAVMATE SYSTEM

GENERAL SYSTEM DESCRIPTION AND OBJECTIVES

Navmate is an in-vehicle ATIS prototype system designed by Zexel USA Corporation to allow drivers the capability of reaching a specific destination from any place of origin. The information obtained for this system originated from three sources: a one-page brochure of Navmate given to drivers; an interview with a member of the design team; and a modest usability study with eight drivers, including three authors of this report. The Navmate analysis relies considerably on the heuristic analyses performed by the authors while performing probe tasks and driving tasks. Verbal protocols from the analysts and other subjects were recorded as the tasks were performed and subsequently transcribed.

Navmate is a route planning and navigation system that is currently undergoing fieldtesting by Zexel and Avis in San Jose, California. The Navmate is a single-destination system that utilizes a combination of vehicle location techniques and provides the driver with turn-by-turn route guidance information en route to the selected destination. Drivers can select from a number of destinations by proceeding through various text-based menu screens and selecting a point of interest or a particular intersection from a database. A driver also may enter a street address as a destination. Once a destination is entered, Navmate calculates the fastest route, taking into consideration distance, posted speed limits, number of intersections, and left/right turns. The route is displayed on a digital map showing varying levels of detail contingent on the driver-selected map scale. The smallest scale displays one complex intersection (e.g., a cloverleaf freeway interchange) in its entirety on the screen.

Table 4 denotes the functional characteristics of the Navmate system as compared to ATIS systems. Currently, the Navmate system is mostly an IRANS system that primarily provides navigation and route guidance information based on position information and map databases. However, the hardware configuration of the system renders it capable of adapting to future software systems that can provide several other ATIS functions. Plans are in progress to develop a version of the Navmate system capable of two-way communication.

Table 4. Comparison of Navmate functions with those from ATIS/CVO systems.

Subsystem	Function	Navmate
IRANS	Trip Planning	
	Multi-Mode Travel Coordination	
	Pre-Drive Route and Destination Selection	✓
	Dynamic Route Selection	✓
	Route Navigation	✓
	Route Guidance	✓
	Automated Toll Collection	
	Route Scheduling (CVO-Specific)	
	Computer-Aided Dispatch (CVO-Specific)	
IM SIS	Broadcast Services/Attractions	
	Services/Attractions Directory	✓
	Destination Coordination	
	Message Transfer	
ISIS	Roadway Sign—Guidance	
	Roadway Sign—Notification	
	Roadway Sign—Regulatory	
IVSAWS	Immediate Hazard Warning	
	Roadway Condition Information	
	Automatic Aid	
	Manual Aid Request	
	Vehicle Condition Monitoring	
	Cargo and Vehicle Monitoring (CVO-Specific)	
CVO-Specific	Fleet Resource Management	
	Dispatch	
	Regulatory Administration	
	Regulatory Enforcement	

USER INTERFACE

General Description

The Navmate unit has a 9-cm x 6.25-cm, 16-color, LCD display that provides both text- and map-based information to the driver. The display unit can be attached to the dashboard with a special mount such that it is located to the right of the driver, near the top of the dashboard. The display unit swivels and adjusts horizontally and vertically. The current Navmate prototype, including all hardware, wiring, and antenna, is designed to be installed in a test vehicle (e.g., rental car) in less than 1 hour without making any permanent modifications to the vehicle. The display is mounted onto the dashboard using existing screws in the vehicle. Therefore, the location of the display is contingent upon the location of existing screws. The GPS unit and other hardware are mounted in the trunk. The adaptability of this quick-installation design allowed the prototype to be tested in several vehicle models.

The display unit has several discrete-setting controls that provide access to the screen displays and control cursor movement. The entire unit is approximately 14 cm wide and 14.5 cm high.

The system utilizes a combination of positioning techniques, including the Global Positioning System, dead-reckoning, and map-matching. It provides the driver with real-time vehicle location and route guidance information as the driver progresses to a selected destination.

Visual Information Display

When the ignition of the vehicle is in the "On" position, power is available to the Navmate. When power is available and the Navmate's "On/Off" switch is turned to "On", an introductory message is displayed. This message notifies the driver that he/she should always drive defensively and implies that the device should not hinder driving safely (figure 43).

Once the driver acknowledges the message, the main "Where do you want to go?" menu is displayed. All the menus are text-based and presented with color schemes to enhance visibility and contrast. While most of the text is white on a black background, several portions of the display (header and help boxes) make use of other color schemes on a colored background.

Please drive safely

NAVMATE™ Route Guidance System is designed solely to help you arrive with ease at your destination.

As in all driving situations, there is no substitute for defensive driving in conformity with all traffic laws.

As a motorist, you alone are responsible for the safe operation of this vehicle.

Figure 43. Message displayed when vehicle ignition is turned on.

The main menu screen is accessible when the vehicle is stationary or in motion. It allows a destination to be selected. From the main menu, the driver has four options for choosing the desired destination:

- Street Address.
- Intersection.
- Points of Interest.
- Guidance History.

The desired selection is chosen by moving the cursor (highlighted box) to the item and pressing ENTER. At the bottom of the screen, an instructional line indicates the manner in which the driver can make his/her selection. Icons of arrows represent cursor controls. "Points of Interest" is the most frequently used category. The directories under "Points of Interest" included the following:

- Airports.
- Gas Station.
- Hotel.
- Restaurant.
- Rental Car Base.
- Sports Complex.
- Theater.
- Toll Booth.
- Tourist Attraction.
- Train Station.
- Winery.
- Yacht Harbor.
- Zoo.

After a specific destination directory is selected (e.g., Restaurant), the system requests that the driver "Select the Listing Mode." The driver is capable of listing each directory alphabetically or by distance (the closest restaurant at the top of the list). When directory items are listed, the driver can scroll through the selections until the desired destination appears in the fixed highlighted box. As selections are highlighted, the direction, distance, and address (and city) of that selection are displayed at the top of the screen. Once the driver enters the desired destination (e.g., Mr. Right's Cafe), the system displays a message indicating that it is calculating the shortest route. This may take several seconds, depending on the distance to the destination.

Once the route is calculated, a map-based display is shown with the route highlighted in magenta (figure 44). All local streets are white, freeways are light blue, and the background is black. Street names are in yellow. At the bottom of the map display, the compass direction in which the vehicle is heading (e.g., NW), the GPS status icon, and the map scale icon are shown in green.

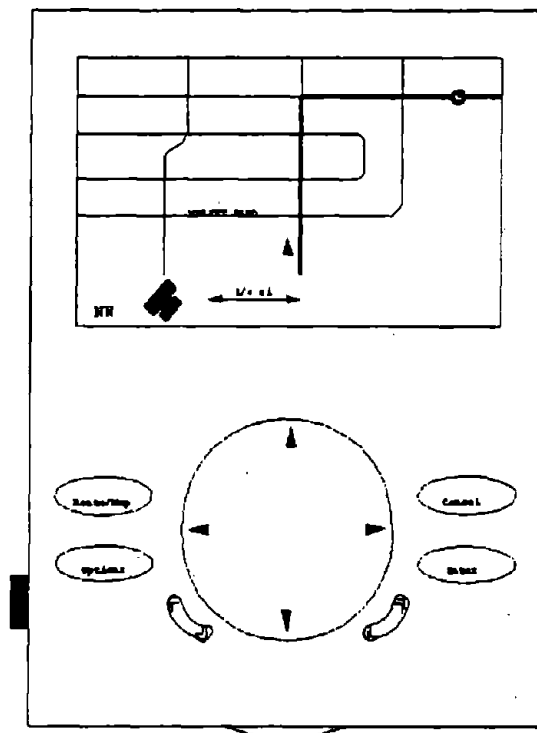


Figure 44. Navmate map display screen.

The map displays the position of the vehicle with a triangle indicating the vehicle heading. The driver can select to have the map displayed in either the heading-up or North-up orientation. Most drivers seem to prefer the heading-up mode. The location of the destination is depicted with a solid dot.

Once the destination has been selected and the route is established, the driver is not capable of altering the route; however, he or she can select a new destination. The driver also can change the system's setup (e.g., the map scale) or switch between the map and route guidance screens.

When the vehicle begins to move, the system automatically switches from the map to the route guidance screen (figure 45). The driver does have the option, however, of selecting the map display while in motion. The route guidance display provides turn-by-turn instructions for proceeding to the destination. The guidance display indicates the name of the street for the next turn at the top of the screen in uppercase letters. Underneath is a large yellow arrow indicating the direction of the next turn. Just below the arrow, the approximate distance to the next turn is displayed in miles. A yellow bar appears at the bottom of the guidance screen when the vehicle is 0.3 km from the next turn, and shrinks as the turn is approached. To the lower right of the screen, the direction of the destination from the current position is indicated with a small arrow in white. Next to it is the "as the crow flies" distance to the destination. The same GPS status icon from the map display is shown on the lower left.

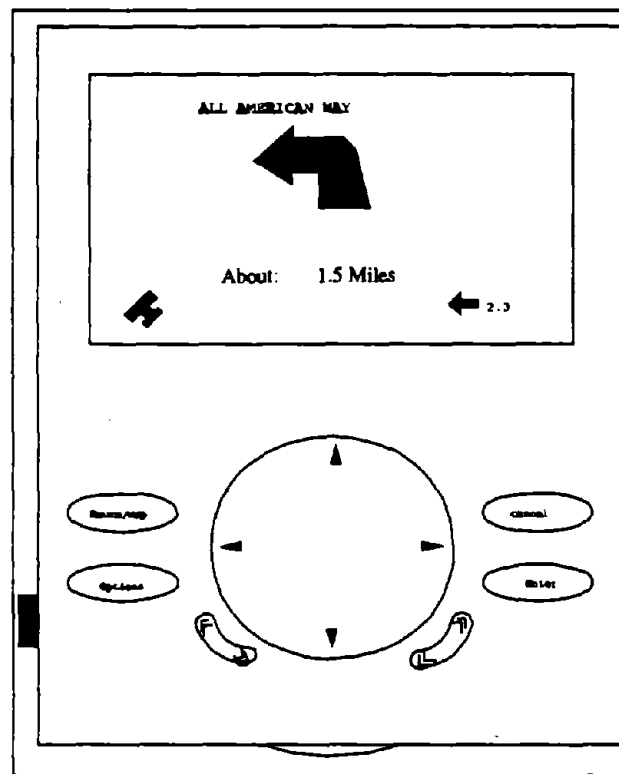


Figure 45. Navmate route guidance display.

If the driver leaves the planned route for any reason, the system displays a message indicating that the driver has "Left the Route" and also asks whether a new (alternate) route should be calculated to the same destination from the current position. The driver acknowledges this request simply by pressing ENTER.

Auditory Information Display

A digitized male voice provides route guidance information to support visually displayed information at two volume levels (low or high), or it can be deactivated. When the vehicle approaches a turn (0.16 to 0.80 km away, depending on the vehicle speed), the system provides a voice announcement such as "Left Turn Ahead."

A short auditory beep is emitted when a key is pressed, providing feedback that the function is engaged. Longer beeps are emitted when the system cannot respond to the key activated. A short beep is also emitted just before each voice message. All beeps seemed identical in pitch and loudness, and intensity was not adjustable. Two short beeps are emitted just before the vehicle reaches a turn.

User Input (Controls)

The Navmate system has several discrete controls located below the display (figure 46). All cursor movements are controlled by activating a large, circular, four-way, rocker control. To activate "Quick Scroll," the driver has to simultaneously press the rocker key and either of the Quick Scroll buttons. Several drivers seemed to have difficulty with this function. The four-arrow control is also used to relocate the vehicle position on the display when a miscalibration occurs (this may occur due to a weak GPS signal).

The ENTER control activates the highlighted feature, and CANCEL acts as an "escape" function, allowing the driver to return to the previous screen or to abort a route calculation.

The ROUTE/MAP button allows the driver to switch back and forth between the map and guidance screens while driving. The OPTIONS key is used to change the system settings for map size (small, medium, large), map orientation (heading up, North up), and Voice Volume (high, low, off). These setup settings may be changed while the vehicle is in motion.

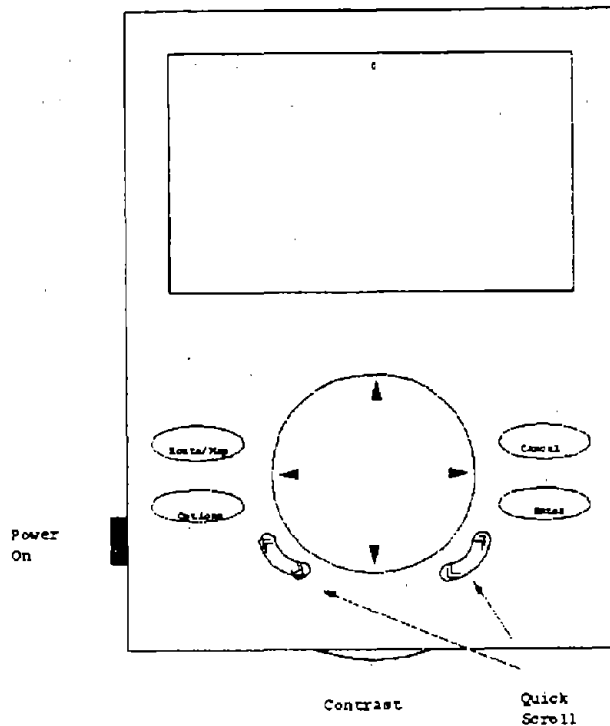


Figure 46. Navmate controls.

Communications Systems

At the present time, Navmate is a one-way communication system (GPS receiver) and does not transmit any signals or information. The map database must be updated by physically loading new databases.

Cognitive Demands

The majority of the system navigation and destination selection functions are normally performed when the vehicle is in PARK or at zero speed. Under normal conditions of use (i.e., destination is selected while parked), very few control inputs are used while driving; thus, the cognitive demands are limited to the time-sharing requirements of glancing at the display under various traffic conditions. The map display is difficult to interpret with a quick glance and can increase attentional demands on the driver. Normally, the simpler guidance display is used while in motion. Because of the simplicity of the guidance display and the distance cuing provided by the speech system, there is no need to look at the display frequently. The two beeps at the moment of the turn reduce the need to watch the display for distance information immediately prior to the turn. In short, the cognitive demands imposed by the Navmate system are not high as long as the driver selects the destination while parked.

System Temporal Requirements

The display change that requires the most amount of time is the calculation of a new route. At times, this can take several seconds (up to 30 seconds) and can lead to user frustration. The map display also takes several seconds to update as the vehicle makes a turn. This is likely to occur when making a U-turn or turning around in a parking lot.

DESIGN GUIDELINES USED

Human Factors Design Guidelines

The Navmate design team was composed of 15 to 20 members with backgrounds in various areas of engineering, such as hardware, software, or computer science. Human Factors engineers were not involved in the design of this system, except for a Human Factors consultant who was asked to briefly evaluate the system's interface. This input was not part of a formal evaluation and the consultant did not participate in any rapid prototyping or experimentation on Navmate.

Other Guidelines

The design of the system seemed to revolve around a "passive system" that would not require input from the driver once the controls were set. The design of the displays also followed this "passive system," providing simplified turn-by-turn guidance; therefore, the driver would not be required to attend to the screen frequently or for long periods of time. Zexel design team members recognized that rental car users are likely to be novice users of the system, and too many controls could be intimidating. The interface was designed to "look easy to use."

Cost was a constraint in the design. The availability of small, low-cost, color displays constrained the system to using fewer colors and lower resolution than desired. Since all graphics and text were drawn by Zexel, the design was only limited by the screen size, resolution, and color capability. Anti-glare devices are also expensive and Zexel opted for using gray filters rather than polarizing filters.

Available technology also impacted the design of Navmate. The infrastructure was not available to provide real-time traffic information. In the future, Zexel plans to use a cellular phone to provide automated destination coordination. Route searches also were not as exhaustive as desired. The present Navmate route search is limited to reduce the amount of time needed to make a larger search. It was anticipated that rental car drivers would not be patient during long search times; therefore, it is possible that the best route (e.g., freeway around a city) is not selected.

Other technology constraints involved the inaccuracy of GPS systems, which can introduce a position error as large as 100 to 300 m. Furthermore, the GPS signal is lost in many situations (e.g., parking garages, tunnels, tall buildings). To compensate for this error, several on-board systems were integrated. Data from the car's odometer and from a gyrometer in the Navmate system are used with dead-reckoning and map-matching technology to attempt to reduce position error.

Updates and modifications to the present Navmate prototype will be made contingent upon the feedback from the current field tests. Customer Satisfaction Surveys completed by rental car users are expected to provide valuable information, including ease of use, ability to reach destinations, ease of entering destinations, and overall system performance. Drivers also are asked the price that they would pay to have the Navmate system installed as optional equipment in a new vehicle (i.e., \$999 to \$1,999).

LESSONS LEARNED

[NM 01] SIMPLE USER ACCESS TO LARGE DATABASES IS ESSENTIAL

- The motorist information for the Bay Area that was contained in the Navmate database was large. The method used for scrolling through long lists was awkward, sometimes requiring the operation of two buttons simultaneously.
- More work needs to be done on enabling users to access large databases quickly. Several drivers required two hands to use the Speed Scroll button in conjunction with the large, four-position button. Subsequent design modification using button-press pressure for slow/fast scroll is better, but still awkward.

[NM 02] DETAILED ACCURACY OF MAP DATABASE MUST BE MAINTAINED

- Map databases for ATIS/CVO systems must account for one-way streets and two-way streets with a center divider. Errors of this type can cause incorrect guidance. The consequences of this error range from inconvenient to dangerous (if the driver follows the incorrect guidance).
- Updating map databases will be a challenge that must be met to provide the foundation for accurate ATIS/CVO systems.

[NM 03] ENTIRE ROUTE PREVIEW IS DESIRABLE

- Users want the capability of previewing an entire route on the digital map at a selectable scale.
- Providing this option during the destination selection process (pre-drive mode) should be considered.

[NM 04] DRIVERS WOULD LIKE TO BE ABLE TO REJECT UNVIABLE ROUTES

- Several drivers commented that ATIS systems should allow drivers to reject an unviable route (e.g., due to inaccuracy in the map database) or request a different route than the one provided (e.g., one that excludes a particular street).
- In-vehicle navigation systems should provide users with the ability to request an alternate route to the one provided.

[NM 05] AUTOMATED STREET SEARCH WAS VALUED WHEN ENTERING ADDRESS DESTINATION

- When entering an intersection as a destination, the system automatically limited the second street options to only those streets that intersect the first street. This was viewed very favorably by the drivers. Several drivers were surprised that this feature existed and felt it saved much time in scrolling through the set of possible intersecting streets.
- ATIS database access time can be shortened by this type of "shortcut" and similar aides should be integrated into each of the destination selection searches.

[NM 06] BUTTON FEEDBACK CAN IMPROVE PERFORMANCE

- Tactile feedback from input buttons was marginal. The tone accompanying the registration of a button press was useful feedback, but several drivers felt there were too many tones. Buttons with better tactile feedback would be an improvement.
- Adequate tactile feedback from ATIS system controls should be provided.

[NM 07] DRIVERS SHOULD BE NOTIFIED WHEN VEHICLE POSITION CALIBRATION IS REQUIRED

- The capability of adjusting the position of the symbol of the vehicle to the correct position in the display was good. However, few of the drivers realized that this could be done, and none made use of the feature without prompting from the experimenter. The lack of use of this manual correction capability indicates that many drivers did not recognize when the system was generating guidance based on an erroneous location.
- An intelligent system to estimate probable error and to notify the driver would be useful.

**[NM 08] ROUTE DEPARTURE NOTIFICATION SHOULD BE PROVIDED
VERBALLY AND VISUALLY**

- The visual display indicating that the driver is no longer following the route was sometimes not detected.
- An auditory indication could be helpful, but would be tolerated only if the high false alarm rate of this indication was reduced.

**[NM 09] SOME DISPLAY SYMBOLOGY WAS CONSISTENTLY IGNORED BY
DRIVERS**

- Some of the display symbology was irrelevant to the drivers, such as the GPS status symbol. Other symbology of low relevance to the drivers included the direction of the destination, the direction of north, and the "as the crow flies" distance to the destination.
- Because such items have low relevance, they contribute to screen clutter and should be eliminated.

**[NM 10] COMPUTING/WORKING INDICATION WOULD CLARIFY SYSTEM
STATUS TO DRIVERS**

- Route calculation time is dependent on destination distance and often takes several seconds. There is no display indication that the system is actually active and computing a route. Drivers felt something was wrong. The lack of such an indicator was noted particularly when the length of the route was very long, i.e., 80.5 km.
- Some indication that the computer is busy calculating a route seems to be advisable.

**[NM 11] ACCURACY OF MAP DATABASE IS CRITICAL IN ESTABLISHING
DRIVER CONFIDENCE**

- On some occasions, the system did not find the "closest" destination known by the driver (e.g., bank). Similarly, the system sometimes provided an outdated destination for a gas station or a store. These types of errors lead to reduced driver confidence in the system.
- The underlying problem in both these instances is outdated map database information that should be minimized in ATIS system design.

[NM 12] DISPLAY MODE CHANGES SHOULD BE UNDER USER CONTROL

- The device changed to guidance mode from text mode automatically. The amount of time the drivers had to review the route in text mode was insufficient.
- In general, users like to have control over display options.

[NM 13] ROUTE GUIDANCE MODE PREFERRED FOR DRIVING

- In most cases, the drivers selected the guidance mode rather than the map mode while driving. The only time the map mode was preferred was when driving down a freeway and monitoring for the desired off-ramp.

[NM 14] COLOR CODING OF ROUTE WAS HELPFUL

- Showing the recommended route in a different color than the streets was considered helpful by the drivers.
- Color coding allowed drivers to easily perceive the route to be followed.

[NM 15] DISPLAY MOUNTING LOCATION WAS ADEQUATE

- The mounting position did not obscure the roadway for any of the drivers, nor did it obscure or limit access to any controls.
- The ideal mounting position would appear to be as high as possible without obscuring any of the roadway. This position, obviously, depends on individual measurements.

[NM 16] LEARNING REQUIREMENTS WERE FEW

- All drivers estimated that it would take less than 1/2 day to learn to operate the system well, and most indicated that the time required would be between 1 and 2 hours.
- ATIS systems need to be designed so that the driver does not have to rely on instruction manuals and reference cards to operate the system.

[NM 17] TRAINING AIDES SHOULD BE USED AS A REFERENCE INSTEAD

- None of the drivers went through the example in the one-page brochure. Most drivers felt the brochure was too cluttered. However, a number of the drivers referred back to the card when they were unable to quickly perform tasks.
- Brochure design should take into consideration use as a reference tool.

[NM 18] DIGITAL SPEECH SYSTEM WAS INTELLIGIBLE

- Use of digital voice is often considered questionable due to its limitations. Drivers felt that the digital voice was intelligible to all of the drivers in this study.
- Future use of digital speech systems in ATIS applications is feasible.

[NM 19] PREFERRED MAP ORIENTATION WAS HEADING UP

- The drivers generally preferred the map in heading-up, rather than north-up orientation. The one exception was an individual with extensive map reading experience.
- ATIS systems should always provide the heading-up orientation as an option, or as the default (if only one orientation is possible).

[NM 20] DRIVER PERCEPTION OF INTERFACE MAY IMPACT USE

- The device was not perceived as intimidating. Consequently, users were open to using and exploring the system's capabilities. In part, this seems to be due to the small number of user controls (buttons). It may be that the willingness to "play" with the system facilitates rapid learning of the system's features.
- Simple interfaces with few controls seem to foster system use and acceptability.

[NM 21] MINIMAL DISPLAY CLUTTER ENHANCES PERFORMANCE

- The earlier prototype of Navmate had more information on each display. However, Zexel design team members seemed to think that clutter was a problem that would lead to a long interpretation time. Therefore, several items were eliminated from the displays.
- The current display clutter seemed acceptable, although it could be reduced further (see NM 09).

[NM 22] ATIS SYSTEM USE AT NIGHT WAS EXTREMELY VALUED

- Navmate was tested by only two drivers in night driving situations. They found the system to be even more useful at night than it was during the day because way finding is difficult under conditions of reduced visibility.
- If in-vehicle navigation systems have more utility at night, the interface should be designed to meet the appropriate environmental conditions.

[NM 23] REDUCTION OF DISPLAY GLARE WAS SUCCESSFUL

- Gray filters seemed to be a cost-effective way to reduce display glare since drivers did not perceive glare as a significant problem. However, there were occasions that glare was apparent when direct sunlight shined on the display.
- Glare-reducing filters may be sufficient to prevent display reflections.

[NM 24] DIRECT DISPLAY GLARE AT NIGHT WAS NOT A PROBLEM

- Glare from the headlights of other vehicles was not a problem.
- The screen was low enough that lights from following vehicles did not strike the screen.

[NM 25] COMMENTS ON VOICE MESSAGE TIMING VARIED

- Drivers seemed to question when it would be most useful for voice messages to convey a turn. The ideal time from the onset of the voice to the actual turn needs to be researched. Opinions ranged from there not being enough time to the amount of time being about right. There were no reports of the turn alert occurring too early.

[NM 26] SUPPLEMENTAL VOICE ROUTING MESSAGES HELPFUL

- The speech output worked well in conjunction with the visual display of route guidance to cue the driver as to the relative distance and timing of upcoming turns.
- Visual and auditory displays should be combined in route guidance.

[NM 27] DRIVER-REQUESTED ROUTE INFORMATION

- Drivers felt route information on estimated time of arrival (ETA), elapsed time, and ground distance to destination should be displayed at all times, or at least be easily selectable.

[NM 28] DRIVER-REQUESTED TRAFFIC CONTROL INFORMATION

- Speed limit information is available to the Navmate, and it is used in selecting the "fastest" route, according to a design team member. However, this information is not displayed to the driver, and some drivers expressed interest in the availability of a speed limit display.

[NM 29] COMPUTING AN ALTERNATE ROUTE TO A GIVEN DESTINATION

- Generating a new route to the same destination when you have left the route is a single button press. The amount of time required is comparable to turning on the air conditioner or changing channels on the radio.
- Allowing re-computation of a new route to the same destination on the fly with a single button press works out well with this system. This is preferable to having to stop and perform the re-computation in the pre-drive mode.

[NM 30] SELECTING NEW DESTINATION AND ROUTE WHILE EN ROUTE

- In the situation where there is more than one person in the car, there may not be a safety problem with having the passenger operate the system. In such a situation, a positive lock-out (preventing the selection of destinations while in motion) would be perceived as a drawback. On the other hand, when a driver is alone in the vehicle, entering a destination would require considerable time, with attention devoted to the device instead of to driving the vehicle.
- This is a potential safety issue that needs to be addressed.

[NM 31] TURN INDICATORS SHOULD REFLECT ROADWAY CHARACTERISTICS

- The shape of the arrows indicating a turn should represent the size and shape of the physical turn. The arrows used in the guidance mode generally provided sufficient information to the drivers regarding the angular size of upcoming turns.
- The arrows indicating whether a U-turn, a 90° (approximately) turn, or a turn less than 90° was ahead provided an adequate number of categories for the driver to plan ahead. The consensus of the drivers seemed to be that the turn arrows adequately conveyed the turn requirements.

[NM 32] CONSECUTIVE TURN INFORMATION WAS VALUABLE

- The verbal warning that a turn was closely followed by another turn was judged favorably. This warning generally allowed drivers to position their vehicle to perform sequential maneuvers.
- Drivers should be made aware of consecutive turns.

[NM 33] REAL-TIME DISTANCE TO A TURN WAS VALUABLE

- Approximate real-time distance to a turn is valuable information. The distance to turn tape [a yellow bar was displayed on the bottom of the screen when the vehicle was within 0.32 km of the turn, according to the brochure] provided a useful cue to the driver that a turn was to be performed in the immediate future.
- Real-time distance should be made available to drivers, possibly as a display option.

[NM 34]

FALSE ROUTE DEPARTURE NOTIFICATION SHOULD BE MINIMIZED

- There was an annoyingly high frequency of false "you have left the route" messages displayed within the first minute of departing (typically in situations when buildings or structures obscured satellite signal strength). Most drivers adopted the strategy of ignoring the message and having a new route computed while driving (one button push).
- Route departure notification messages should be accurate and should not be dependent on signal strength. A different message could be displayed when the signal is weakened or blocked.

CHAPTER 6. THE OmniTRACS MOBILE COMMUNICATIONS TERMINAL

GENERAL SYSTEM DESCRIPTION AND OBJECTIVES

The OmniTRACS system, developed by QUALCOMM Incorporated, is a two-way mobile satellite communications and vehicle-tracking system designed for use in Commercial Vehicle Operations (CVO). This system was commercially available for use in 1988 and is now currently utilized by over 225 customers and is installed in over 50,000 trucks. The design of the OmniTRACS system was based primarily on the current demands of the CVO industry. Unlike the other six systems included in this report that are still at the prototype or testing phase, OmniTRACS has been introduced into the commercial market and has been favorably accepted since its initial deployment.

The design of the OmniTRACS system was customized to the needs of the CVO customer (i.e., motor carrier/trucking company). CVO customer needs differ from the needs of the typical ATIS user (e.g., leisure driver). One of the greatest costs involved in CVO is related to the amount of idle and wasted time the driver spends in trying to find a telephone to contact dispatch with information such as arrival and departure times, billing information, delays, emergencies, and loading/unloading information. Dispatchers are responsible for the scheduling and routing of up to 60 drivers/tractor units, which means that drivers are often placed on hold or cannot get through at all. This frequently creates a bottleneck in the CVO system that translates into increased costs, low productivity, and driver dissatisfaction. Ultimately, it translates into dissatisfied clients (i.e., shippers and consignees), which motor carriers rely on for business.

The objective of the OmniTRACS system was to enhance the customer's communication with and the control of their CVO equipment (i.e., trucks and trailers). The ATIS/CVO functions provided by OmniTRACS are denoted in table 5. These functions were achieved by designing a Mobile Communications Terminal (MCT) to be installed in each vehicle, which consisted of three hardware units: an outdoor antenna, a communications unit, and a display unit. This satellite-based MCT allows drivers to be in constant touch with dispatchers who also have a computer-aided system to continuously track the location of each driver/truck. Forward host-based data (e.g., load assignments) are sent directly to the appropriate truck or fleet of trucks. This driver-dispatcher data link also allows motor carriers to access vehicle-based data (e.g., driving statistics, engine diagnostics) via optional Vehicle Information Systems. All messages and positioning information from the vehicles are transmitted, via satellite, through the QUALCOMM Network Management Center to dispatch centers nationwide.

Table 5. Comparison of OmniTRACS functions with those from ATIS/CVO systems.

Subsystem	Function	OmniTRACS
IRANS	Trip Planning	
	Multi-Mode Travel Coordination	
	Pre-Drive Route and Destination Selection	✓
	Dynamic Route Selection	
	Route Navigation	
	Route Guidance	✓
	Automated Toll Collection	
	Route Scheduling (CVO-Specific)	✓
	Computer-Aided Dispatch (CVO-Specific)	✓
IMISIS	Broadcast Services/Attractions	
	Services/Attractions Directory	
	Destination Coordination	
	Message Transfer	✓
ISIS	Roadway Sign—Guidance	
	Roadway Sign—Notification	
	Roadway Sign—Regulatory	
IVSAWS	Immediate Hazard Warning	
	Roadway Condition Information	✓
	Automatic Aid	
	Manual Aid Request	✓
	Vehicle Condition Monitoring	✓
	Cargo and Vehicle Monitoring (CVO-Specific)	✓
CVO-Specific	Fleet Resource Management	✓
	Dispatch	✓
	Regulatory Administration	✓
	Regulatory Enforcement	

Network Management Center (NMC)

The function of QUALCOMM's Network Management Center (NMC) is similar to the Advanced Traveler Management Systems (ATMS) component proposed in ITS applications. All information from fleet vehicles and dispatch centers passes through the NMC, which monitors and logs messages. Each motor carrier is charged a fee for the number and the length of the messages they transmit. The NMC, where all messages are processed, is located in San Diego, California, and is staffed 24 hours a day. A fully equipped backup station is located in Las Vegas, Nevada.

As the hub for the entire OmniTRACS system, the NMC features two DEC VAX 6410 computer cluster systems (one acts as a backup). All communications are transmitted via satellite through a 7.6-m dish. The satellite service is provided by GTE aboard an existing satellite and QUALCOMM is guaranteed that transponders will be available from one of the three GTE satellites. Communications to the NMC are supported through dedicated leased lines, dial-up services, or time-share networks. QUALCOMM operates the largest transportation communications center in the world via numerous communication protocols supported at the NMC. Further investigation of this NMC seems warranted for future research on Automated Traffic Management Systems functions and design.

Computer-Aided Dispatch

QUALCOMM has developed various software products to enhance the dispatcher's organizational and communications tasks. Many different hardware platforms (PC's, LAN's, mid-range, and mainframe systems) can be used to run these programs. These software packages are intended to automate the motor carrier's functions and to integrate with already-existing transportation software available for dispatchers, such as accounting, dispatch, sales order entry, maintenance requests, personnel data, and payroll. The dispatcher's interface to the OmniTRACS system may be the greatest selling point to potential customers. Once the software products are loaded on the company's dispatch computer systems, the dispatch process is automated to a real-time process by linking vehicle information transmitted by the OmniTRACS system. For example, one group of software products dynamically optimized the operations of truckload carriers by considering key facts, forecasts, and management priorities to recommend the right truck for a certain load. This program maximizes revenue per truck per day and minimizes cost. Another group of software programs integrates vehicle information systems and compiles data generated by a vehicle's on-board sensors and subsystems to enhance overall fleet management. The objectives of this optional set of software programs were to provide the capability to produce performance statistics reports, vehicle diagnostics data, and trailer status information.

Vehicle locations are displayed to dispatchers in text format or on a map display, as specified by the dispatcher. Text formats provide the number of miles to the nearest city/landmark and to the nearest large city. Another software package passes position and location history from the host computer to a PC computer with a VGA color graphics monitor for mapping. Mapping features include: displaying major cities, State lines, highways, and roads; aiding in

the process of calculating estimated times of arrival (ETA's); allowing reduced-scale capability for the dispatcher to zoom in on a specific vehicle or landmark; entering customer's locations as landmarks on the map (and in text format); color-coding vehicles by class; and displaying current capacity and demand status of the fleet. QUALCOMM's satellite triangulation technique provides position reporting accurate to within 305 m.

Mobile Communications Terminal (MCT) Driver Display Unit

The driver is continuously linked to dispatch through the Mobile Communications Terminal (MCT) display unit mounted in the truck cab. Through this unit, the driver reads incoming messages and assignments, and can send messages to dispatch. While there are few limitations on the content of text messages provided by dispatch, the system is not capable of providing drivers with route guidance and navigational information via map displays. Navigation information is not the focus of the communications link between drivers and dispatchers. The transmission of position and location data through the OmniTRACS system was intended as a benefit for fleet management rather than an enhancement of driver navigation tasks. The design of the driver interface emphasized ease of use and acceptance by truck drivers in their normal operations.

Customer-Driven Support

The configuration of each system is different. Several options are available, and each unit can be customized to the customer's needs. After motor carriers understand the various features and optional software packages and how each can enhance their company's functions, QUALCOMM delivers the OmniTRACS hardware components, configures the system, and establishes communications links according to the customer's specifications. They also demonstrate or perform installation procedures, provide Driver's Manuals and Reference Cards for each unit, and suggest training programs to teach drivers and dispatchers how to use the system. This continued relationship with each customer has been the basis for QUALCOMM's evaluation of their design.

The analysis that follows is based on the information obtained from two applications of the OmniTRACS system, each configured to the specific requirements of the motor carrier. Since the system can support a variety of configurations and options to meet the various needs of diverse CVO customers, the analysis was performed at a higher level than for the other systems in this report. Specific design issues relevant to ATIS applications are raised in the context of the applications observed and may not reflect other possible configurations of this system. The emphasis of the analysis was on the interface of the on-board display unit used by the driver.

USER INTERFACE

General Description

The Mobile Communications Terminal (MCT) display unit is installed in the cab of trucks as determined by the motor carrier. The dimensions of the display unit are 29 cm long x 19 cm wide x 7 cm deep and weighs 1.1 kg (figure 47). It fits into a support bracket (i.e., holster) that is permanently attached to a sturdy panel. The MCT functions on power from the vehicle and has a coiled power cord that can be extended several feet.

The system is not intended to be used while the vehicle is in motion. Therefore, the MCT is typically installed by the customer so that the driver cannot see text displayed on the screen when the unit is in the holster. The drivers are instructed by the motor carrier to remove the MCT display unit from the holster and read/enter messages when they are parked. Drivers that were interviewed reported that the unit is easily retrieved from the holster located (with one motor carrier) below the dash panel, to the right of their legs, near the floorboard, next to the gearshift. Drivers hold the unit with one hand or support it on their laps or on the steering wheel when reading or entering information.

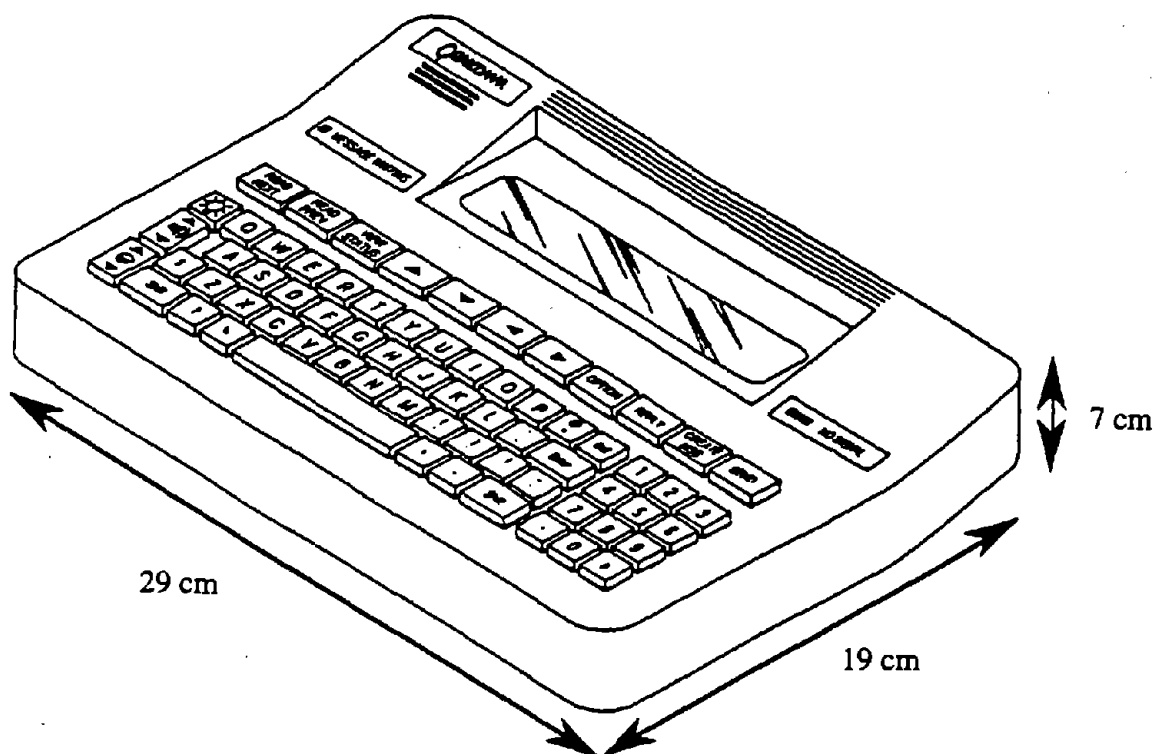


Figure 47. Dimensions of the MCT display unit.

The keyboard and display terminal of the OmniTRACS MCT is designed to be rugged and portable. All three hardware components, MCT communications unit, and antenna are designed to endure temperatures between -30° C to 70° C and much shock and vibration.

Visual Information Display

The display unit has a 5-cm by 13-cm, back-lit Liquid Crystal Display (LCD) message screen that displays 4 lines of text, 40 characters/line (figure 48). The back lighting can be turned on or off by pressing one of the control keys to the left of the keyboard. The display unit is automatically activated when the vehicle's ignition is turned on and will remain on for a period of time to be established by the dispatcher (up to 60 minutes) after the vehicle is powered down.

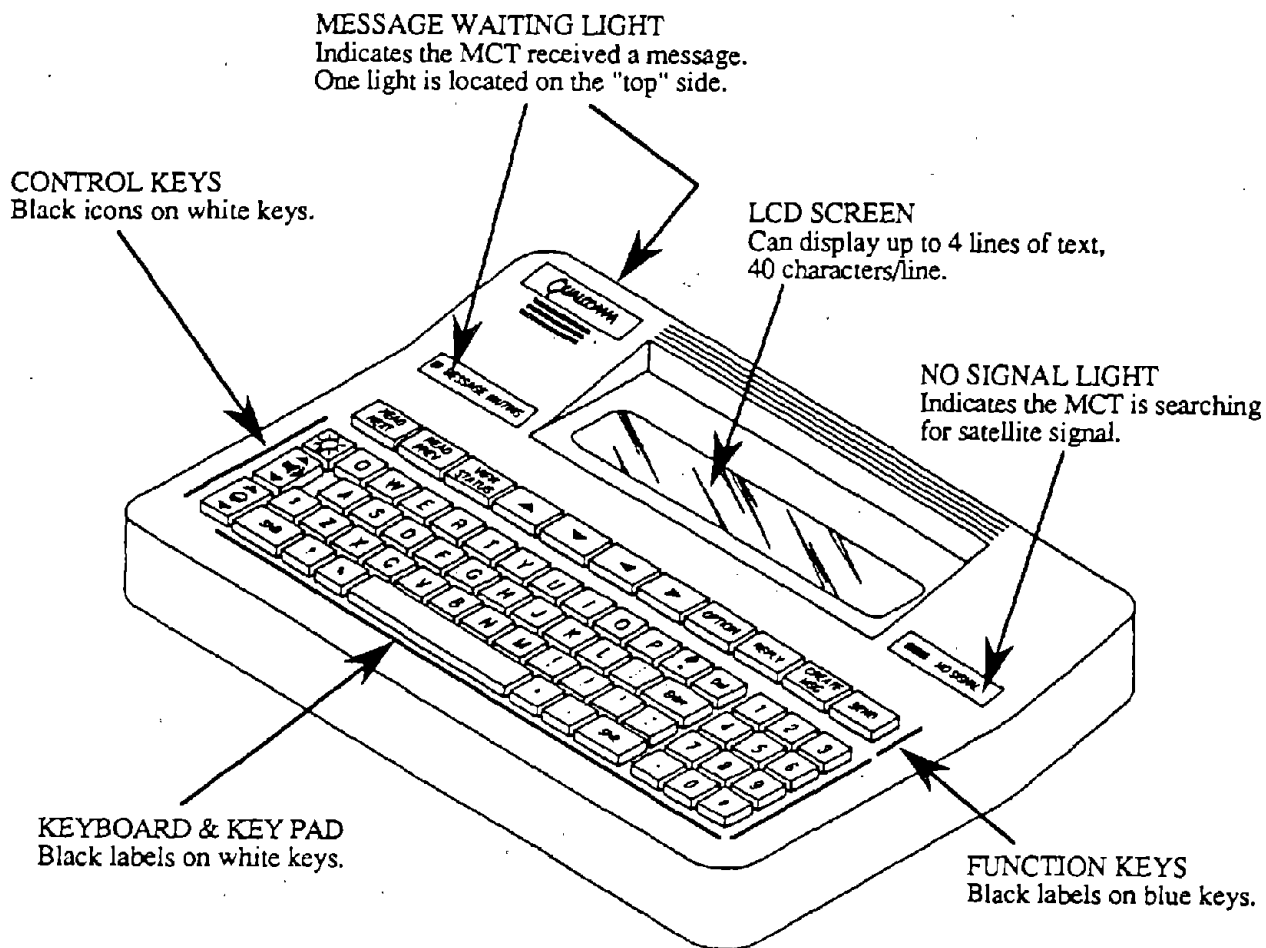


Figure 48. Features of the MCT display unit.

The main VIEW STATUS screen (figure 49) appears at start-up and indicates the time (for the driver-specified time zone) and date, whether the system status is "good," number of unread messages from dispatch, and number of messages being sent by the driver. The system has a buffer that allows drivers to send a maximum of three consecutive messages.

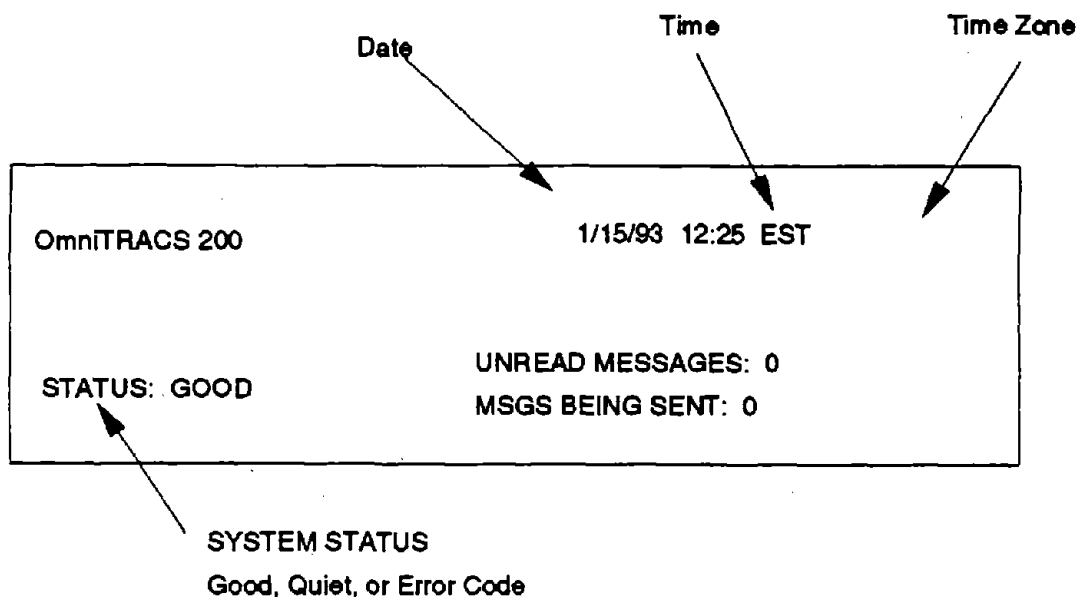


Figure 49. Display unit STATUS VIEW screen activated at start-up.

The information content of text messages varies depending on the application and can be as long as 50 lines. The system allows various types of information—either sent by dispatch or collected by vehicle monitoring systems—to be made available to the driver. There are no hardware limitations as to the content of messages. However, QUALCOMM does provide specific software products capable of providing specialized information links to customers that include the following:

- Directions.
- Routing.
- Comments.
- Basic Check Calls.
- Driver-Entered ETA.
- Location Validation.
- Load Assignments.
- Customer Service.
- Maintenance Information.
- Personnel.
- Accounting.
- Weather/Accident Reports.

All messages received from dispatch are displayed to the driver in uppercase text (figure 50). Messages created and sent by drivers are seen on the screen in lowercase text (figure 51). The case distinction enables drivers to readily determine the source of messages when drivers review previous messages. Messages can be received or transmitted whether vehicles are

stationary or in motion. If desired, an axle sensor option enables customers to halt interaction between the MCT and display unit when the vehicle is in motion. A wake-up timer feature operates when the unit is turned off that "wakes up" the unit at periodic intervals (defined by the dispatcher) and downloads messages.

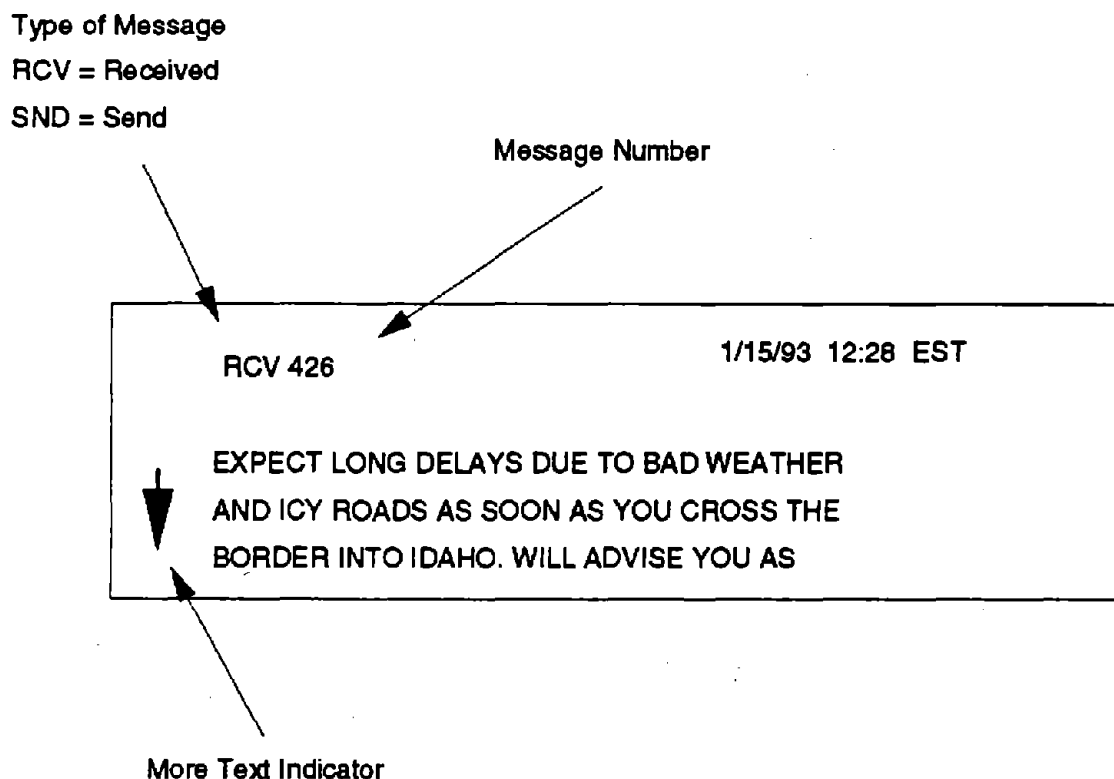


Figure 50. Sample text message received by driver.

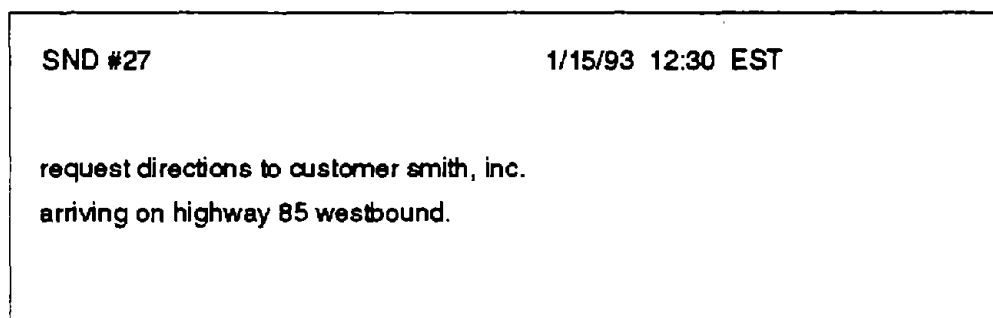


Figure 51. Sample text message created and sent by driver.

Upon request, dispatch can send drivers information about routes to a shipper/consignee location if that information is available. The level of information depends on the route planning databases or software connected to the dispatcher's system (e.g., Rand McNally's *Mile Maker* or ALK's *PC*MILER*). The routing information can be developed internally by a carrier by creating a database of instructions from actual drivers who have previously made a delivery/pick-up to the same destination.

Two red MESSAGE WAITING lights, one on the front and one on top of the unit, light up when a message is received. The lights flash if one of the messages received is a priority message (i.e., needs immediate driver attention). When the red light to the right of the message screen is lit, it indicates NO SIGNAL from the satellite is being received by the unit's antenna.

Auditory Information Display

The display unit emits a tone (beep) when a message is received from dispatch. The sound level of this tone is adjustable by the driver. The pattern of beeps emitted indicates the priority of the message and corresponds to the flashing of the message waiting lights (i.e., one beep indicates a message was received, three consecutive beeps indicates a priority message was received). Some drivers perceive single beeps to be similar to those heard through other on-board electronics (e.g., CB radio) and report false alarms in which they thought a message was received. They had to repeatedly check the status of the message light to determine whether a message was received.

The unit also emits two beeps whenever the driver presses a key that the system cannot act upon (e.g., pressing READ PREV when there are no previous messages listed). During training and in the Driver's Manual, drivers are told that the system is designed so that any key can be pressed at any time without damaging the system or losing typed information.

User Input (Controls)

The majority of the controls are discrete keys and include dedicated function keys, arrow (cursor) keys, a standard QWERTY keyboard, and a numeric key pad (figure 52). The entire control panel is constructed of an elastomeric-type material and is "splash-resistant" against contaminants. The screen backlight control key allows the driver to set the screen backlighting on or off. The audio control and contrast control rocker switches (continuous settings) adjust the volume of the message waiting beeps and the contrast of the text screen.

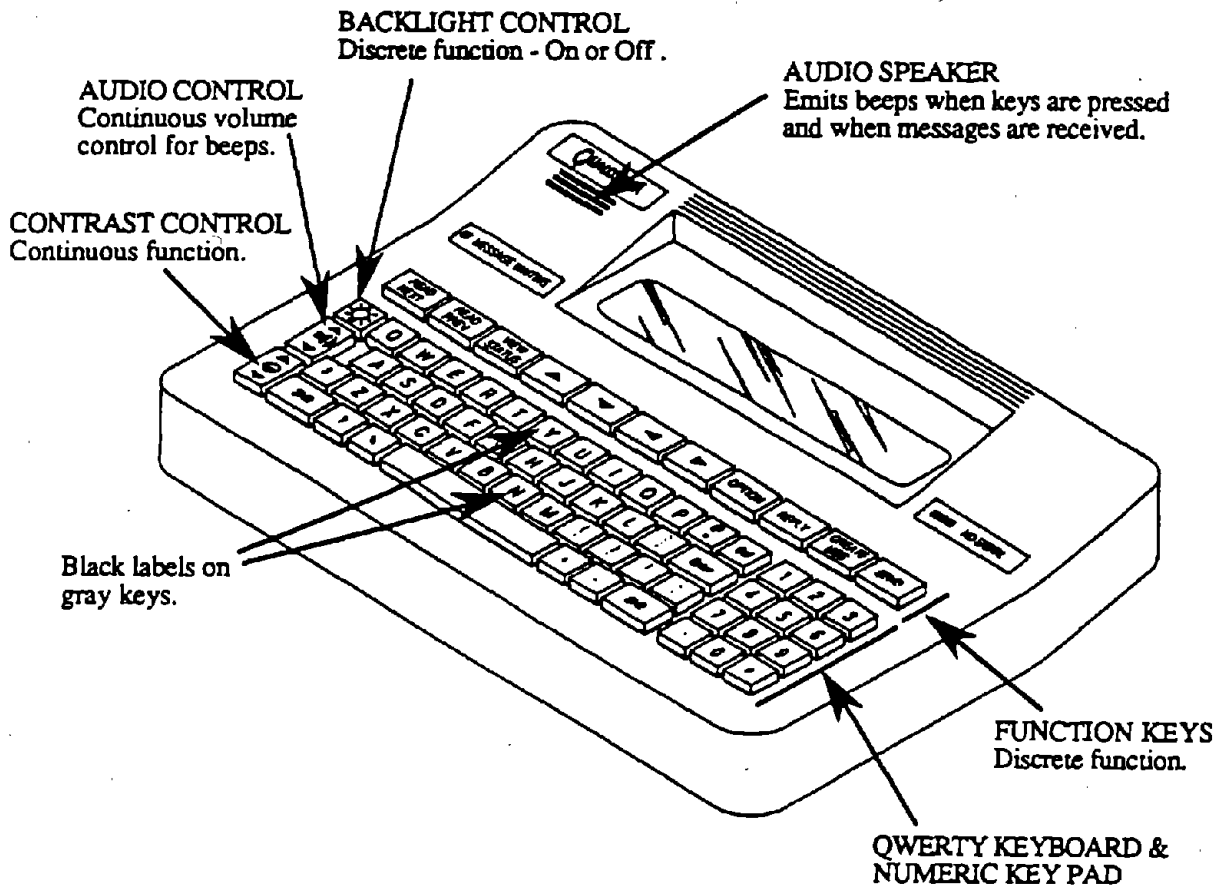


Figure 52. MCT display unit controls.

The blue dedicated function keys above the keyboard activate specific screens to read or enter information. A driver can access incoming messages by pressing the READ NEXT key; the READ PREV key is used to review a previous message. The memory stores 99 messages that can be reviewed by pressing the READ PREV key. The REPLY key initiates a reply to a message just read. The CREATE MSG key is used to create a new message and the SEND key calls up the option to transmit the entered message. The left and right arrows, ENTER, and DEL keys are used to edit text; and the + or - keys allow the driver to run through a list of company-defined, pre-formatted messages. These pre-formatted, fill-in-the-blank messages are designed to allow motor carriers to structure commonly used messages to minimize the number of characters the driver has to enter. For example, "Departing Information" could be a pre-formatted message in which the driver simply sends the time-stamped message with number of pallets loaded or other information.

The QWERTY keyboard and numeric key pad are used to enter alphanumeric text when creating messages and entering information. Drivers can scroll through a message by pressing the down arrow key. The screen indicates that there is more information beyond what is being displayed by using a ↑ and/or ↓ to the left of the text.

One of the main objectives in the design of this system was to ensure its ease of use by means of simple function keys. As the system was purchased by motor carriers, requests for additional features were made and those features were slowly incorporated into the system by adding them onto an OPTIONS function that allows access to several screens of information.

All the labels on the controls are black. The top row of dedicated function keys are blue and the rest are white. The Y and N keys, which are used most frequently, are a gray color to distinguish them from the rest. Drivers report that the darker color does allow them to find the Y and N keys easily in daylight conditions, but not in darkened conditions. They reported that tactile information (e.g., an etched key) could be helpful in identifying the two keys in the dark. Most drivers said the screen was easy to read in the dark, but it was difficult to enter messages using the keyboard at night without a cab light on. When prompted, the drivers agreed that having illuminated labels on all keys could make the system much easier to use in reduced-lighting conditions.

Communications Systems

The communications unit installed underneath the cab of the vehicle provides the computing capability to send and receive digital (i.e., text) messages to and from the truck. A decoder and microprocessor were designed to provide reliable signal processing capability. The manufacturer provides its own automatic satellite position reporting system to link fleet vehicles with dispatch centers and the NMC. This system utilizes existing electronics and satellite triangulation methods to provide vehicle position reports accurate to approximately 305 m. Drivers reported that the system loses the satellite signal when overhead objects block the direct line of sight between the antenna and the satellite. Position information directly impacts dispatchers' vehicle-tracking tasks and mapping capabilities.

Cognitive Demands

The issue of shared attentional demands—of great concern in the ATIS area—is not directly relevant with this system when it is used as recommended. This system was designed to be used while the vehicle is stationary. Customers are made aware of the limitations and intent of the system and are given the option of configuring the system to "lock out" the driver when the vehicle axles are in motion. The training materials and sessions provided by the manufacturer instruct drivers not to use the unit when in motion.

The display unit has a warning notice etched into the display explicitly instructing drivers not to use the system while driving (figure 53).

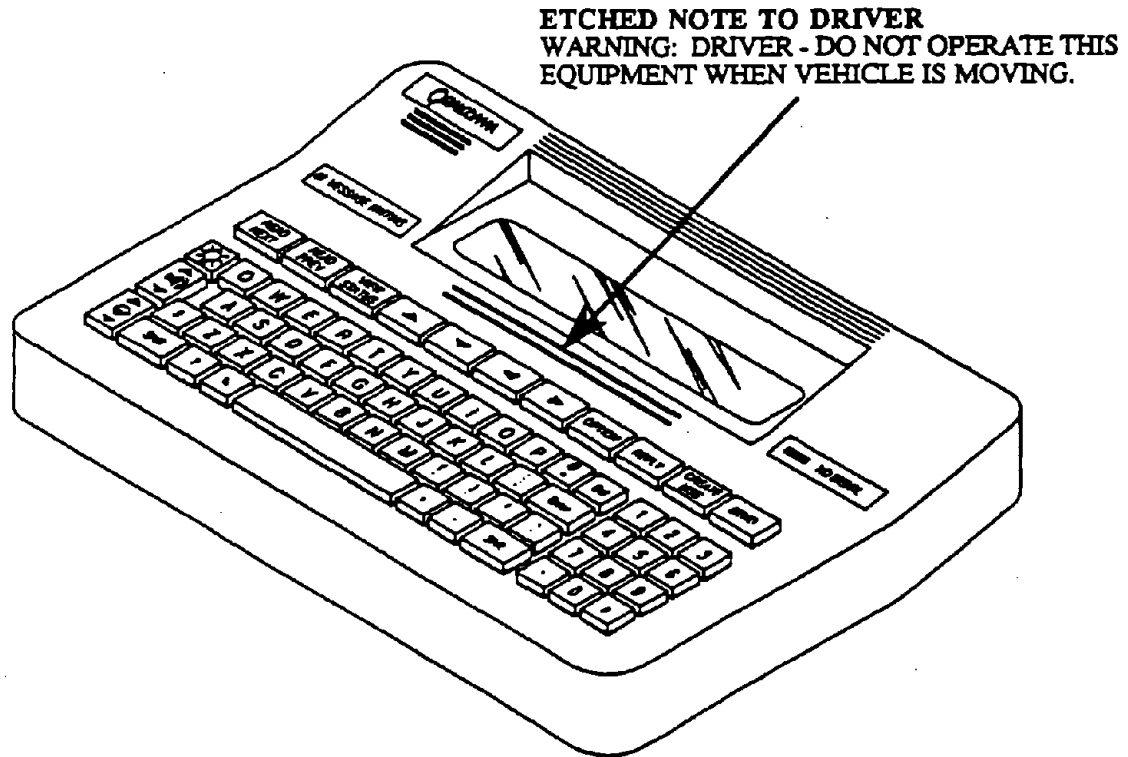


Figure 53. Warning notice engraved on front of MCT display unit.

The Driver's Manual also states a similar message:

Never use your MCT while you are driving. This will divert your attention from the road and could lead to a serious accident.

A lesson learned when we interviewed several drivers was that drivers do use the system while driving. When drivers use the system while the vehicle is in motion, the issue of cognitive demand is relevant, just as in ATIS systems. The allocation of attentional resources required to perform a secondary task utilizing an in-vehicle system may hinder driving performance and safety. Insufficient research data exist to set a criteria for attentional resource requirements in a driving task or for secondary tasks. The number of factors and individual characteristics, plus the dynamic and complex nature of the driving task, make it

difficult for research efforts to provide useful data. In CVO applications, there is even less data to make such recommendations. However, this issue must be resolved before in-vehicle systems can be confidently designed without jeopardizing driver safety.

In interviews, several truck drivers who admitted using the OmniTRACS system while driving said that they did not feel that it reduced their level of safety any more than the existing systems and paper maps that they already use. The benefits, on the other hand, completely outweighed the current system requirements and increased their job performance.

System Temporal Requirements

The LCD screen seemed to respond at a rate that did not affect data entry tasks. Some drivers reported a slight lag in messages being sent to dispatch, but it was acceptable in most cases. Drivers said the system does not indicate when dispatch reads their messages. In the observed system, the driver was informed that messages were sent to the dispatch center, but they had no idea when the dispatcher received or read the message. This feature did not seem to be a limitation of the system, but an aspect of the procedures developed by the customer.

DESIGN GUIDELINES USED

Human Factors Design Guidelines

The OmniTRACS design team seems to have been composed mostly of personnel from engineering and marketing. The objective of the first prototype was to meet the specific communications needs of commercial vehicle operations. There were no human factors members in the design team and it is uncertain whether human factors guidelines were used to design the driver or dispatcher interface. Once the needs of the CVO industry were delineated, the design team relied on available technology and cost-benefit decisions in selecting the components of the driver interface.

Other Guidelines

The evaluation of this system by QUALCOMM has been based primarily on its market use and consumer feedback. The success of the system was measured by the increased productivity and reduced costs of the customer (i.e., motor carriers, trucking companies), driver comments, and design team review. After company-mandated beta testing, the prototype was installed in a fleet of 5,000 vehicles belonging to the largest truck load carrier in the United States. This resulted in field-tested, positive reviews from various drivers, interested customers, and other members of the CVO industry. While engineers working on improving the system admit that the system could be enhanced considerably if customers supported the increase in cost, they also say the customers like the system as designed. The heavy use of this system and positive customer feedback has led QUALCOMM to feel that

the system is well designed and meets the needs of the CVO industry. Therefore, few alterations in the driver interface have been made since the first prototype, although changes may occur in the future.

Some of the design criteria emphasized environmental abuse (e.g., truck vibrations, temperature, humidity, impacts) in the trucking industry. For example, the existing size of the LCD screen seemed appropriate for the anticipated temperatures and vibrations in long-haul trucks, and integrating the display screen and keyboard into one "unit" or "terminal" was thought to be more practical and would endure more impacts.

Ease of installation was a primary design goal. All three components of the MCT system were designed to be installed in 2 to 4 hours and would be easily configured to different types of truck styles. The holster for the display unit can be mounted on any existing panel, allowing the customer to install the MCT to fit the types of trucks in their fleet.

The interface was designed to be user-friendly to a population with little computer knowledge and perhaps a dislike for computer-based products. The use of dedicated function keys was expected to simplify the interface and reduce the number of menu levels necessary. This guideline resulted in what drivers report to be an easy system to use. The design team is currently upgrading the system's functions. Whether these added features will require introducing more menu levels/options to each dedicated function key or integrating more dedicated function keys has yet to be determined.

Guidelines in the development of a training program revolved around simplicity, brevity, and ease of understanding. One customer developed its own training program to instruct drivers on the proper use of the MCT. Two hours of classroom demonstration were given as part of the company's general training program. Additional in-vehicle instruction also was integrated into the training. The Driver's Manual was designed to be brief, easy to read, and easy to find necessary information. A Driver's Reference card also was provided that showed drivers how to perform the most essential tasks (i.e., reading and sending messages).

LESSONS LEARNED

[OM 01] LCD DISPLAYS CAN PRODUCE GLARE WHEN DIRECT SUNLIGHT IS SHINING IN THE VEHICLE

- LCD screens can produce glare, especially when the sunlight is over the driver's left shoulder and shining on the unit or on reflective surfaces.
- LCD screens should be designed to minimize glare.

[OM 02] ADJUSTABLE DISPLAYS ALLEVIATE GLARE PROBLEMS

- Since some drivers hold the unit on their lap, or with one hand, glare problems seem to be remedied easily by changing the angle of the display screen. While this led drivers to respond that glare was not a problem, when prompted, they did say glare could be a problem at times.
- ATIS system display angle should be readily adjustable to the driver's preference.

[OM 03] DIRECT SUNLIGHT MAKES THE ACTIVATION OF WARNING LIGHTS DIFFICULT TO DETECT

- It was difficult for drivers to detect whether the red MESSAGE WAITING lights were lighted (or flashing) when direct sunlight was present.
- An auditory beep may provide necessary message waiting notice under direct lighting conditions.

[OM 04] LCD DISPLAYS REQUIRE BACKLIGHTING AND CONTRAST CONTROL

- In order to read text on the LCD screen under various conditions of lighting (from dawn to dusk), drivers reported that they relied on the back-lighting and contrast controls.
- Contrast and illumination controls should be made available to enhance visibility.

[OM 05] TEXT-BASED DISPLAYS THAT LACK "WRAP-AROUND" CAPABILITY CAN BE CONFUSING

- Drivers from one carrier complained that the words within messages and route information were broken up due to the lack of "wrapping text" and this made messages more difficult to understand. After reviewing one example of a typical message, it was evident that increased time was necessary to read and understand such messages.
- Display wording should remain intact and hyphenation should be kept to a minimum in order to facilitate message comprehension.

[OM 06] DRIVERS SOMETIMES SPILL BEVERAGES ON IN-VEHICLE EQUIPMENT

- The splash-resistant MCT display unit seemed to tolerate instances reported by drivers in which a beverage (e.g., coffee, soda, or water) was spilled over the screen and keyboard. The drivers reported relief when the unit's operation was not affected.
- ATIS/CVO displays and controls should be splash-resistant.

[OM 07] AUDITORY SIGNALS MAY BE MASKED BY, OR CONFUSED WITH, OTHER SOUNDS AND NOISES

- Besides the higher level of noise found in trucks versus cars, truck drivers typically have several other types of equipment in their vehicles. Two drivers with CB radios in their cabs said the beeps that occur when messages are received sound very similar to beeps emitted by CB communications. This causes false alarms and leads drivers to look at the light on top of the unit much more frequently than needed. Increased head-down time can lead to greater probability of near-incidents and accidents.
- Auditory information must be unique and easily discernible from background sounds.

[OM 08] TEXT-BASED ROUTE GUIDANCE DISPLAY IS PREFERRED OVER VERBAL INSTRUCTIONS AND MAPS

- Drivers relied on verbal instructions from dispatch and from conversations with the consignee to obtain route guidance to a destination. Some drivers supplemented this information with their personally purchased city maps. All drivers preferred the OmniTRACS system for route guidance over traditional methods.
- Drivers seemed to favor the use of text-based navigation displays over baseline procedures using paper maps.

[OM 09] NAVIGATION/ROUTE GUIDANCE FEATURES ARE NOT ESSENTIAL TO LONG-HAUL TRUCK DRIVERS

- Route guidance and navigation information was not a primary objective in the design of OmniTRACS. Some carriers have established interstate/highway routes that drivers are supposed to follow. Therefore, alternate routes and route planning are not necessary. Also, after repeated trips to the same destination, routes are easily remembered.

[OM 10] NAVIGATION/ROUTE GUIDANCE FEATURES CAN BE HELPFUL WITHIN CITY LIMITS

- Within city limits, some drivers do rely on verbal route instructions or city maps to reach an unfamiliar destination.
- In-vehicle navigation may be helpful for inner city and suburban CVO applications.

[OM 11] FOLLOWING TEXT-BASED ROUTE GUIDANCE INFORMATION IS NOT DIFFICULT

- Drivers reported that following text-based route guidance information on the display was easier and probably safer to use than following written instructions on paper or using paper maps.
- Text-based route guidance is feasible in CVO applications.

[OM 12] PRE-FORMATTED MESSAGES DECREASE THE AMOUNT OF DATA INPUT NEEDED IN REQUESTING ASSISTANCE

- The system is designed with a set of pre-formatted (i.e., "canned") priority messages intended for use when the vehicle breaks down. The time, date, and location of the vehicle are automatically sent to the company's maintenance/repair department when the driver sends the message.
- Users should be allowed to define short text-based messages that can be sent at the touch of a button.

[OM 13] DEDICATED EMERGENCY RESPONSE BUTTON IS VALUABLE FOR TRANSPORTING CERTAIN TYPES OF CARGO

- An automatic emergency response button provides the driver with the ability to call for immediate assistance at the push of a button. This feature is currently mandated for certain types of load assignments involving a Defense Transport Tracking System shipment.
- Requests for assistance should be made at the touch of a button.

[OM 14] ROAD ASSISTANCE REQUESTS CAN BE IMPEDED BY A TRUCK POWER FAILURE/SHUTDOWN

- Problems were encountered when the vehicle's power was disabled, which could affect the ability of the system to send the message or acknowledge that the message was actually transmitted.
- A backup power source should be available in case of vehicle power failure.

[OM 15] KEYBOARDS WITH QWERTY LAYOUT ARE PREFERRED OVER ABC-DEF LAYOUT

- A short pilot study by the OmniTRACS design team indicated that even drivers with very little, if any, typing experience preferred the QWERTY keyboard layout as opposed to an alphabetic keyboard layout.
- A QWERTY keyboard layout may be preferable over alphabetical keyboard layouts for typing specific text messages to communicate with dispatchers.

[OM 16] DEDICATED FUNCTION CONTROLS SIMPLIFY THE INTERFACE

- The interface was designed to be user-friendly for drivers who did not have any experience using computers and may be hesitant to use one. The use of dedicated function keys was expected to simplify the interface and reduce the number of menu levels necessary to use the various features of the system.
- Dedicated function keys and a small number of menu levels were successful in simplifying the ATIS system interface.

[OM 17] DRIVERS FIND GREAT BENEFIT IN VIEWING MESSAGES ON THE SCREEN WHILE DRIVING

- Some drivers suggested that the greatest benefit of this system was that they were not forced to interrupt their route to find a phone and contact dispatch. To some of the drivers interviewed, the instructions to discontinue their driving and pull over to communicate through the system seemed to contradict the function of the system.
- These drivers admitted that they found great value in reading messages from the display as the messages were received, especially route guidance messages. One driver cited an occasion when he received a message while he was on a bridge with slow-moving traffic. Pulling over was not possible for an unforeseen amount of time, so he had to read the message while driving.

[OM 18] DRIVING PERFORMANCE USING IN-VEHICLE DISPLAYS MAY BE COMPARABLE TO USING PAPER MAPS OR OTHER EQUIPMENT

- When drivers divide their attention between the primary task of driving and the secondary task of reading or typing messages, they reported that their performance on both tasks could be affected. While most of these drivers were aware of the hazards involved in doing both tasks simultaneously, some of them implied that the benefits outweighed the perceived risk. They reported that the system was so easy to use that with caution, concentration, and practice, they could maintain their level of driving performance and reduce the risk involved.
- Drivers did not feel that operating the OmniTRACS equipment hindered their driving performance any more than reading maps or written instructions, or operating other equipment, such as a CB, scanner, stereo, or cellular phone.

[OM 19] DRIVING WHILE HOLDING THE DISPLAY CAN LEAD TO INCREASED HEAD-DOWN TIME

- To incorrectly use the current system as a secondary task, the driver holds the unit in his/her lap or rests it on the steering wheel. This forces the driver to look downwards, away from a head-up position. While short glances at the display and a few key presses constitute the short and "not too demanding" task

of reading a message, several drivers confessed to typing messages with the unit on their lap while driving, and felt it hindered their driving.

- Display units should be located (and fixed) near the forward line of sight.

**[OM 20] *DISPLAYS MOUNTED AT EYE HEIGHT AND ARM'S LENGTH
REDUCE HEAD-DOWN TIME WHEN DRIVING***

- Some drivers acknowledged that if the unit were mounted closer to their horizontal line-of-sight, they could operate the equipment with greater ease. One driver had actually modified the support bracket that holds the display unit and reconfigured it to be mounted on the dashboard. In this position, the display unit was held to the right of the steering wheel, at arm's length, facing the driver, with the display window close to eye height. This driver believed he had improved the system by allowing him to easily retrieve and read the text messages while driving. He also admitted typing messages while driving, but felt that this did not result in a deterioration in driving performance.
- Display units should be located (and fixed) near the forward line of sight.

**[OM 21] *MANUFACTURERS MAY BE RELUCTANT TO MARKET DEVICES TO
BE USED WHILE DRIVING***

- The legal implications of requiring drivers to take their sight away from the road seems to be an obstacle that will have to be addressed by all ATIS in-vehicle display manufacturers. Until such issues are resolved, manufacturers may resort to systems that are only operable when a vehicle is parked. However, some drivers reported that the utility of the OmniTRACS system would be reduced considerably if they were forced to be parked to use the system. While it would still provide the ability to communicate with dispatch without a public phone, it would require them to interrupt their driving and increase the cost to the motor carrier.
- User acceptance of the ATIS system may be influenced by the ability of the system to be used while the vehicle is in motion.

[OM 22] *TRAINING PROGRAMS ARE AN ESSENTIAL PART OF THE SYSTEM*

- Guidelines in the development of a training program for OmniTRACS revolved around simplicity, brevity, and ease of understanding. One customer developed its own training program involving 2 hours of classroom instruction to train drivers on the proper use of the MCT. Additional in-vehicle instruction was also integrated into the training. The Driver's Manual was designed to be brief, easy to read, and easy to find necessary information. A Driver's Reference card also was provided that showed drivers how to perform the most essential tasks (i.e., reading and sending messages).
- Classroom and in-vehicle training, instruction manuals, and reference cards are beneficial component of an ATIS training program.

[OM 23] THE ABILITY TO COMMUNICATE WITH DISPATCH WITHOUT LEAVING THE VEHICLE IS PERCEIVED TO BE THE GREATEST UTILITY

- Drivers were enthusiastic about the ability to be in constant touch with dispatch, without having to stop and find a phone. Savings in time and frustration were emphasized.
- A continual communications link between driver and management center should be integrated into ATIS/CVO systems.

[OM 24] PAGERS ALLOW DRIVERS TO BE NOTIFIED OF INCOMING MESSAGES WHEN AWAY FROM TRUCK

- Carriers have the option of providing pagers for their drivers to further enhance the driver-dispatch communications link. Pagers allowed drivers to leave the vehicle (e.g., to check load) and still be connected to the system. The pagers were activated if dispatch sent a "priority" message (e.g., stop loading—go to another location). Most drivers were pleased to have the paging system, yet some mentioned occasions when dispatchers did not attempt to discriminate between priority and non-priority messages and would page the driver with a low-priority message. This resulted in some drivers ignoring their pagers until it was convenient to return to the vehicle to review the message(s).
- A continual communications link between driver and management center should be integrated into ATIS/CVO systems.

[OM 25] CUSTOMER-DRIVEN DESIGN APPROACH PROVED TO BE BENEFICIAL

- Customer-driven systems, such as OmniTRACS, may be constrained by the functions and features the CVO industry will purchase. The greatest need was seen for a communications link between dispatch and fleet vehicles. The secondary needs were efficient fleet management and reducing management costs. While the carrier that purchases the OmniTRACS system has to be persuaded that the system is cost-effective from a management perspective, the ultimate user is the driver. Therefore, carriers also have to be confident that the system is easy to use. This is the main impetus for a user-friendly interface. Future designs of ATIS/CVO systems will have to take into consideration whether the driver is going to purchase the system. If so, an ergonomically sound, user-centered approach can be easily justified in the cost of developing and designing the system.

- Designers of CVO in-vehicle systems will have to address a number of other factors, besides usability, related to the marketability of the system. While ergonomists contend that a user-centered design would result in a safer, more productive, and easier-to-use system that accounts for the capabilities and limitations of drivers, CVO customers are more likely to evaluate the system by its cost-effectiveness.

[OM 26] HUMAN FACTORS DESIGN GUIDELINES WERE NOT USED

- There were no human factors members in the OmniTRACS design team and it was uncertain whether human factors guidelines were referenced in the driver or dispatcher interface design. Once the needs of the CVO industry were delineated, the design team relied on available technology and cost/benefit decisions to select the components of the driver interface.
- Human Factors design guidelines are currently not used in the design of some ATIS/CVO systems.

[OM 27] DESIGN CRITERIA WERE MEDIATED BY MARKET DEMANDS

- The manufacturer evaluates the success of the system in terms of market penetration, sales, and consumer feedback. If customers report improved productivity and acceptance by drivers and dispatchers, then the user requirements are considered met. Few alterations in the driver interface have been made since the first prototype and few are likely to be incorporated in the future.
- Assessment techniques such as human factors evaluation or usability testing are not viewed as relevant when no problem is apparent.

[OM 28] DESIGN CRITERIA WERE DEPENDENT ON KNOWN SYSTEM ENVIRONMENTAL FACTORS

- Some guidelines were invoked regarding anticipated environmental abuse in the trucking industry. Factors such as vibration, temperature, humidity, and physical impact have a direct relation to the technology used in developing in-vehicle displays. In the CVO industry, these factors have a wider range of values and require systems that will endure. These system may not have the interface features that would be recommended to enhance usability and optimize performance.
- Usability factors may not be the highest priority in selecting in-vehicle systems technology.

[OM 29]

SYSTEM DESIGN REVOLVED AROUND INSTALLATION REQUIREMENTS

- Ease of installation was a primary design objective. All three components of the MCT system were designed to be installed in 2 to 4 hours and to be easily configured to different types of truck styles. The holster for the display unit can be mounted on any existing panel, allowing the customer to install the MCT to fit the types of trucks in their fleet.
- Installation requirements should be kept simple and procedures should support installation across different vehicle types.

CHAPTER 7. THE TravelPilot SYSTEM

BACKGROUND INFORMATION

The in-vehicle component of the TravelPilot system evolved from an earlier ETAK product called Navigator. The Navigator was intended to provide information regarding the current position of a vehicle and a destination referenced to the road system. The TravelPilot then evolved as a product for commercial applications that featured route selection and two-way communications to a dispatch center—functions that were not available in the consumer-targeted Navigator system.

The Navigator relied solely on dead reckoning to determine the location of the vehicle. Inputs to the dead-reckoning algorithms include heading from a non-gimballed, solid-state (fluxgate) compass and two wheel rotation sensors, one on each non-driven wheel. Systems currently in the prototype stage also rely on dead reckoning, but can be augmented with GPS. In addition, the Navigator, like other ETAK positioning systems (including the TravelPilot) use proprietary map-matching techniques to compute the position of the vehicle.

In the case of TravelPilot, ETAK and Blaupunkt (a subsidiary of Bosch) provided the in-vehicle positioning and mapping system and the in-vehicle display to a system Integrator company (i.e., PRC). TravelPilot was a second-generation product for the after-market. It is primarily a Bosch product. Blaupunkt was primarily responsible for display design, including modifications between the Navigator system and the TravelPilot system. ETAK performed the initial design of the hardware and pilot production. Since then, many of the hardware details have been changed by Bosch. Currently, the device is produced entirely in Germany. The TravelPilot is currently in its fourth version.

TravelPilot by ETAK is currently installed and used in trucks of the Seattle Fire Department. This on-board display system provides a communications link between emergency response vehicles (e.g., fire engines) and the Seattle Fire Department Dispatch Center. Because of the similarities between the Navigator and the TravelPilot systems, the lessons learned developing the Navigator also apply to the TravelPilot system and are included here.

GENERAL SYSTEM DESCRIPTION AND OBJECTIVES

The primary objective of this application of TravelPilot is to enhance the effectiveness of the Seattle Fire Department's emergency response capability. Specifically, many calls require immediate emergency response where every minute can make the difference between life and death. In the case of cardiac arrest, the goal is for emergency response to arrive 4 to 6 minutes after the call was placed. This requirement stresses the need to quickly dispatch the closest available vehicle to the scene of the accident. The dispatchers also have the

responsibility of managing the vehicles so that they may respond to emergencies around the city. This becomes difficult when severe emergencies (large fires) demand resources from across the city. In this situation, dispatchers must balance the immediate needs associated with the emergency with the need to accommodate other calls throughout the city.

A secondary objective of this system is to support record keeping that spans many functions of the fire department. The record-keeping system automates report filing, tracks response time of emergency crews, and tracks hazardous waste. The hazardous waste tracking includes identifying permits and fees required, and maintaining a record of the type, amount, and location of the material so that dispatchers and drivers are warned of dangerous materials before they arrive at the scene.

The TravelPilot system links emergency dispatchers with emergency response vehicles. Thus, the system includes units located in each vehicle and units with which dispatchers control several response vehicles/crews. The in-vehicle system provides drivers with location information regarding the emergency site and enables them to send and receive messages from the emergency dispatchers. For example, when the computer-aided dispatch sends a vehicle to an emergency, the TravelPilot in-vehicle system automatically receives a message from the dispatch center specifying the address and location. This is displayed in the vehicle on a simple map display. When the driver leaves the station, the TravelPilot automatically notifies the dispatch center that the driver has left. Thus, the TravelPilot system provides drivers with location information and it enables them to communicate their location and status to dispatchers more easily than is possible with standard radio communication. In addition, the system aids dispatchers in monitoring the status of vehicles and in dispatching the appropriate type and quantity of emergency vehicles. Furthermore, the system helps identify specific vehicles based on their location and operational status. The ATIS functional characteristics that apply to TravelPilot are listed in table 6.

Table 6. Comparison of TravelPilot functions with those from ATIS/CVO systems.

Subsystem	Function	TravelPilot
IRANS	Trip Planning	
	Multi-Mode Travel Coordination	
	Pre-Drive Route and Destination Selection	✓
	Dynamic Route Selection	
	Route Navigation	✓
	Route Guidance	✓
	Automated Toll Collection	
	Route Scheduling (CVO-Specific)	✓
	Computer-Aided Dispatch (CVO-Specific)	✓
IM SIS	Broadcast Services/Attractions	
	Services/Attractions Directory	
	Destination Coordination	
	Message Transfer	
ISIS	Roadway Sign—Guidance	
	Roadway Sign—Notification	
	Roadway Sign—Regulatory	
IVSAWS	Immediate Hazard Warning	
	Roadway Condition Information	
	Automatic Aid	
	Manual Aid Request	
	Vehicle Condition Monitoring	
	Cargo and Vehicle Monitoring (CVO-Specific)	
CVO-Specific	Fleet Resource Management	✓
	Dispatch	✓
	Regulatory Administration	✓
	Regulatory Enforcement	

USER INTERFACE

General Description

Driver Interface

There is no auditory component to this system. A monochrome CRT located on the vehicle's dash is used to display the text-based menus and messages, and the maps showing the current position of the vehicle and the destination. The CRT is approximately 11.4 cm measured diagonally. The CRT is covered with a sheet of treated lexan. This sheet protects the occupant in the event the CRT is broken. It also is used to mitigate the effects of glare and reflection off the screen. The screen displays information in green characters and symbols on a black background.

The graphic display consists of a simplified road map of Seattle, centered on the driver's location and oriented in the direction of travel (i.e., heading up). The driver can select from a variety of map scales, including low-resolution views that display a large portion of the city and high-resolution views that display only a small part of the city. At the bottom of the map graphic is a text message sent by the dispatcher; generally, this message contains the address of the destination. At the top of the map display is a status line that provides information regarding map scale, straight-line direction to destination, distance to destination, direction of north, and unit status.

Buttons along each side of the CRT control the display and allow the driver to enter a menu system that guides the driver through a variety of screen configurations and message choices. Thus, the screen can contain text and graphics (a heading-up map with icons representing the current vehicle position and the destination). The functions of the buttons along the two sides of the display depend on the system state and change with menu selections. For instance, if the map is shown and the "MEN" button at the top of the left row of buttons is pressed, the display changes to show a text description of the standard system menu functions. Pressing this button again engages the "Select Destination" function. Other buttons also change function in a similar way as the driver engages different functions of the system.

Dispatcher Interface

Dispatchers interact with a different part of the system and their interface is substantially more complicated. The room that houses the dispatchers consists of five self-contained workstations that have identical capabilities. From each of these five workstations, dispatchers can receive telephone calls, enter information into the computer system, communicate with drivers, and monitor driver and vehicle status and position. The controls and displays that face the dispatcher include banks of buttons for manually alerting fire stations, multiple radio control channels for communicating directly with drivers, and a keyboard and two 33-cm displays for interacting with the computer-aided dispatch and automatic vehicle location functions. The dispatchers' room also includes two large-screen monitors (approx-

mately 122 cm diagonally) that display position information of emergency vehicles on a simplified map of Seattle.

Visual Information Display

Driver Information

The primary driver information display is the in-vehicle map. Their own vehicle position is fixed at a point in the middle of the screen laterally and approximately two-thirds of the way down from the top edge (figure 54). Text, when displayed on the map, appears on the bottom of the screen.

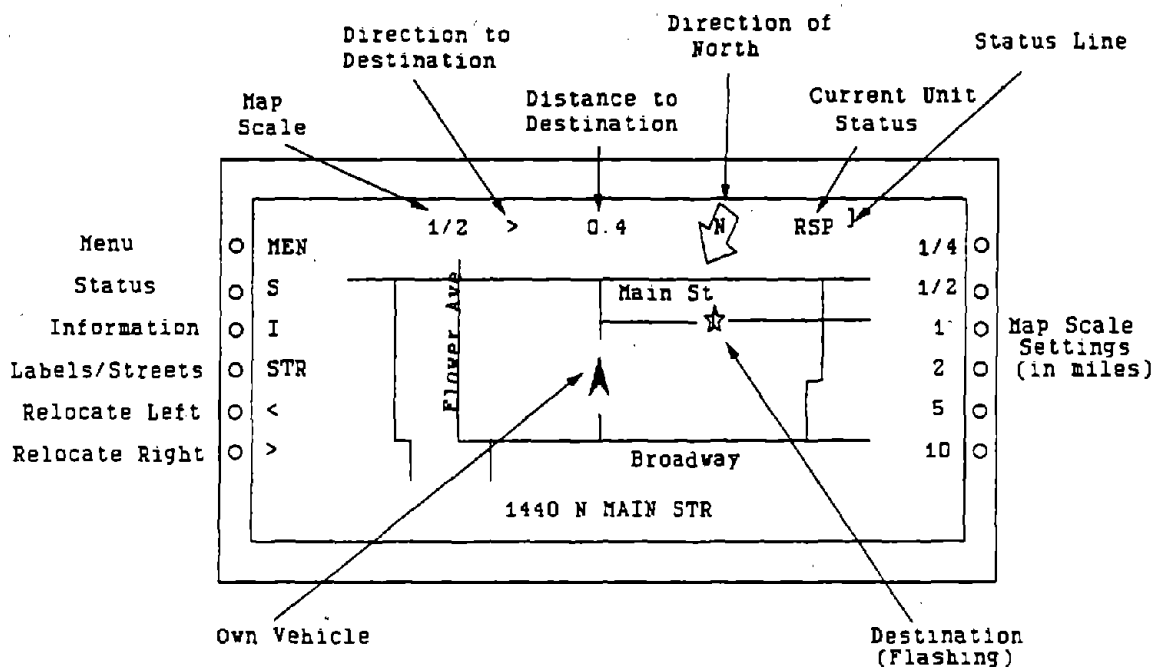


Figure 54. Sample map display screen that appears when vehicle is started or when requested by driver.

The distance between the "own vehicle" symbol and the top edge of the screen defines the scale of the map display. For example, if the user selected an 8-km scale, then the distance between the vehicle symbol and the top edge of the screen would correspond to 8.0 km. If a 1.6-km scale were selected, then this distance would reflect 1.6 km. More detail is shown on the larger map scales (e.g., 0.8-km scale) than on the smaller scales (e.g., 16.1-km scale). When a destination is entered, the largest map scale (i.e., the scale showing the smallest geographic area) that allows both the destination and the own vehicle position to be displayed is automatically selected. There are some situations in which the destination may be farther away from the own vehicle than the scale would suggest. For example, the destination could be more than 8 km away when the 8-km scale is selected. This occurs when the destination

is outside a circle centered on the own vehicle, but within the rectangular limits of the screen. The destination will normally be in the upper-left or upper-right corner of the screen in these situations.

As the scale of the map is changed, the level of detail also changes. At the largest scales, a small geographic area is displayed and all of the roads are depicted. As the scale is reduced, the amount of area depicted increases and the level of detail is reduced. At small scales, the road that the own vehicle is on may be removed from the map, particularly if the road is a "minor" one. The map is always displayed in a "heading-up" mode. There is no provision for presenting the map in a "north-up" orientation.

Not all of the roads are labeled. There is a provision for cycling through the streets, putting names on a different subset of the streets displayed on each cycle. (The "STR" button on the left side of the map display performs this function.) ETAK has developed a patented technique of dynamic labeling. This technique does not clip the labels at the screen edge, and does not allow labels to overwrite one another. In addition, the letters in the labels are always parallel to the street that they name, regardless of the orientation of the street. In addition the labels are always read left to right. This last constraint results in some labels being read from bottom to top, while others are read from top to bottom, depending on the orientation of the road on the screen.

To the left and right of the map display are short labels for the function buttons that are used to control the display. As mentioned earlier, these labels, and consequently the functions of the buttons, change as the operator selects different functions. The labels to the right of the map control the map scale and those to the left provide access to text screens containing menus of system functions. The buttons on the left also control the level of detail in the map display; street names can be removed to reduce display clutter. The status screen (figure 55), selected from one of the left buttons when the map is displayed, re-labels the function buttons with a short abbreviation of the text messages that the unit sends when the buttons are depressed in the "status" mode. For example, pressing a button on the left side marked "STA" sends a message to the dispatchers that the unit is available at the station. When activated, the "RSP" button on the right notifies the dispatchers that the unit is responding to the incident.

Activated When Pressing
S Key in Map Mode

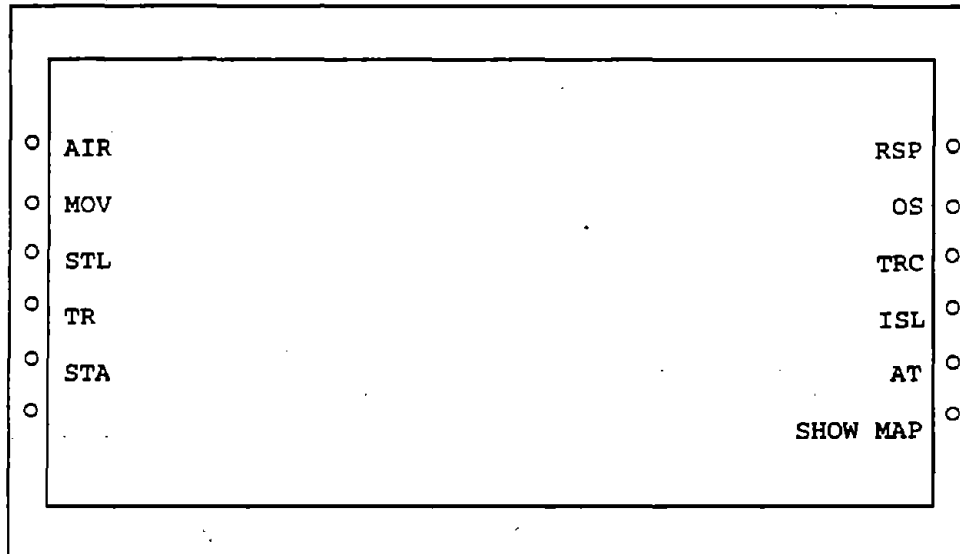


Figure 55. Text-based status screen that is activated by pressing the S button on the map screen.

Destinations are typically received by dispatch and subsequently issued to one or more specific emergency vehicles, yet the system does allow the driver to select a destination when necessary. This procedure is based on text-based menu screens from which a driver chooses various categories of destinations. The driver may choose among the following options:

- **Select Destination:**

- Street address.
- Stored address.
- Street name.
- Intersection.

- **Stored Locations:**

The system allows the operator to maintain a set of stored locations, which can be an address or point on a map, that have been assigned a mnemonic name. Stored locations can be added, deleted, or sorted. These locations can be entered into the system as a street address, any location on the map, the current destination, a street name, or an intersection.

Dispatcher Information

The information display for the dispatchers consists of two standard CRT's located at each workstation and two large monitors mounted at either end of the room. One CRT in each

workstation displays the history of the incident and provides the dispatcher with a command line that can be used to enter information into the system (Data Entry CRT). The other CRT in each workstation displays the status of incidents and vehicles, and of the resources available to the dispatcher (Status CRT). The information on the Status CRT includes incidents that have been entered into the computer but are waiting to have emergency crews dispatched. The information also includes active incidents, which includes any incident for which crews have been dispatched. The display also shows the available vehicles and those that are classified as being on special status (in the shop for repair, out of service to conduct inspections or ceremonies and other special events).

When the dispatcher receives an emergency call, information concerning the incident is entered into the computer and simultaneously displayed on the Data Entry CRT by using the keyboard. This information includes an address and a type code that describes the type of accident or incident. For example, the type of code would differentiate between a house and an office building fire, and a heart attack. The system does not directly support the dispatcher in entering the type code; they must remember the appropriate code or find it in a separate paper-based index. After the incident has been entered into the computer, the CRT displaying the status of the vehicles and incidents adds it to the queue. In addition, the computer-aided dispatch system pairs an appropriate response (an appropriate set of vehicles selected from a location near the accident) with the incident. The information specifying the type and number of emergency vehicles appears as alphanumeric codes. The information appearing on the Status CRT appears on the status displays of all the dispatchers.

The two large monitors at each end of the room display map information concerning the location of the incident and the movement of emergency vehicles to the incident. This information can be manipulated by any of the dispatchers using the command line interface associated with the Data Entry CRT. For example, dispatchers can display parts of the map associated with each of the incidents. The operators can also specify the scale and detail included in the view (e.g., removing street names to reduce clutter).

Auditory Information Display

We are not aware of any auditory display associated with the in-vehicle portion of TravelPilot. There are conventional voice radio communication systems in the vehicles equipped with TravelPilot.

User Input (Controls)

There are six buttons arranged vertically on either side of the CRT. These buttons appear to be about 9.5 mm in diameter. The buttons are separated by about 12.7 mm (the size and separation are estimated, not measured).

The buttons along the side of the display are the primary controls available to the user. The physical characteristics of the button were described in the General Description section above. The function of each button is labeled by text on the screen adjacent to the button. Buttons

that are not active have no label. Similarly, functions that do exist in the system but are not available from the current page are not displayed. If the user wants or needs to use this control, the system, or vehicle (if there is a motion interlock), must be put in the correct configuration. No system aids have been identified that assist the operator in configuring the system or vehicle.

Some features are not available when the vehicle is in motion. For example, a destination cannot be entered by the driver when the vehicle is in motion. Sensors attached to the wheel report vehicle motion. The driver need not put the transmission in "park" as is the case on another of the systems (e.g., TravTek) reviewed here. Other functions, such as being able to change the scale of the map, are available while in motion. There is an override that allows entry of a destination while in motion as part of the Navigator system. This is intended to allow a person other than the driver to enter a destination while in motion. We were not able to confirm whether this optional feature was provided in the systems used by the Seattle Fire Department. (This override feature is provided in response to user specifications.)

Communications Systems

Since the purpose of the emergency response dispatch system is to communicate information from the dispatchers to the drivers, a critical element of this system is the communication system. The communication requirements involve both information from the dispatchers to the drivers, and information from the drivers to the dispatchers. Specifically, drivers must know where and when they are to respond to incidents. Likewise, dispatchers must efficiently allocate a limited resource (emergency response vehicles and crews). This implies that dispatchers must be able to track the location and status of vehicles under their purview.

Traditionally, dispatchers and vehicles transferred vital information using voice communication over standard radio frequencies and hardwired alarms at the stations. The TravelPilot augments this communications channel by enabling the dispatch system to track the location and status of vehicles without voice communication over radio channels. An Automatic Vehicle Location (AVL) system monitors vehicle location and status, and transmits that information to the dispatch center automatically. This information is broadcast over an RF channel, received by a radio tower, and forwarded to the dispatch center by a telephone line. In a similar manner, information such as messages deploying vehicles to an incident is transferred from the dispatch center to a broadcasting tower through a dedicated telephone line. The broadcast center forwards this information to the vehicles through an RF transmission. The drivers and dispatchers also communicate by voice using a standard radio.

The voice communication takes place in two phases. In the first phase, dispatchers send a message that informs the crew of the general area of the incident and sends them on their journey. During the journey, a second message provides specific information regarding the exact location of the incident and detailed information regarding what the crew is to expect.

Cognitive Demands

Attentional Demands on Drivers

The cognitive demands associated with the TravelPilot system in the vehicles should not affect drivers because they are not meant to observe or manipulate the device while driving. However, the passenger could use the device to provide the driver with more precise location information and better directions when traveling in unfamiliar areas. In addition, the system can help reduce the workload associated with reporting the unit's status to the dispatcher. Conversely, the system also imposes significant cognitive demands on the vehicle operators that would not have occurred otherwise. For example, accessing the functions of the TravelPilot requires navigation through a structured menu system. This task may impose demands on long-term memory in terms of remembering the menu structure and the commands to invoke specific functions. The cognitive demands associated with learning system functions are illustrated by the training requirements. The vehicle crews participated in 8 hours of training before the system was fielded and then received another 2 hours of on-road training when the system was installed. In addition, efficient operation of the system requires that operators understand the factors that cause the location estimation ability of the device to become miscalibrated. Likewise, drivers must know how to re-calibrate the system. Otherwise, the system generates erroneous information for the vehicle operators and the dispatchers.

Cognitive Demands on Dispatchers

The system eliminates many error-prone and repetitive tasks for dispatchers (e.g., manually looking up address to determine appropriate station for response). In addition, the system provides dispatchers with the capability to manage the emergency vehicle in ways that were not possible before. For example, the system keeps an electronic log of all responses. This log includes response times and incident types. These data can be analyzed to obtain measures of system performance. In addition, the system is able to pair a set of vehicles with an incident type. For example, the system would automatically assign a different set of vehicles to a two-alarm fire, a minor brush fire, or a cardiac arrest report. Previously, the dispatcher had little support in matching incident type with an appropriate response. In addition to selecting the appropriate type or set of vehicles, the system also identifies specific vehicles for the response by using AVL to first determine if any emergency vehicles might be available and already near the scene of the incident. If no vehicles are in the immediate proximity of the incident, then the system identifies vehicles in nearby stations. In this way, the system minimizes the cognitive load on the dispatcher, while enabling the dispatcher to match the emergency response centers' limited resources to the emergency response needs of the city.

Although the system reduces the cognitive load of the dispatcher in many ways, the new technology also introduces some new demands and potential problems for the dispatchers. For example, although the system automatically identifies sets of emergency response vehicles, the dispatcher has the ultimate responsibility for ensuring that the most appropriate

team has been selected. Since the computer-aided dispatch system may not have access to the current state of all vehicles (drivers forget to place them out of service when they go to the shop for maintenance), the group of vehicles the system recommends may not actually be available. Similarly, in some circumstances, the algorithm used to select vehicles may not accurately choose the best set of vehicles. Specifically, if the system is not able to find a vehicle already in the vicinity of the incident, it selects a group of vehicles from the nearest station. However, the algorithm does not verify that those vehicles are near the station. For instance, the needed vehicle may be available, but it may be returning from a call across town. In this situation, the computer provides a poor selection of vehicles because it fails to select the closest available vehicles. Since the computer makes these types of mistakes, the system introduces a substantial cognitive load associated with monitoring the feasibility of the computer recommendations.

The introduction of the new system also changed the processing of aid requests and the interaction among the dispatchers. In the previous system, dispatchers used a card file of addresses to identify the appropriate station from which to dispatch vehicles. In the current system, the computer does this task automatically. While the previous system forced dispatchers to perform a tedious and somewhat time-consuming task, performing this task had a side benefit of increasing the awareness of dispatchers of the other calls that the center had received. When an incident was reported, this information quickly became shared knowledge; and when an incident generated multiple calls, the dispatchers were able to identify multiple aid requests associated with the same incident. Now that the dispatchers do not rely on the same common resource (the card file of addresses), multiple reports of the same incident may be entered into the system. This results in added workload as the multiple entries must be filtered so that dispatchers do not mistakenly send multiple responses to a single incident.

More generally, introducing the computer-aided dispatch generates additional cognitive demands associated with simply interacting with the system. Often the command line interface can frustrate dispatchers because it requires memory of precise syntax. For infrequently used commands, this becomes problematic. These demands may reduce dispatcher efficiency, especially when workload demands are already high and the added burden of remembering and entering the precise data or syntax can severely degrade dispatcher performance. In addition, the barrier that the command line interface imposes can inhibit the users so that they fail to use the system to its full potential. For example, the dispatch center has two monitors at either end of the room. These monitors display a city map and provide an overview of the situation by displaying the real-time location of the emergency response vehicles and the incident. The operators do not use this map, in part, because the command line interface makes changing scales and views awkward. Thus, the characteristics of the computer interface may reduce dispatcher efficiency and inhibit their use of the full capability of the system.

DESIGN GUIDELINES USED

Human Factors Design Guidelines

Development of the Navigator began in 1983 and required more than 2 years to bring to market. Roughly 2,000 Navigator systems were sold as after-market equipment through an ETAK dealer network in California. The size of the design team ranged between 15 to 35 people. The members of the Navigator design team had backgrounds in computer science, engineering, navigation, and cartography. Human factors guidelines were consulted in the development of the Navigator. The areas where the input was useful are exemplified by the selection of font size and reach envelopes for installation position guidelines. Unfortunately, the titles of the specific human factors references and guidelines were not available.

The interview with the principal engineer from the system integrator, PRC, suggested that their group has little knowledge of human factors or ergonomics. However, for many of their objectives, they feel no need for human factors guidelines. Much of their concern focuses on a systems perspective that addresses information requirements and system architecture specifications. PRC focuses on the content of displays and not their form; they identify what to display, not how to display it. Conversely, their role in system development spans the spectrum from specifying the size and location of information on the screen to training the operators after the system is installed. They do not currently employ human factors specialists or use any human factors guidelines:

This lack of understanding of the scope of human factors is commonplace in the engineering community. Clearly, human factors practitioners contribute to a systems perspective, information requirements, the content of screens, and operator training.

Other Guidelines

The Navigator was evaluated by an outside agency (Failure Analysis Associates, Inc.). This evaluation focused primarily on crashworthiness and liability issues, rather than usability testing or Human Factors issues such as glance frequency and duration.

A variety of standards and guidelines were used in developing the Navigator. Standards were used to determine the location of the device within the vehicles. Society of Automotive Engineers (SAE) standards were mentioned as being used specifically. Examples of areas in which standards were used to guide the design include ruggedization and moisture resistance. The design team also relied on standards concerning crashworthiness. Standards and conventions from cartography were examined in the development of the dynamic labeling algorithm. Notably, the decision to position labels parallel to roads to minimize the difficulty of associating a name with a road, rather than keeping all text horizontal to improve readability, was decided based on the cartographic literature.

More generally, the process used for system development does not seem to rely on any formal guidelines developed by any discipline. The single exception lies in the use of DOD engineering benchmarks for architecture and performance standards. In this instance, these standards were employed as a checklist to ensure product quality, rather than a tool that guides the design process. PRC employs methods and techniques that have been developed and tailored to the needs of emergency dispatcher centers. The methods and techniques focus on identifying user needs and then constructing a system to meet those needs. They elicit user needs through an intensive process of interviews with all potential users, including managers, drivers, dispatchers, and administrators. PRC uses people with domain expertise (e.g., experienced dispatchers and former police officers) and technical expertise (e.g., system engineering and computer science) to bridge the gap between defining user requirements, conceptual development, and operational implementation.

In addition to the methods that PRC has developed to gather and process information regarding user needs, they use several other tools to guide the software development process. Since each emergency dispatch installation is unique they do not install ready-made systems, rather they provide custom-designed solutions to the client's problems. However, since they install many similar systems, they are able to develop custom-designed software from a collection of relatively generic modules that can be tailored to specific needs. To aid in this process, PRC uses a variety of Computer-Aided Software Engineering (CASE) tools. These tools can aid in the understanding of complex workflow and data modeling problems.

Other Sources of Design Guidance

ETAK has, almost since its inception, required all staff working on vehicle navigation to have a device in their personal vehicle and to keep logs of the use of the system, particularly errors and anomalies. All staff members are required to personally install the system in their own vehicle. The result is that they have lots of documented on-the-road mileage using their systems in a wide variety of vehicles.

ETAK has performed evaluations of concepts and design options using non-staff members. In particular, they have brought in subjects who were not experienced with the use of navigation devices and tasked them to drive to various locations. Subjective data were normally obtained. In some instances, they placed video cameras into cars to monitor the amount of time the driver spent looking away from the road. The purpose was to measure the time drivers looked at the display instead of the road (e.g., at stop lights or while in stop-and-go traffic), and to see if that amount of time and pattern were subjectively acceptable to drivers. No results of this effort are available.

ETAK reportedly tested novice users from various categories of the driving population. Age and gender were two of the factors used to stratify subjects.

Failure Analysis Associates, Inc., analyzed the Owner's Manual and the User's Manual prepared for the Navigator. The emphasis was on the adequacy of the warning labels.

Effectiveness of Human Factors Guidelines Used By System Designers

Human factors guidelines were useful in the interface aspects of the design. Selection of font size is an example. Human factors guidelines were not available (or were not found) on which to base other design decisions. Examples reported include:

- Map Orientation (heading up vs. north up).
- Map Presentation vs. "Guidance" Information Displays (e.g., turn arrows).
- Dynamic Map Scaling.
- Dynamic Labeling Techniques.
- Adaptive Displays.
- Fail-Safe Design.

The human factors literature used by ETAK in the development of the Navigator was inadequate to guide design decisions regarding map display features (e.g., area fills) that facilitate "situational awareness" or enhance "spatial awareness." As an example, no information was reportedly found that indicated whether coding notable regions, such as a body of water, in addition to the road network, would result in easier navigation to a destination.

LESSONS LEARNED

[TP 01] HFE GUIDELINES USED FOR FONT SIZE

- Human Factors Engineering (HFE) guidelines were consulted in the development of the Navigator, particularly for the selection of font size, and reach envelopes for installation position guidelines. The titles of the specific human factors references and guidelines were not available.
- Engineers/designers used existing human factors guidelines only for font size and reach envelope recommendations in the design of the interface.

[TP 02] HUMAN FACTORS IS NOT RECOGNIZED BY INDUSTRY MANAGERS

- The interview with the principal engineer from PRC (the system developer/integrator for TravelPilot) suggests that their group has little knowledge of, or perceived need for, human factors or ergonomics.

[TP 03] THE SYSTEM EVALUATION CRITERIA EXCLUDED HUMAN FACTORS

- The Navigator was evaluated by an outside agency that focused on crashworthiness and liability issues, rather than usability testing or human factors issues.

[TP 04] SAE STANDARDS WERE USED IN THE DESIGN PROCESS

- A variety of standards and guidelines were used in developing the Navigator. Society of Automotive Engineers (SAE) standards were used to determine the location of the device within the vehicles, and for criteria for ruggedization and moisture resistance. The design team also used standards on crashworthiness. Standards and conventions from cartography were used in the development of the dynamic labeling algorithm.
 - Engineering design guidelines other than human factors were integrated into the design process.

[TP 05] AN ENGINEERING APPROACH TO SYSTEM DEVELOPMENT WAS USED

- The process used for development of the TravelPilot system did not rely on any formal guidelines other than SAE and DOD engineering benchmarks for architecture and performance standards.
- The TravelPilot developer relied on people who have domain expertise (e.g., experienced dispatchers, former police officers) and technical expertise (e.g., system engineering, computer science) to bridge the gap between defining user requirements, conceptual development, and operational implementation.

[TP 06] CASE DESIGN TOOLS WERE USEFUL

- A variety of Computer-Aided Software Engineering (CASE) tools were used. These tools can help to understand complex workflow and data modeling problems.

[TP 07] IN-HOUSE STAFF USABILITY TESTING CAN PRODUCE VALUABLE INFORMATION

- ETAK has historically required all staff working on vehicle navigation to install a device in their own personal vehicle and to keep logs of the use of the system, particularly errors and anomalies.
- This policy fosters personal experience with the technology developed and can lead to early design improvements.

[TP 08] INFORMAL DRIVER STUDIES CAN PROVIDE INSIGHTS INTO DESIGN ISSUES

- ETAK has performed evaluations of navigation concepts and design options using non-staff members. They measured the time drivers spent looking away from the road, when they looked at the display instead of the road (e.g., at stop lights or while in stop-and-go traffic), and to see if that amount of time and pattern were subjectively acceptable to drivers.

- Effort was placed on methods for "knowing the user" and their driving behaviors that seemed to lead to a better design early in the development process.

[TP 09] EVALUATIONS OF MANUALS NOT CENTERED ON USABILITY

- An evaluation of the Owner's Manual and the User's Manual was performed that focused on the adequacy of the warning labels rather than on the usability or instructional value of the manuals.

[TP 10] MANY DESIGN FEATURES AND CRITERIA ARE PRIMARILY BASED ON COST

- Cost is the biggest constraint for the consumer versions of navigation systems. In current dollars, ETAK believes that there is a market below the \$1000 level. However, they could not reach this level with the technology in the Navigator. Cost may not be as big a constraint in the CVO product line where companies, rather than individuals, are the targeted buyers and can see fleet-wide cost benefits.

[TP 11] LIMITED EFFECTIVENESS OF HFE GUIDELINES PERCEIVED

- Human factors guidelines were used only in certain aspects of the design, such as character size. Human factors guidelines were not available (found) on which to base many of the other design decisions, such as map orientation (heading up vs. north up); map presentation vs. "guidance" information displays (e.g., turn arrows); dynamic map scaling; dynamic labeling techniques; adaptive displays; and fail-safe design.
- Designers believed that existing human factors guidelines had limited effectiveness in vehicle system applications.

[TP 12] HUMAN FACTORS LITERATURE HAS MANY LIMITATIONS

- The human factors literature used by ETAK in the development of the Navigator was inadequate to guide design decisions regarding map display features that facilitate "situational awareness" or enhance "spatial awareness." As an example, no information was reportedly found that indicated whether coding notable regions, such as a body of water, in addition to the road network, would result in easier navigation to a destination.
- Designers believed that existing human factors guidelines had limited effectiveness in vehicle system applications.

[TP 13] MAP ORIENTATION PREFERRED HEADING UP

- ETAK has a strong, general preference for maps to be displayed in heading-up mode. This design decision was made based on in-house experience with prototypes, and after having novice users test prototypes with both heading-up and north-up options. No formal experimentation was performed.
- Map-based displays should be presented in a heading-up mode unless drivers choose another option.

[TP 14] SIZE OF MAP SCALES CAN VARY GREATLY

- Route guidance provided by TravelPilot is limited to showing the position of the driven vehicle in relation to the road network. At some scales, the road that the vehicle is on may not be displayed on the same screen as the destination.
- ETAK reports that map scales that do not depict the destination simultaneously with the vehicle position are acceptable to the drivers, but scale selection should be chosen by the driver.

[TP 15] ACCURACY OF VEHICLE LOCATION IS CRITICAL TO USER ACCEPTANCE

- TravelPilot used dead reckoning with a magnetic compass, and appeared to be quite susceptible to problems of calibration. Problems with calibration can mislead the dispatchers as to the vehicle location and the problems make the navigation information relatively useless. The Global Positioning System (GPS) circumvents many of the problems that plague the dead-reckoning system.
- Accurate navigation information must be presented to drivers to instill trust in the in-vehicle system.

[TP 16] ETA DATA NEEDED IN CVO APPLICATIONS

- The dispatcher's objective is to get a vehicle to the site as rapidly as possible and avoid sending more units than are needed. Dispatchers sometimes dispatch multiple emergency vehicles simultaneously to the scene, originating from opposite sides of the destination. Once it becomes evident as to which vehicle will be on the scene first, the one that would arrive later is called off. Dispatchers need accurate Estimated Time of Arrival (ETA) data to support effective decisions. Real-time traffic and vehicle information is an important element needed to achieve accurate ETA.
- Accurate ETA based on real-time traffic and vehicle information should be made available to emergency vehicle dispatchers.

[TP 17] DATA STORAGE DIFFICULTIES CAN AFFECT SYSTEM DESIGN

- The original data media (1983-85) used by ETAK for navigation systems was audio cassette tape. This was the only media that could withstand the heat and vibration of the automotive environment at that time. The main problem with audio tape was that it took a long time to access the data (45 seconds). In the mid-1980's, Winchester drives (hard disks) began to be rugged enough for use in vehicles. The switch to hard disks eliminated the problems associated with using a sequential access device, which resulted in speed improvements. Also, in the mid-1980's, compact discs (CD's) first began to show promise for use in holding digital applications other than music in automobiles. Access time is still an issue with the CD's, particularly since the amount of data on a CD can be around 500 megabytes.
- The system response time can be reduced by limitations in the data storage medium and technology.

[TP 18] MAP DATABASE LIBRARIES NEED TO BE UP-TO-DATE

- ETAK has performed field data capture for the 40 largest cities in the United States that provide high levels of detail (e.g., one-way streets, center islands) along with the layout of the road network.
- Future ATIS system designs also should account for database update procedures and cost.

[TP 19] MAP DATABASE SIZE IMPLICATIONS

- ETAK provides the map database used in the TravelPilot. The database is contained on a compact disc (CD). Current storage capacity is adequate for all of the roadways in a region, but addition of other information (e.g., restaurants, speed limits, etc.) can reduce the amount of space available for the roadways.
- To address the size limitation, the CD in the ATIS system, as in the TravelPilot system, should be easily exchanged by the driver. This allows use of the vehicle positioning and map display capabilities in other locales. However, the data-link capabilities require significant, perhaps unique, infrastructure that may not be available in all areas. These issues are being addressed in the Intelligent Transportation Systems (ITS) national architecture development by FHWA.

[TP 20] VEHICLE LOCATION ACCURACY IS CRITICAL

- ETAK believes that the requirement for maintaining an accurate position without realigning the system is more strenuous in the case of ATIS consumer devices than in CVO systems. Their rationale is that commercial users are more likely to monitor the performance of the system and take care to remove small errors frequently. Consumers are likely to let errors accumulate during their routine commuting and will be put-off when they try to use the system on

the weekend to navigate to an unfamiliar destination and see an erroneous position indicated.

- Vehicle location discrepancies and system errors may be less tolerated in passenger vehicles than in commercial vehicles.

[TP 21] *MAGNETIC DISTURBANCES CAN IMPACT VEHICLE LOCATION ACCURACY*

- The position of the vehicle can be corrupted by magnetic disturbances in TravelPilot. If a magnet is brought into close proximity to the compass, the system needs to be re-initialized. An example of a situation where a magnet would be close to the car occurs when a car is taken in for service. The "cones" with numbers on them that many service shops use to identify cars are attached on the hood or top of vehicles with magnets. These are strong enough to disrupt the system. Also, some of the fender aprons used to protect the paint from scratches when a mechanic is working on the engine are held in place magnetically.
- ATIS system users should be made aware of circumstances that affect system accuracy and should provide feedback as to when accuracy has been degraded.

[TP 22] *MESSAGE-RECEIVED FEEDBACK IS DESIRED*

- Originally drivers were required to send messages to dispatchers regarding their position or status, and TravelPilot provided the driver with no feedback as to whether the dispatcher received the information. This lack of feedback can lead to serious misunderstandings because, with unreliable communication channels, it is likely that a message occasionally will be lost. Currently, the system has been modified so that when a dispatcher reads a message, feedback will be provided notifying the driver that the message was received.
- Feedback regarding whether a message has been received needs to be provided to the sender (i.e., driver or dispatcher).

[TP 23] *VEHICLE IDENTIFICATION SEQUENCE CAN BE CONFUSING*

- In the original TravelPilot system, the emergency response vehicles were ordered and presented to the dispatchers alphabetically, according to their alphanumeric code. This led to substantial confusion when dispatchers needed to coordinate the arrival of the vehicles to the incident. To solve this problem, the system was changed so that the vehicles were ordered by proximity to destination, with the lead vehicle first.
- Dispatched vehicles' identification sequences should be presented to dispatchers in order of proximity (e.g., lead vehicle first) rather than alphabetically.

[TP 24]

CUSTOMER-DRIVEN APPROACH TO ATIS SYSTEM DESIGN IS COMMON

- A common approach to the development and continued market success of an engineering product is to promote close ties with the customer. This approach tends to replace human factors engineering with customer-to-design engineer communication regarding user-requirements and prototype evaluation.

[TP 25]

TRAINING REQUIREMENTS NEED TO BE DIRECTLY ADDRESSED

- The TravelPilot training program may have been insufficient. Users received an initial 8 hours of training and a written technical description of the system. The fire department felt that the 8 hours of training were not sufficient and they developed a 2-hour on-road training session to better familiarize the drivers with the system. In addition, they rewrote the technical description of the system in a way that was more comprehensible to the drivers. Rewriting the manual and adding a new training session illustrates the relatively large investment needed to teach people how to use this equipment.
- Instructional materials and training development need to be included in the ATIS/CVO system development process.

CHAPTER 8. CREW STATION RESEARCH AND DEVELOPMENT FACILITY (CSRDF)

GENERAL SYSTEM DESCRIPTION AND OBJECTIVES

The Crew Station Research and Development Facility (CSRDF) is an Army advanced rotorcraft simulation research facility that supports engineering research and development in cockpit automation and pilot-vehicle interface design. It enables the Army to address issues such as crew complement (one versus two pilots) and advanced cockpit technologies for future aircraft in a full-mission simulation environment (see figure 56). The crew station, with its tandem, two-pilot configuration, is the focus of the system. The full-mission capability is achieved by multiple support stations that enable control of other aircraft, both friendly and hostile, and representation of command, control, and communications. Some of the advanced technology features of the CSRDF crew station include a wide-field-of-view, helmet-mounted display; a high-end image-generation system; advanced digital flight control model; side-arm four-axis hand controller; "glass cockpit" with touch-sensitive control points; speech input and output; and a simulated digital communications link. For the purposes of the present investigation, only a subset of the CSRDF is of interest, namely, the digital map with associated navigation and route planning capability. The ATIS functional characteristics that apply to CSRDF are shown in table 7.

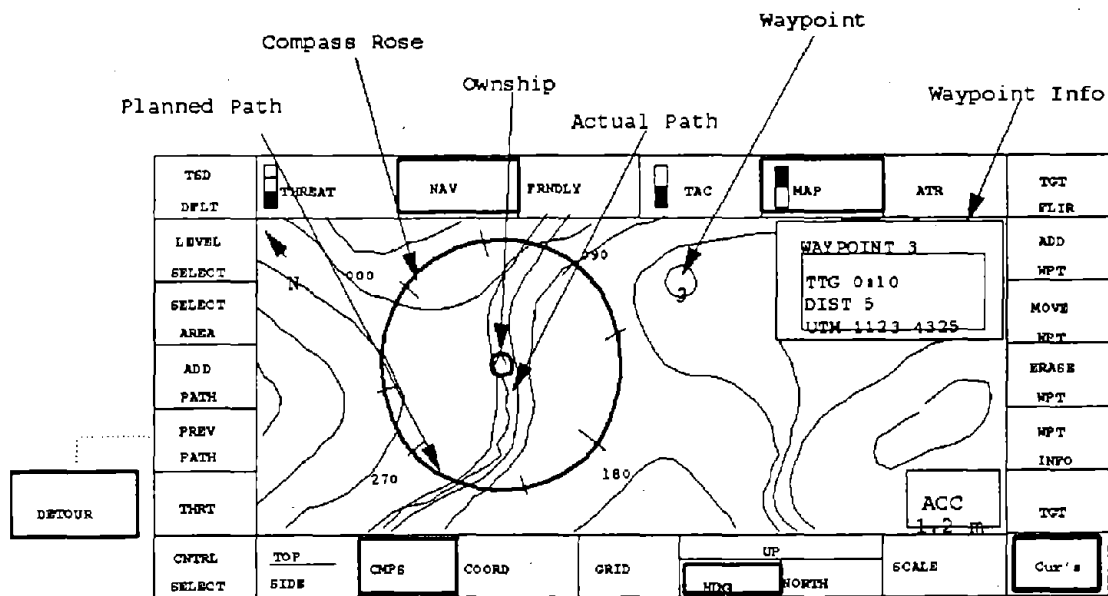


Figure 56. CSRDF tactical situation display in MAP/NAV mode.

The CSRDF was conceived and designed in 1985 at the NASA Ames Research Center and manufactured by CAE Electronics in 1986. The CSRDF is unique among the systems described in this report in that six of the seven members of the crew station design team had Ph.D.'s in behavioral science and were experienced human factors engineers. The leader of the design team, Dr. James Voorhees, had combat experience as an Army aviator in addition to his background in psychology and human factors. He was able to perform the dual roles of Subject Matter Expert (SME) as well as human factors design leader. This design team was collectively familiar with human factors design guidelines and with developments in the field of human factors research that had not yet been included in standards. In the other systems described in this report, with the possible exception of UMTRI, this level of input by human factors specialists was not available.

The CSRDF, unlike flight simulators that mimic a specific aircraft, is a generic reconfigurable rotorcraft simulation facility. It is routinely modified to accommodate new research needs and to incorporate new technologies. Design flexibility and a reconfigurable cockpit were key design goals.

Navigation is fundamental to the accomplishment of any mission in Army aviation. To date, paper maps have been used as navigation aids. A second crew member is often given responsibility for navigation while the first crewmember flies the aircraft, often very near the terrain. Rogers (1983) and others have found that Army aviators frequently are uncertain of their position using traditional navigation methods. One reason for this problem is that when flying at low levels or at nap of earth (NOE) level, it is difficult to determine current location with respect to the terrain features shown in plan view on a map. Current technology, such as Global Positioning Systems, combined with digital maps, can show the aircraft current location with great accuracy. This is a boon for the busy aircrew and an essential technology for single-pilot operations. The digital map has been used in simulation at CSRDF since its inception and is part of the design for the new Army aircraft, the RAH-66 Comanche, which is currently being developed. It is likely that digital map technology, combined with GPS, will be common in future aircraft as well as ground vehicles.

USER INTERFACE

General Description

There are two related, but independent, subsystems associated with navigation and route planning. One is the CSRDF crew station, specifically, the digital map that is the normal mode selection on the pilot's Tactical Situation Display (TSD). The second is an off-line Mission Planner (MP).

Table 7. Comparison of CSRDF functions with those from ATIS/CVO systems.

Subsystem	Function	CSRDF
IRANS	Trip Planning	✓
	Multi-Mode Travel Coordination	
	Pre-Drive Route and Destination Selection	✓
	Dynamic Route Selection	✓
	Route Navigation	✓
	Route Guidance	✓
	Automated Toll Collection	
	Route Scheduling (CVO-Specific)	
	Computer-Aided Dispatch (CVO-Specific)	
IMSI	Broadcast Services/Attractions	
	Services/Attractions Directory	
	Destination Coordination	
	Message Transfer	✓
ISIS	Roadway Sign—Guidance	
	Roadway Sign—Notification	
	Roadway Sign—Regulatory	
IVSAWS	Immediate Hazard Warning	✓
	Roadway Condition Information	✓
	Automatic Aid	
	Manual Aid Request	
	Vehicle Condition Monitoring	✓
	Cargo and Vehicle Monitoring (CVO-Specific)	
CVO-Specific	Fleet Resource Management	
	Dispatch	
	Regulatory Administration	
	Regulatory Enforcement	

CSRDF Navigation and Route Planning

The CSRDF cockpit navigation system interface consists of a keypad and a touchscreen CRT in both the front and rear aircrew cockpit positions. In the primary (front) seat, the TSD is located in the center of the cockpit display area. The color digital map shows current location of the aircraft; surrounding terrain; and symbology overlays, including waypoints, the location of known friendly and hostile forces, and tactical areas of interest, such as the Forward Area Refueling Point (FARP) and the Forward Line of Troops (FLOT). The digital map always displays the letter "N" with an arrow pointing North in the upper-left corner of the TSD.

Pilots plan a route prior to takeoff by inserting a series of numbered waypoints onto the digital map. The waypoints are displayed as small octagons enclosing the number of the waypoint. The waypoints are inserted by selecting "waypoint" and then touching the selected location on the map. Numbers are assigned automatically with consecutive waypoint placements. An alternative method for inserting waypoints is to enter the Latitude/Longitude coordinates for a selected location. This method is more cumbersome to enter, but locates the waypoint more precisely than touching the digital map. Turnpoints, which unlike waypoints are not numbered, may also be used to increase the articulation of the route. Once the series of waypoints are established, there is an edit function that allows the pilot to move or erase one or more waypoints to modify the planned route.

In addition to the waypoints, a flightpath can be selected that connects the waypoints with parallel lines depicting a virtual highway over the terrain. During flight, the current location of the aircraft is continually depicted as an "ownship" symbol. At the option of the pilot, a trail of dots is excreted from the ownship symbol on the map to indicate historical position information. Because the planned flightpath is displayed on the digital map, deviations from the planned flightpath are readily apparent by the relative location of the ownship symbol and associated trail of dots. Instantaneous deviation from the planned flightpath is indicated by deviation between the ownship symbol and the flightpath. The ownship symbol is centered laterally on the TSD and located approximately two-thirds of the way down from the top of the display.

Other navigation information, selectable by the pilots, includes current position (Latitude/Longitude coordinates), compass rose, grid (1 km at the lowest two map scales and 10 km at the highest), and heading and distance to any selected waypoint.

A "Mark" feature enables the pilot to locate an "X" on the map at any desired location. This can be used as a reminder to perform some task when arriving at that location or it may designate the potential location of some other entity or item of interest.

Mission Planner

The Mission Planner (MP) was a resource intended to be used by engineers rather than pilots. Pilots used the mission planner indirectly, via a software engineer who operated the terminal.

The MP ran on a Silicon Graphics Iris machine. The MP system was not designed by a human factors team. The MP software required substantial modification for the software engineers to determine what the pilots said they needed. It had a "terrible user interface" (to quote one of the persons interviewed about this system), was awkward to use, and, hence, has been discontinued.

Despite the interface, the MP did provide some utility. For example, it would plan a route between two points that took into account threat position, terrain type, and type of flight requirements (e.g., low level, contour, or NOE).

Visual Information Display

The CSRDF presents navigation information on the Tactical Situation Display (TSD), a 33-cm color CRT equipped with a touchscreen. The digital map has three scales available (1:50,000; 1:100,000, and 1:250,000) that correspond to the scales used on the paper maps used by Army aviators. The smallest map scale (1:250,000) depicts a large area with rich detail and consequently has a slow update rate, especially during a rapid turn while in the heading-up orientation. A toggle touchpoint switches between north-up and heading-up orientations of the map. A grid overlay can be selected to provide latitude and longitude grid lines over the map. The coordinates of any location on the map can be obtained by selecting "Lat/Long" and then touching the location on the map. A compass rose, centered on the ownship symbol, can be selected for display on the map. These navigation display options were designed for ease of access, enabling a single pilot to fly safely at NOE altitudes while navigating.

The TSD with digital map is located at the center of the cockpit instrument panel, approximately 20 degrees below the top of the panel. The pilot must look down from the outside scene to obtain information from the map display. When flying at NOE, Army pilots want to minimize the time looking in the cockpit, lest they encounter terrain obstacles. The aircraft design attempted to address this issue in two ways: (1) provide essential flight information as symbology on the helmet-mounted display, and (2) provide automated flight control modes (e.g., auto-hover, radar and barometric altitude holds, velocity hold, and turn coordination). The helmet-mounted display symbology enables pilots to perceive basic guidance information such as heading without looking away from the dynamic, out-of-cockpit visual scene. The auto-flight modes, alternatively, enable the pilot to perform tasks inside the cockpit, such as navigation, by reducing the workload caused by the high-frequency, closed-loop flight control task.

The digital map includes terrain features, forests, rivers, lakes, and manmade features such as bridges, roads, towns, and so on. Several levels of detail are selectable. This serves as a "declutter" function. Before flight, each pilot may establish a selected configuration as his or her default. An example might be heading-up, terrain-contours 15.24 m, no grid lines, no compass, show friendlies and show threats. For any reason during the flight, the pilot can modify one or more of these settings, but at any time he or she can return to the selected default setting with one button push. This design effectively allows each pilot/user to

establish his or her own declutter technique, and to tailor the information displayed to the changing demands of the mission.

A feature added later to the map display was the capability to slew (recenter) the map to obtain a closeup (Scale = 1:50) view of terrain near the destination or any other area of interest. Simply changing map scale was inadequate because too much detailed information was lost with the "big picture" view (Scale = 1:250,000). The pilot recenters the map by touching any point on the map, which then becomes the new map center (rather than the normal "ownship" location). The pilot can then change map scales to view the area of interest in detail. One human factors concern was that if the pilot was to become distracted at that time, he or she might look down at the map for current navigation information, forgetting that the map had been recentered. This mistake has been observed. It may be prudent to design digital map interfaces to clearly indicate to users when they are in a mode that does not depict their current location.

The accuracy of the navigational information is monitored by the system, and poor input data from the simulated navigation system can be noted by the pilot. Several procedures are available to recalibrate the navigational system by confirmation of current position from outside sources or visual landmarks.

A side view of the map is available. It displays a 5-km radius and moves in concert with the roll, pitch, or yaw of the aircraft. This view, although rarely used, allows the pilot to investigate elevation or obstacle information from the side (perspective) view.

Auditory Information Display

A tone is presented with each input on the touchscreen to provide auditory feedback that the system has accepted the input. Little auditory information is associated with the navigation functions in the CSRDF.

Cautions and warnings are presented by a synthesized speech system. Additional information is presented on displays after acknowledgment of the problem by the pilot. It was thought that anything important enough to be a caution or a warning required audio cues to get the pilot's attention, followed by more specific information presented on cockpit displays when selected by the pilot.

User Input (Controls)

User input to the navigation system in the CSRDF cockpit is accomplished primarily by the TSD touchscreen. An alternative interface is provided by a second control/display unit called the Systems Management Display (SMD), which provides a hierarchical data entry format. The SMD is often used for pre-mission system setup. The digital data entry is slower, but more precise, than the digital map touchpoints provided on the TSD. Pilots rarely use the SMD when airborne, particularly when flying single-pilot operations (i.e., when flying solo). The touchpoints on the TSD can be accessed much more quickly. Entry of a waypoint, for

example, would take two touches on the TSD or approximately 10 button presses on the SMD.

One design goal was to enable the user to access any cockpit function within three levels of a menu hierarchy. The design team felt that more than three levels would be difficult to use and would require more training to "navigate" through the hierarchy.

User input to the Mission Planner (MP) was through a system expert. The system expert interacted with the MP via a keyboard and a mouse.

Communications Systems

The CSRDF cockpit has the ability to simulate all forms of communication that are typical of contemporary Army helicopters. Voice, encrypted voice, and data link technologies are fully simulated.

One aspect of the communications system is linked to the digital map display. Pilots can select one of three radios and tune it to the proper frequency simply by touching the appropriate "friendly force" icon on the digital map. This feature facilitates communications and reduces pilot workload. It does, however, require that the radios and frequencies be assigned in advance to the friendly forces.

Cognitive Demands

Aircrew workload is exceedingly high in a night, adverse weather mission into hostile territory. Part of the rationale for procuring the CSRDF was to enable the Army to address issues of pilot workload in an environment that would enable control over tactical and environmental factors that influence workload. The CSRDF cockpit was designed to enable rapid access to the functions provided by advanced technology. The digital map and associated navigational features represent a central part of the theme to reduce pilot workload to acceptable levels under difficult circumstances. The initial issue to be addressed by CSRDF was whether advanced technology could enable one pilot to accomplish such a mission. The one- versus two-crew decision has large cost implications over the life cycle of an aircraft.

It was a design goal to prevent information overload by limiting the type and amount of information routinely displayed to the pilot. Instead, pilots were given the option to increase or decrease the amount and type of information displayed in different sub-systems, such as navigation information, display of grid lines, density of contour lines, and distance and direction to waypoints. Pilots can select any one or all combinations of three overlays and, on two of the overlays, they can select from several levels of information to be displayed.

Previous research on Army aviation indicated that navigation is not only difficult, but often unsuccessful. Studies leading to guidelines for the design of digital maps found that "descent to NOE flight levels greatly increases the likelihood of geographic disorientation due to the

aviator's limited view of [geographic] checkpoint features useful in navigation." And further, "both anecdotal evidence and controlled field tests have indicated that the percentage of NOE sorties in which the aviators experience no navigation problems and remain well oriented throughout the flight is exceedingly small" (Rogers, 1983).

The digital map as implemented in CSRDF has virtually solved that problem. It has been easy to learn, easy to use, and dispenses with the need to fumble with paper maps while flying at low levels. Location error becomes a matter of error or drift of the navigation and position-determining equipment, rather than pilot confusion about the identity of geographical reference points. The digital map may be the single most effective technology included in CSRDF with respect to the reduction of pilot workload and successful mission accomplishment.

System Temporal Requirements

The update rate of the map display must be adequate to provide information that is perceived as being current by the pilot. The latency that is perceived as being "current" by the pilot depends, at least in part, on how accurately the pilot can relate the position of the aircraft on the display with what is seen in the out-of-cockpit visual, and the required precision of the task.

Large demands are put on the digital map system when operating in the heading-up orientation, which seems to be preferred by the majority of pilots in CSRDF. In addition to "heading up," other pertinent variables are map scale, aircraft dynamics, and the richness of the terrain features at the location. The worst case is:

- Heading up.
- Smallest map scale (1:250,000).
- Rapid turn or yaw.
- High density of map features at that location.

The capability of the digital map system to update smoothly can be exceeded under this combination of circumstances. This problem leads to a series of apparent rotational "jumps" in the map. Future increases in computational speed and capacity are likely to meet this challenge, but the design goal should be to achieve smooth and accurate map representation even under the most difficult conditions.

DESIGN GUIDELINES USED

Human Factors Design Guidelines

General human factors design guidelines were available, but seldom used by the system designers who had backgrounds in behavioral science and human factors engineering. Few

guidelines were available for development of the digital map display other than the prior work by Rogers (1983).

MIL-STD 1472C was available to help define the physical characteristics of the cockpit displays, such as size of soft keys and minimal separation between soft keys. Also, the use of color in the CRT displays was carefully considered by the professional psychologists involved who had considerable background and understanding of the limitations and usefulness of color in CRT displays (e.g., Hennessy, Hutchins, and Cicinelli, 1989).

Human factors design guidelines and reference materials were not consulted systematically during the design of the CSRDF. However, the individual design team members may have made use of standards and current research results in formulating their design recommendations. Two members of the design team had previously published general design guidelines for speech input/output systems (Simpson, McCauley, Roland, Ruth, and Williges, 1987).

Other Guidelines

Specific functions performed by the CSRDF cockpit interface were decided by the designers involved at the beginning of the project. They took into account their knowledge of Army aviation requirements, available technology, human factors and research psychology tenets, and user interviews.

Designers consulted available Army aviation manuals and documents to provide additional background for user needs. However, most of the systems modeled were new technology and had no supporting documentation or guidelines associated with them.

Army aviation manuals, helicopter operations manuals, and communications systems manuals were used as background for decisions on symbology, color meanings, and nomenclature.

Route guidance information was determined by expert opinion about what an Army helicopter pilot needed to do the job. The design team chose to display planned path and actual path differently so that the pilot could see his or her deviations from the planned ground track. CSRDF provides no information to the pilot concerning steering cues to get back on route. However, more recent systems (e.g., Comanche helicopter) do provide this information, and the capability may be added to the CSRDF.

Standard Army aviation symbols were used for most icons displayed. For information that had no standard symbols, icons were developed for simplicity and associative value with the information to be presented. Text size is large enough to be legible, but small enough to not obscure too much information on the map itself.

Effectiveness of Human Factors Guidelines Used by System Designers

The standard human factors guidelines were rarely referred to during the system design. The reasons for this are twofold: (1) the systems were advanced, notional technologies, for which no previous experience was included in the guidelines; and (2) the design team was very familiar with human factors principles without looking at the guidelines. Also, the CSRDF was software-intensive and modifiable, rather than being a fixed-point design intended for production. The design team believed that their best efforts would probably surpass the standard human factors design guides, and, if they were wrong, it would be a relatively straightforward task to modify the interface characteristics in the future.

LESSONS LEARNED

[CS 01] *DIGITAL MAP HELPFUL FOR NAVIGATION AND ROUTE FOLLOWING*

- Pilot reaction to the in-vehicle display of a digital map has been uniformly positive because it provides a rapid reference for current location relative to geographic and manmade features as well as planned route.
- A digital map is an excellent method for displaying current location and providing a basis for navigation and route following.

[CS 02] *MAP ORIENTATION DEPENDS ON APPLICATION MODE— PRE-MISSION PLANNING OR EN ROUTE*

- The most common use of the north-up orientation is in pre-mission route planning. Most pilots select the heading-up orientation while flying.
- Users appreciate and make use of the option to select either north-up or heading-up orientation of the digital map.

[CS 03] *POOR USABILITY OF A USER INTERFACE LEADS TO DISUSE*

- The displays and controls of the independent Mission Planner were not prototyped, designed with input from human factors professionals, or subjected to usability analyses. Use of the Mission Planner has been discontinued partly because the interface made it so difficult to operate.
- Advanced vehicle navigation and route planning systems are not likely to be employed unless they are easy to use.

[CS 04] *INTERFACE "MIDDLE-MEN" ARE UNACCEPTABLE*

- The inability of pilots to operate the Mission Planner without an intermediary was reported to be frustrating. Future systems should not require a "guru" between the user (route planner) and the system.
- The vehicle controller (pilot or driver) should be given direct access to navigation and route planning systems.

[CS 05] *IN-VEHICLE DIGITAL MAP CAN PREVENT BEING LOST*

- The CSRDF digital map makes it easy to follow a planned path through specified waypoints. This represents a major reduction in pilot workload compared to navigating with paper maps. This distinction is even more pronounced for the Army aviation environment than for ground transportation, because when flying at very low altitude and unsure of current location, navigation in featureless terrain is problematic.
- In-vehicle digital maps are particularly useful under difficult conditions when the probability or consequences of being lost are great.

[CS 06] *ROUTE PLANNING BY WAYPOINTS IS SIMPLE*

- Army pilots can plan a route by depositing a sequence of waypoints on the digital map. This process can be accomplished rapidly and requires very little training. The application of this technique to ground transportation is unclear, although it would loosely equate to the pre-departure identification of major turns by placing a symbol on the appropriate locations on the digital map.

[CS 07] *ROUTE CAN BE DEPICTED BY PATHWAY LINES*

- Numbering waypoints and connecting them with a line or with parallel lines representing a path is an effective way to depict a route. For aviation applications, the width of the path can represent acceptable deviations from the planned route.
- Symbolic pathways created by parallel lines between waypoints on a digital map represent a continuous "highway" that can be flown by the pilot.

[CS 08] *MAP SCALE/SLEW FEATURES CAN LEAD TO MISINTERPRETATION OF CURRENT POSITION*

- When planning or previewing a route, or when en route, pilots wanted the capability to slew the map to any location of interest and to change map scales. This feature is particularly valuable when one wants to use a map scale that does not contain both current position and destination on one screen. Occasional errors of interpretation occur, however, when the pilot views a slewed map and fails to note that the "ownship" symbol is not in the center.

Thus, the pilot erroneously reverts to the normal interpretation of the map representing current position.

- Map slew and scale features are desired by in-vehicle navigation users, but can lead to position interpretation errors.

[CS 09] *SYSTEM STATUS INDICATIONS ARE ESSENTIAL*

- Some functions on the crew station digital map allowed the user to select one of several levels, such as map scale, by toggling through the available choices. Early versions of the user interface did not provide explicit feedback as to what level was currently selected. Some functions, such as Map Grid On/Off are so obvious that no other indication may be needed. However, some explicit indication of current level selected is needed if there is any chance of confusion by the user.
- Map scale and other selectable features should include an explicit indication of the feature or level of the feature that is currently selected.

[CS 10] *THE OPTION OF TWO INPUT METHODS FOR SPEED VS. PRECISION CAN BE A GOOD DESIGN FEATURE*

- Pilots appreciated having two methods to enter waypoints for route planning. A one-touch method enables quick and direct placement of a waypoint by using the touchscreen digital map. To achieve greater precision, the pilots entered exact coordinates (two 4-digit numbers).
- Providing more than one method for data entry allows the user to choose between speed and accuracy of data input.

[CS 11] *INTEGRATE ROUTE PLANNING AND GUIDANCE FUNCTIONS*

- The CSRDF route planning system (the Mission Planner) was not integrated with route guidance and navigation systems. This contributed to under-utilization of the Mission Planner system and failed to provide for aided replanning while en route.
- Route planning functions should be seamlessly integrated with route guidance and replanning functions.

[CS 12] *TOUCHSCREENS CAN SUFFER FROM DEGRADATION*

- Pilots generally liked the rapid, direct interaction with the digital map through touchscreen "soft" buttons. However, the visual display can be degraded by fingerprints. Adequate character size and contrast are required to offset the degradation.
- Touchscreens have positive and negative attributes. Careful engineering and human factors engineering, as well as regular maintenance and calibration, are needed to achieve desired performance.

[CS 13] TOUCHPOINT FEEDBACK ON TOUCHSCREENS IS VALUABLE

- When the CSRDF touchscreen drifted out of calibration, a useful optional mode was available that showed where the system registered the touch. This immediate visual feedback enabled the user to achieve intended control actions by correcting for the drift.
- Digital maps with touchscreens should have available the option to display immediate feedback of the touch registration location.

[CS 14] DISPLAY UPDATE RATES MUST BE SUFFICIENT FOR THE APPLICATION

- The delay between motion of the vehicle and update of the displayed digital map is important. The map display must be updated at a rate that appears smooth to the user. If the display updates too slowly, pilots (and presumably drivers) will not make use of the system. In the CSRDF, this was manifested by pilots not using the map scale that showed the largest region, even though this would provide the "big picture" of the tactical area. The greater detail of the map at that scale required longer to update. Consequently, when the map was in the largest scale, it lagged and stepped noticeably during a turn.
- Digital map engineering should ensure smooth updates of the visual display under worst-case conditions—highest scene detail and maximum expected turn rates.

[CS 15] ONE-TOUCH DESIGN FOR IMPLEMENTING A COMPLEX, MAP-ORIENTED FUNCTION

- One successful approach to reducing pilot workload in the CSRDF was achieved by allowing the pilot to touch an icon on the digital map corresponding to one of several preprogrammed radio call destinations. This technique was considerably faster than the traditional method of selecting the radio and tuning the desired frequency.
- Complex functions, such as radio transmission (or telephone dialing), that are geographically based, can be implemented by a one-touch process on a touch-sensitive digital map. This type of design reduces the need to look "inside" and reduces pilot (or driver) workload.

[CS 16] COMMUNICATIONS FROM THE VEHICLE CAN BE EXPEDITED BY MENU-BASED, CONTINGENCY-SEND MESSAGES

- Non-voice communication between the CSRDF crew station and central command centers was accomplished by a simulated digital data link. It was feasible for a busy pilot to use automated flight control modes, e.g., auto-hover, and to fill out a prompted form to report current status and other important information. The report could be sent either immediately, at a selected time, or

upon arrival at a specified location. The interface for this activity was designed to enable communication without voice and to require minimal time on the part of the pilot.

- Communications, such as status reports or position reports, can be pre-programmed and sent automatically by establishing in advance, contingency lines on the digital map.

[CS 17] EMPHASIS ON HUMAN INTERFACE DESIGN YIELDS A HIGHLY EVOLVED USER INTERFACE

- Assigning a team of highly experienced research psychologists and human factors engineers to participate in the initial design of the system interface, without regard to cost, reliability, maintainability, logistics, and other engineering constraints, will result in a highly evolved user interface. This was the approach used in CSRDF.
- A blend of emphasis on the user-centered design and the pragmatic realities of engineering design is needed for operational or commercial systems.

[CS 18] SUBJECT MATTER EXPERTS ARE ESSENTIAL FOR SUCCESSFUL SYSTEM DESIGN

- Experience in the CSRDF development reaffirmed that Subject Matter Experts (SME's) who represent the prospective user community are essential for designing a good system. More than one SME should participate to avoid idiosyncratic opinions about operational requirements.
- SME's interacting with human factors experts lead to good human interface design.

[CS 19] ITERATIVE TESTING AND RAPID PROTOTYPING SUPPORT CONTINUOUS REFINEMENT OF THE SYSTEM

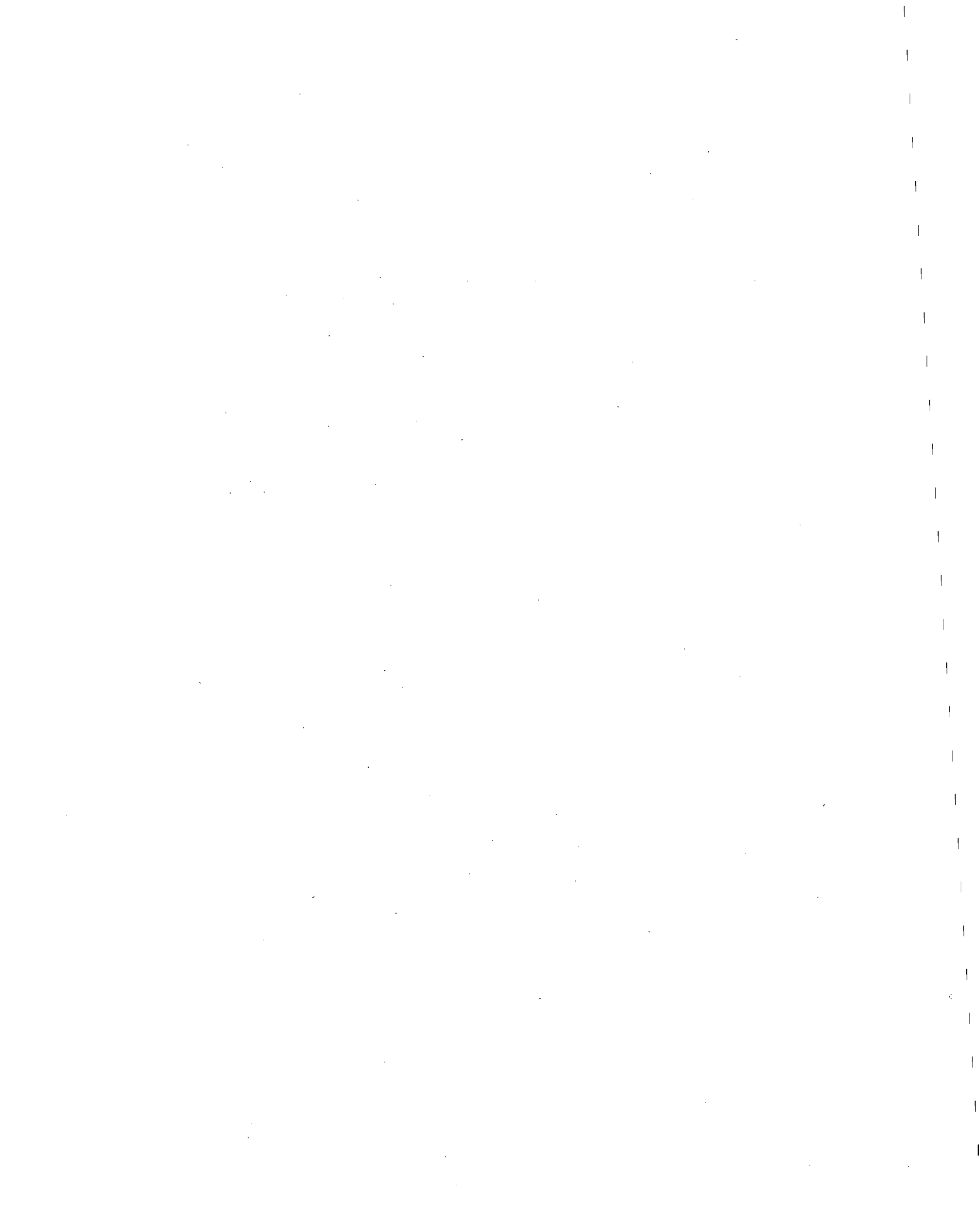
- Iterative testing of prototypes is an excellent way to refine the design. This process occurred in CSRDF when a working model of the cockpit interface was prototyped as a training device. That process was helpful in identifying subtle, but important, improvements in the interface functions. One advantage of a flexible, modular design is that continued improvement is feasible even after initial fielding of the system.

[CS 20] MEASUREMENT OF HUMAN AND SYSTEM PERFORMANCE IS ESSENTIAL FOR SIMULATION AND SYSTEM DEVELOPMENT

- Although the CSRDF was designed as a research simulator (as contrasted with a training simulator), funding issues proscribed implementation of all of the data collection and analysis features originally specified. Consequently, in some instances, data collection, reduction, and analysis work-arounds have had

to be developed. One area mentioned by several of the investigators working in the facility is the absence of video recording equipment that can capture the broad perspective of the pilot's behavior. It is difficult to address certain simple questions when faced with gigabytes of data on hundreds of variables collected at 30 Hz (Hennessy, 1990). Another example, relevant to the type of in-vehicle displays envisioned for ITS, is the lack of a means to track the pilot's eye movement. To do cost-effective research that yields quality data, careful consideration should be given to data collection resources and capabilities. This is true regardless of whether the research is conducted on the road or in a device such as the National Advanced Driving Simulator (NADS), currently being developed by DOT.

- Measures of human and system performance should be developed early and the means for accurately and reliably collecting those performance measures should be part of the system development requirements.



CHAPTER 9. THE SIKORSKY COGNITIVE DECISION-AIDING SYSTEM

GENERAL SYSTEM DESCRIPTION AND OBJECTIVES

The Army's Aviation Advanced Technology Directorate (AATD) sponsors the Rotorcraft Pilot's Associate (RPA) program, which is intended to promote the application of advanced technology to enhance man-machine performance in Army aviation. Their approach has been to emphasize cognitive decision aiding (CDA) across a variety of cockpit tasks and subsystems. One aspect of that program is to develop prototype systems for aiding the pilot in navigation and piloting tasks (flying, navigating, and communicating) during extreme conditions such as nap-of-the-earth (NOE) flight at night in adverse weather. This Day-Night Adverse Weather Pilotage System (D/NAPS) program is a subset of RPA and is intended to enhance mission effectiveness through innovative integration of advanced sensors, computing technologies, and controls and displays.

Sikorsky Aircraft and Texas Instruments were one of two teams of contractors selected by AATD to develop and demonstrate a Cognitive Decision-Aiding System (CDAS) for the D/NAPS program. The CDAS was selected as one of the non-ground transportation systems in the ATIS Comparable Systems Analysis because it shares certain features with future intelligent navigation systems in ground transportation. The CDAS objectives were to aid the pilot in determining appropriate navigation and route selection decisions, to combine conventional and Artificial Intelligence (AI) processing to reason about data received from multiple sources (including the pilot), to use expert systems to formulate recommendations or decision augmentation, and to perform within operational time constraints.

The Sikorsky CDAS focused on mission replanning. After a pilot has established a route, perhaps with the aid of a mission planning system, and has begun to fly the mission, he or she may encounter unanticipated threats or other factors that override the planned route. Replanning is a difficult task for the pilot while fully engaged in flight tasks. Thus, the CDAS provides an expert system to process information about alternate routes while the pilot continues to focus on flying the aircraft at or below treetop level (Casper, 1993). NOE flight involves maintaining minimal clearance over terrain to limit exposure to threats. It requires nearly constant out-the-window attention to maintain clearance over ground and vegetation. Also, the pilot must keep hands on the flight controls for continual adjustment of the flight path. This "eyes out - hands on" requirement, plus communications, navigation, and other cockpit tasks, induce high-workload conditions that make navigation replanning particularly difficult for the hypothetical single-crew situation (Casper, Smith, Smith, and Hubanks, 1991).

Similar difficulties in navigation replanning may be faced by a driver in heavy traffic who has missed a turn and cannot safely consult a paper map to investigate alternate routes. The CDAS also may generate an alternate route when a mission change is promulgated by higher command. Similarly, a Commercial Vehicle Operator (CVO) may receive a priority change in destination from a dispatcher while en route and engaged in heavy traffic.

One objective of the Sikorsky effort was to achieve an intelligent Pilot-Vehicle Interface (PVI). The concept is to combine technological advances in automation and artificial intelligence with human factors engineering to fully integrate the pilot, the cockpit, and the aircraft (Casper et al., 1991). Key elements of the intelligent PVI are seen as pilot command assessment, pilot capability assessment, pilot intent assessment, and cockpit display management. The CDAS included a set of six cooperating expert systems that provided a single pilot with assistance in threat avoidance, navigation, and system failures.

The CDAS demonstration was accomplished on a full-mission simulator, comparing a baseline configuration, representing the RAH-66 Comanche, and the combination of the Comanche and CDAS. The CDAS calculated a route "cost" estimate based on terrain, threat location and lethality, fuel, time, distance, weather, and other information. When triggered by various events, the mission replanner computed alternative routes and presented the least-cost recommended route on the digital map. The recommended alternate route is presented to the pilot by a distinct color on the digital map.

Several CDAS evaluations were conducted in simulation, the results of which are not yet published in the open literature (Casper, 1993). The ATIS functional characteristics that apply to the Sikorsky system are shown in table 8.

USER INTERFACE

General Description

The pilot interface to the CDAS was implemented through four displays—the digital map, the Helmet-Mounted Display (HMD) symbology, the Right Multi-Purpose Display (RMPD), and by synthesized speech output. Pilot controls included bezel switches around the digital map screen and a cursor control on the handle of the collective (flight control).

Visual Information Display

Symbology overlaid on the digital map was the primary display of route information. The display included waypoint locations and a path indication between the waypoints. When the CDAS recommended a new route, it was displayed in red to distinguish it from the original route, which was displayed in yellow. The portion of the route already flown was displayed in blue.

Table 8. Comparison of Sikorsky functions with those from ATIS/CVO systems.

Subsystem	Function	CSRDF
IRANS	Trip Planning	
	Multi-Mode Travel Coordination	
	Pre-Drive Route and Destination Selection	✓
	Dynamic Route Selection	✓
	Route Navigation	✓
	Route Guidance	✓
	Automated Toll Collection	
	Route Scheduling (CVO-Specific)	
	Computer-Aided Dispatch (CVO-Specific)	
IMISIS	Broadcast Services/Attractions	
	Services/Attractions Directory	
	Destination Coordination	
	Message Transfer	
ISIS	Roadway Sign—Guidance	✓
	Roadway Sign—Notification	
	Roadway Sign—Regulatory	
IVSAWS	Immediate Hazard Warning	✓
	Roadway Condition Information	
	Automatic Aid	
	Manual Aid Request	
	Vehicle Condition Monitoring	✓
	Cargo and Vehicle Monitoring (CVO-Specific)	
CVO-Specific	Fleet Resource Management	
	Dispatch	
	Regulatory Administration	
	Regulatory Enforcement	

In addition, waypoints were shown as symbology on the HMD. They appeared as earth-referenced signs, similar to a stop sign, but with a circular rather than octagonal top, with the waypoint number and distance depicted on the sign. The round portion of the sign for the upcoming waypoint was rendered a constant 2.58 degrees visual angle and the height of the sign pole was proportional to the aircraft altitude. This meant that the sign at the waypoint was always easy to see and appeared to be at the same altitude as the ownship. When a new waypoint was out of the field of view of the HMD by less than 30 degrees, an indication (> or <) was given showing the direction to the next waypoint. If the waypoint was greater than 30 degrees outside of the HMD field of view, the indication appeared as double arrows.

The alternate route information computed by the intelligent software and displayed on the digital map is directly relevant to ATIS/CVO systems. Also, the earth-referenced symbology shown in the HMD has potential application for future ATIS systems capable of displaying symbology on the vehicle windshield as a head-up display (HUD). One major difference, however, is that in the aircraft application, the field of view is wider and the user can slew it by natural head movements. In a ground vehicle, earth-referenced symbology on the windshield would be limited to the windshield field of view. Some ground-vehicle applications could be envisioned, however, where the driver wears a helmet, thus providing an extra safety margin, plus a head-oriented display medium.

When a new route was calculated by the CDAS and presented to the pilot, this fact was indicated by an icon on the RMPD. The icon represented three joined waypoints enclosed in a box. The box was depicted in inverse video when CDAS was calculating a new route. It changed to normal video when the new route was computed and presented.

Adjacent to the new-route icon was an "explanation" icon that gave an indication of the reason for calculating a new route. Examples include Fuel, Off Course, Threat, and Message (referring to receipt of a digital message that redirected the mission or warned of bad weather).

The digital map also had the capability to display other aids to location and navigation, such as grid lines (2 km), three levels of map scale, and coordinates (equivalent to latitude/longitude).

Auditory Information Display

When the system began to calculate a new route, in addition to displaying an icon, a synthesized voice message also was given, such as, "Threat; Planning," followed by "New Plan Ready." Time to compute a new route was around 5 seconds. Speech output also was given to note deviations in either time or course from the planned route.

Other speech output was associated with the baseline Comanche cockpit and included threat information, aircraft health and status information, and cautions and warnings, such as, "Warning, Engine Failure." In the simulator, the speech was produced by a Dec Talk speech

synthesis system. Examples of speech output information are location and type of threat and, if lethality appears high, it suggests avoidance maneuvers.

User Input (Controls)

The pilot did not initiate a request for navigation assistance. The pilot did have normal control over the digital map (independent of the CDAS), including zoom in/out and slew (X,Y reposition of map). Other relevant controls included a toggle that either centered the map on the ownship symbol, or froze the map and allowed the ownship symbol to move over the frozen map.

The pilot activated an "Accept" button to acknowledge and accept a new route recommended by the CDAS.

Communications Systems

Communication tasks were included as part of the mission in the CDAS simulation demonstration, but were not an integral part of the decision-aiding system.

Cognitive Demands

The objective of the CDAS was to aid pilots in navigation and route replanning under adverse conditions when cognitive task loading is extreme (Casper et al., 1991). Flying at NOE levels at night and in adverse weather is assumed to be a worst-case scenario for pilot workload. It is under such extreme cases of cognitive demand that expert systems for decision aiding can be most beneficial. Under such circumstances, pilots are in a moment-to-moment survival situation and simply do not have spare resources to evaluate multiple sources of information and thoroughly consider alternative navigation solutions. Because this level of demand was difficult to achieve in the simulator, an extra task was given to the pilots, namely, an "authentication" task, essentially requiring mental arithmetic and verbal report.

System Temporal Requirements

The CDAS demonstration required that the system operate in real time with respect to the pilot's tasks and the simulated mission.

DESIGN GUIDELINES USED

Human Factors Design Guidelines

Human factors guidelines, such as MIL-STD 1472D and Boff and Lincoln (1988), were used in the development of the baseline Comanche aircraft that provided the basis for the simulator. However, for the CDAS itself, no human factors guidelines were used directly. A

small group of human factors experts played a role in the development and demonstration of the system and were able to make some inputs to the design of the system. For this demonstration, the emphasis was placed on AI software, expert system architectures, and real-time performance, rather than optimizing the pilot interface to the system.

LESSONS LEARNED

[SK 01] COLOR-CODED ROUTES SUCCESSFULLY DEPICTED RECOMMENDED PATH ON DIGITAL MAP

- The use of color symbology overlays on the digital map was successful in allowing the user to distinguish among: (1) planned route already traveled, (2) planned route to go, and (3) new, recommended alternative route.
- Recommended routes on a digital map are easy to perceive when they are color-coded.

[SK 02] SPEECH OUTPUT SHOULD BE USED FOR EXCEPTIONS, NOT FOR CONFIRMATION OF ROUTE COMPLIANCE

- Pilots did not like a "chatty" speech output system. They wanted to hear from the speech output system only when they deviated from the planned route (in time or course) by a non-trivial amount. This example falls into the "display by exception" concept.
- The use of speech output to confirm conformance with planned route should be avoided. Consider the user a negative-feedback servomechanism and provide route compliance information only when an error needs to be corrected.

[SK 03] THE TIME AT WHICH EXPERT SYSTEMS GENERATE NAVIGATION ADVICE CAN BE OF INTEREST TO THE USER

- The "freshness" of a new route was a concern of CDAS users, particularly if more recent incidents or events may have reduced the validity of the advice.
- Intelligent navigation systems should include information as to the time at which a new route is recommended.

[SK 04] USERS OF NAVIGATION EXPERT SYSTEMS MAY WANT DIAGNOSTIC INFORMATION

- Users of CDAS sometimes wanted information about why a new route was being recommended. They were not satisfied with command information about rerouting, and preferred diagnostic information supporting the recommendation. The expert system should be capable of providing an explanation to the user for a recommended action, if the user requests it.

- At a minimum, such diagnostic information should be available to the user upon request.

[SK 05] DANGEROUS AREAS CAN BE COLOR-CODED ON A DIGITAL MAP

- Current altitude information was made relevant by showing all terrain on the digital map in a different color if it was equal to or greater than current altitude.
- Although there is no direct analog to ground transportation systems, it might be possible to use dynamic color-coding to distinguish potentially dangerous routes, locations, weather, traction (ice), etc.

[SK 06] PILOTS PREFERRED TO FLY IN THE HEADING-UP ORIENTATION ON THE DIGITAL MAP

- Given the option of operating in heading-up or north-up modes, virtually all of the pilots chose to fly in the heading-up mode.

[SK 07] MESSAGE SEMANTICS AND SYNTACTICS IMPORTANT IN SYSTEM DESIGN

- Ambiguities existed in some common usage of terms such as the meaning of "Current Waypoint" and "Next Waypoint."
- Care must be given to semantic and syntactic conventions in the use of language.

[SK 08] NAVIGATION EXPERT SYSTEMS SHOULD ADVISE, BUT NOT ACTIVELY CONTROL WITHOUT USER CONSENT

- Based on input from the pilot SME's, the CDAS was never allowed to execute an action without first announcing the proposed action to the user and receiving a "go-ahead" confirmation. This rule applied to all actions that could affect any current activity of the user, including display mode changes and map scale changes.
- Intelligent software navigation aids should provide information, but not take action without active concurrence of the user (e.g., the expert system should not autonomously slew the map away from the ownship position).

[SK 09] ACKNOWLEDGEMENT OF ACTIONS TAKEN BY AN EXPERT SYSTEM PROVIDE SYSTEM STATUS INFORMATION TO THE USER

- Interaction with the navigation expert system followed the principle of positive communication, e.g., transmit, acknowledge, and confirm. For example, the expert system might recommend slewing the map to show the location of an

- important incident (transmit) if the pilot concurs (acknowledge), then the system executes the action and confirms successful execution (confirm).
- Clear communication of system status should be given to the user whenever an expert system performs an action that could affect the user. Expert system actions should not only be withheld until approved, but confirmation should be communicated to the user afterwards.

[SK 10] USER-EXPERT SYSTEM INTERFACE DESIGN MUST BE EXPLAINED TO THE USER

- The responsibilities of the navigation expert system and the user must be assigned and understood. The pilots using CDAS were able to perform better when there was no confusion about which tasks were to be assumed by the CDAS, under what circumstances, and how they were to be performed.
- Effective use of a navigation expert system requires the user to have an accurate mental model of the "behavior" of the expert system. This can be achieved through training and consistent functioning of the user-system interface design.

[SK 11] TIMELY ASSISTANCE FROM THE EXPERT SYSTEM CAN BE ACHIEVED IF THE SYSTEM "ANTICIPATES" THE USER

- Experience with CDAS indicated that timely system performance was achieved by the expert system "anticipating" what navigation information the pilot might require.
- User acceptance is reduced when time-critical navigation information is not readily available.

[SK 12] INTELLIGENT INTERFACES CAN MAKE MULTIPLE DISPLAY MODE CHANGES TO ACHIEVE A USER'S REQUEST FOR INFORMATION

- If the pilot initiates a menu option such as "Show on Map," which refers to a location not currently within the bounds of the map scale, the system could "decide" whether to change the map scale to display both the ownship and the identified location on the same screen, or display a line drawn from the ownship to the identified location.
- Intelligent display control can be responsive to user requests for information, rather than forcing the user to manually implement a series of inputs.

[SK 13] KNOWLEDGE ACQUISITION IS THE KEY TO EFFECTIVE EXPERT SYSTEM DEVELOPMENT

- The successful development of the CDAS was attributed in part to the effort placed into knowledge acquisition early in the design process.

- Knowledge acquisition (sometimes called "knowledge engineering") for the development of expert systems requires thorough, time-consuming analysis that must include detailed knowledge of all sources of information, including sensor capabilities and limitations, user strategies, and system performance objectives.

[SK 14] A USER-VEHICLE INTERFACE FOCUS CONTRIBUTED TO A SUCCESSFUL DECISION-AIDING SYSTEM

- The pilot-vehicle interface, or, more generally, the user-vehicle interface, should be a major focus for the development and application of cognitive decision-aiding systems.

[SK 15] HMD's AND HUD's SHOULD BE USED ONLY FOR CRITICAL INFORMATION

- Navigation and vehicle control information that is non-critical in nature should not be presented on the helmet-mounted display (HMD) unless called for or accepted by the pilot. This same concept is believed to apply for head-up displays (HUD) in ground vehicles.
- Navigation and vehicle control information presented in HMD or HUD formats should not interfere or distract the user from the visual scene of the terrain and environment.

[SK 16] NON-INTRUSIVE CURSOR CONTROL FOR IN-VEHICLE NAVIGATION DISPLAYS PROMOTES CONTINUOUS VEHICLE CONTROL

- Cursor control achieved by a switch on the collective (left-hand flight control lever) enabled pilots to interact with the digital map without taking their hands off of the flight controls. The analog for ATIS/CVO systems would be to provide cursor control on the steering wheel.
- Placing the cursor control function on a primary vehicle control surface (e.g., stick, cyclic, collective, or steering wheel) reduces the user's time-sharing workload.

[SK 17] SME's PROVIDE INVALUABLE INFORMATION FOR THE DESIGN OF INTELLIGENT SYSTEMS

- Subject matter experts (SME's) (Army pilots) were involved at several stages of the CDAS program, particularly during the knowledge acquisition stage of expert system development. Early prototypes produced on SuperCard or HyperCard were used to extract information and opinions from SME's.
- Involvement of SME's and prototyping techniques contributed to successful design and development of the system.

[SK 18] SIMULATION WAS A VALUABLE DEVELOPMENT TOOL

- The CDAS was evaluated in a full-mission simulation context. Difficulties and challenges in simulation, such as performance measurement, also occur in field studies. The simulator allows control over salient variables and repetition of events that cannot be achieved under field-test conditions.
- High-fidelity, operator-in-the-loop simulation is recommended as a test and evaluation medium for advanced technology.

[SK 19] SYSTEM PERFORMANCE MEASUREMENT ISSUES ARE IMPORTANT

- Empirical approaches to the assessment and evaluation of intelligent systems are challenging because of the tradeoff between "realism" and experimental control. Long scenarios and realistic, complex environments equate to variability, which, in turn, requires large sample sizes to achieve statistical reliability. Short, constrained (unrealistic) test scenarios limit the generalizability of results.
- The methodological challenges inherent in evaluating intelligent man-machine interfaces, including intelligent ATIS/CVO systems, should not be underestimated.

[SK 20] INTELLIGENT DECISION AIDING IS FEASIBLE

- The CDAS program demonstrated the potential for the application of computational methods and expert systems to provide intelligent decision aiding for navigation tasks.
- Real-time cognitive decision aiding for navigation is feasible with today's (1993) technology.

IN-VEHICLE DISPLAY DESIGN

1. The orientation (north up or heading up) should be selectable by the user. When in the route planning mode, the default orientation should be north up; when in the route guidance mode, the default orientation should be heading up. [UM12, NM19, SK06, TP13, CS02]

2. The capability to preview a destination on a digital map should be provided to the user by map scale and slew (recenter) features, but the system should be designed to prevent confusion about whether the map is showing current position. [CS08, NM03, TP14]

3. Digital maps should be available to depict the user's current location, destination, and a recommended route, but are not the preferred method for depicting route guidance. [CS01, CS05, UM13, NM13, OM08]

4. Digital maps should have a refresh rate that is sufficient to support smooth rotation of a heading-up display at any map scale during vehicle turns. [CS14]

5. Head-up display of computer-generated symbology is useful for avoiding the "eyes-in" vehicle problem, but should be used only for critical information. [SK15]

6. Displays of alphanumeric messages should include word-wrap, i.e., the display should not break one word onto two lines. [OM05]

7. Veiling glare should be minimized for all ATIS/CVO in-vehicle display applications. LCD displays, in particular, are susceptible to glare and should have back lighting and contrast control. [OM01, OM02, OM03, OM04, NM23, NM24]

8. Character size for in-vehicle displays should be large enough for the diverse driving population to read easily without undue visual search. The minimum visual angle is a function of variables such as contrast, but is estimated to be approximately 0.30 to 0.45 degrees. [UM03, TT26]

CHAPTER 10. PRELIMINARY HUMAN FACTORS GUIDELINES

INTRODUCTION

The objective for performing this comparable systems analysis was to compile lessons learned from existing ATIS applications in the United States and to produce preliminary guidelines for the purposes of guiding empirical research to improve the design of future ATIS/CVO systems. Human factors design guidelines for ATIS/CVO systems represent the final product of the present contract. The preliminary guidelines from Task D, the comparable systems analysis, are one source of information that will feed into the process.

In Task F, Barfield et al. (1993) discussed the nature of guidelines and offered a four-star "guideline applicability rating system." The guidelines presented in this chapter do not fit conveniently into that rating system. They are "one-star" guidelines in that rating system, because they are based primarily on expert judgment rather than empirical data. However, the guidelines offered here are derived directly from ATIS and CVO or related systems. Perhaps Barfield's rating system should be modified slightly to include two independent dimensions: (1) empirical basis and (2) application domain similarity. There is little doubt that preliminary guidelines, even when based on subjective analysis, are more likely to be applicable and relevant when they are derived from actual ATIS and CVO systems rather than from different application areas. Different applications can involve many types of differences, such as system objectives, task demands, user population characteristics, and environmental factors. The following guidelines are based on ATIS/CVO comparable systems and are, therefore, directly appropriate. However, they are based on observation, expert judgment, user opinion, and other subjective analyses and should be considered preliminary. Empirical validation is needed before accepting them as guidelines.

The preliminary guidelines are sorted into somewhat arbitrary categories. In many cases, a preliminary guideline has implications for more than one of the categories. Each preliminary guideline is presented with a notation as to the lessons learned from which it was derived. That notation enables the reader to follow an audit trail for the lessons learned that was the source of the preliminary guideline.

9. Only essential information should be included in in-vehicle displays to prevent display clutter and increased visual search time. [NM09, UM13]

10. In-vehicle displays should be mounted as near as possible to the driver's normal line of vision (high, center) without obscuring any view of the roadway or outside terrain. [NM15, OM20]

11. Color coding is useful to convey information such as recommended route, danger areas, or areas of traffic congestion. Color coding should be used judiciously and according to accepted human factors standards for display design. [UM01, NM14, SK01, SK05]

12. Speech output should be used in conjunction with visual displays for route guidance, although the user should be given control (on/off and volume) over the speech output system. [TT09, TT11, NM26]

13. Speech output can be used to identify the location of hazards, to provide information about vehicle status, and to indicate cautions and warnings, but should not be used to confirm routine events. [UM05, UM06, SK02]

14. The syntactics and semantics of both speech and alphanumeric messages should be tested with the target user population for intelligibility and comprehension. [TT22, UM06, SK07, TT10]

CONTROLS

15. Controls for ATIS/CVO systems should be designed for ease of use to minimize the time and attention required of the driver. [TT16, TT17, OM16]

16. Buttons on the steering wheel should be considered as a viable design option because they are easy to reach. [TT17, SK16]

17. Touchscreens on a digital map provide the ability to designate a location with one touch. [CS10]

18. Touchscreens should be designed to resist fingerprints and smudges and should be robust to calibration error. [CS12, CS13]

19. Entering an alphanumeric character should not require more than one button push. [TT16]

20. Adequate user feedback (tactile, auditory, or both) should be provided for each button press or control input. [NM06]

21. ATIS/CVO in-vehicle display and control components should tolerate fluid spills, such as beverages, without affecting system operation. [OM06]

USER-SYSTEM INTERFACE

22. If an expert system is included in an ATIS/CVO system, the responsibilities of the driver and the system must be clearly understood. No action should be taken by the expert system (such as slewing the map) without the knowledge and permission of the driver. [SK08, SK10]

23. If an intelligent navigation aid recommends an alternate route, the reason for the recommendation and the time of the calculation should be conveyed to the driver or conveyed upon request. [SK04]

24. An intelligent navigation system should develop a model of the driver to anticipate when assistance may be needed and what criteria may be appropriate (speed, safety, travel time, scenic beauty, etc.). [SK04, SK11, SK13]

25. Display mode changes should either be under direct control of the driver or should be selectable in advance as defaults. [NM12]

26. The status of the major system components, modes, selectable features, and computer should be indicated or available upon request. [NM10, CS09]

27. Driver interfaces to ATIS/CVO systems should be consistent in format, location, and content. [UM02]

28. An easily perceived indication should be given quickly to a driver who departs from a recommended route while in route guidance mode. [NM08]

29. The driver should be given the option to reject a recommended route (for any reason, such as recent knowledge of road closure) and the system should calculate an alternative. [NM04]

DRIVER ATTENTION/WORKLOAD/SAFETY

30. The use of ATIS/CVO systems, compared to traditional navigation methods, should not increase the driver's attentional demands and mental workload during driving tasks and should not compromise safety. [TT05, TT06, TT23, OM18, UM04]

31. While the vehicle is in motion, the interface design should reduce driver workload through restricted access to control functions, guidance screens rather than maps, and supplementary use of voice output with the visual display. [TT23, UM04, NM26]

32. Maintaining the driver's normal attention directed towards the out-of-the-windshield scene should be fostered by mounting ATIS/CVO displays as close to the origin of optic flow without obstructing the view of other in-vehicle equipment or outside objects. [OM19, OM20]

33. ATIS and especially CVO systems should incorporate a structured training program that provides the ability of repeated "hands-on" practice and increased automation while reducing attentional demands. [TP25]

DRIVER INFORMATION REQUIREMENTS

34. ATIS/CVO systems should provide the driver with information about roadway hazards and traffic congestion. [UM07]

35. CVO systems should include a paging system to inform drivers of incoming priority messages when they are not in their vehicles. [OM24]

36. Real-time distance to a turn should be integrated into ATIS route guidance displays. [NM33]

37. Route turn information should reflect the physical characteristics of the roadway. [NM31]

38. ATIS/CVO systems should provide text-based route guidance if graphic displays are not viable. [OM11]

39. Automatic and manual emergency aid and road-assistance request features should be designed to function with a backup power source. [OM13]

40. Motorist services information is highly valued by ATIS users. [TT14]

ROUTE GUIDANCE/PLANNING/NAVIGATION

41. ATIS/CVO systems should allow drivers to navigate with a map display without entering a destination. [TT13]

42. Route planning functions should be fully integrated with route guidance and navigation functions when designing ATIS/CVO systems. [CS11]

43. Route navigation displays should clearly depict the selected route to a destination by using thicker street lines, color coding, or other distinguishing features. [NM14, UM14]

MAP DATABASES

44. ATIS/CVO map and directory databases should be updated frequently to maintain a current system that reflects roadway and destination changes. [NM11, TP18]

45. ATIS/CVO planned routes should account for one-way streets and two-way streets with a center divider. [NM02]

VEHICLE LOCATION ACCURACY

46. Accurate vehicle location is fundamental and essential for effective ATIS/CVO systems. Engineering design teams should ensure accurate vehicle location even under worst-case conditions. The user interface should inform drivers (and dispatchers, for CVO systems) as to significant decrements in location accuracy. [NM07, TP15, TP21]

DRIVER ACCEPTANCE

47. The design of ATIS user interfaces should incorporate the following features to increase driver acceptance: voice plus visual route guidance, selection of alternate routes, and both map and guidance screens. [TT01, TT08, TT09, TT12]

48. Criteria for user acceptance of ATIS systems include: reduced trip planning time and travel time; safety should not be degraded; the number of turn errors should be reduced. [TT02, TT03, TT06, TT07]

49. To increase driver acceptance of CVO systems, the system should outperform current dispatch-driver communication methods (e.g., finding a phone to call dispatch). [OM08, OM23]

COMMUNICATION BETWEEN DRIVER AND DISPATCH/HELP CENTER

50. CVO in-vehicle displays should indicate when a dispatcher receives and accesses a driver-transmitted message. [TP22]

51. CVO systems, including emergency response vehicle systems, should provide both the driver and the dispatcher with estimated time of arrival (ETA) to the destination. [TP16]

52. ATIS/CVO systems should have adequate manuals and/or reference materials to answer problems, or "on-line" help should be made available as an option for cellular phone users. [OM22, TT18]

53. ATIS systems should provide the driver with the ability to transmit free-format and/or pre-defined messages to a dispatch center via the in-vehicle display in CVO applications. [OM23]

TRAINING ISSUES/REQUIREMENTS

54. Training should be provided for new users of ATIS/CVO in-vehicle systems. The amount of training time required to use an ATIS system efficiently should take no more than 1 hour. For CVO systems, 4 to 8 hours is acceptable, depending on the complexity of the system. [NM16, TT24, OM22, TP25]

55. ATIS/CVO brochures and driver manuals should be easy to understand and easy to reference when drivers need to find information. Other training and job aids, such as audiotape and on-line tutorials, may be appropriate. [OM22]

HANDBOOKS AND GUIDELINES

56. ATIS design team members should be made aware that human factors design handbooks and literature exist and can assist in the design process. [OM26, TP02, TP05, TP12]

57. Human factors guidelines should provide design information regarding mental workload, attentional demands, situational awareness, and time-sharing requirements in the use of ATIS/CVO systems. [TP11]

58. ATIS/CVO interface design criteria should be based on the usability and safety of the system, anticipated environmental abuse, crashworthiness, ease of installation, cost to the user, and driver acceptance. [OM28, OM29, TP04]

59. ATIS/CVO brochures and manuals should provide essential directions for using the system, presented in a format and style that is easy to understand. [OM22, NM17]

DESIGN APPROACHES

60. Iterative usability testing, based on rapid prototypes, should be done early in the design of ATIS/CVO systems. [TT21, CS19, UM01, TP07, TP08]

61. Subject Matter Experts (SME's) representative of the projected user population should be included throughout the design of ATIS/CVO systems. [CS18, SK17]

62. A design team should include human factors and systems engineering experts throughout the design of ATIS/CVO systems. [TT19, TT20, CS03, CS17]

63. Operator-in-the-loop simulation is recommended as a test and development tool during the development of ATIS/CVO systems. [SK18]

64. Careful attention should be paid to the definition of performance measures and measures of effectiveness to be used during system development, testing, and evaluation. [UM15, SK19, CS20]

65. Evaluation of the benefits of ATIS/CVO systems should be done with reference to baseline methods for accomplishing the same functions (e.g., paper maps for route guidance). [UM08]

66. Cost-benefit analysis and a customer-driven approach are essential parts of an overall design process and should include human factors analysis of user requirements and user-interface design. [TP24, OM25, TT19]

CHAPTER 11. DISCUSSION AND RESEARCH ISSUES

DISCUSSION

Strengths and Constraints of the Comparable Systems Analysis

The analysis of comparable systems is a valuable approach for obtaining and organizing information about the successes and shortcomings of early attempts to design advanced systems for traveler information. The strength of the approach is that the lessons learned and the preliminary guidelines derived therefrom are based on systems that are directly relevant to ATIS/CVO systems. The weakness of the approach is that a limited number of specific systems (seven) were subjected to analysis. This represents a very small sample size from a hypothetical set of all possible ATIS/CVO-related systems that have been or could be developed. For example, not all of the ATIS/CVO subsystems (such as ISIS) were represented in the seven selected systems, and budget constraints prevented coverage of relevant systems in Europe and Japan. Therefore, the lessons learned and the guidelines presented here are not exhaustive. Other insights and lessons would have been learned if other systems had been covered.

The lessons learned and the guidelines presented must be considered not only non-exhaustive, but preliminary. They are based primarily on expert observation and interviews. Ultimately, they need to be subjected to empirical testing, corroboration, and refinement before being promulgated as design guidelines or specifications.

User-Centered Design With or Without Human Factors

Presumably, all people in the human factors profession acknowledge the need for user-centered design. One subtle lesson learned, or at least a reminder, from the present analysis is that the commercial forces that drive much innovation may invoke user-centered design without human factors input. At least two of the systems included in this analysis showed that an engineering design team may develop an advanced system, including the user interface, through strong communication with the user community, bypassing the skills and knowledge offered by human factors experts. Perhaps this reinforces the need for the human factors community to offer design guidelines to design engineers that are readily available and easy to use.

RESEARCH ISSUES

The comparable systems analysis indicated that there are some fundamental issues that need to be addressed to achieve the overall goals of efficiency and safety in surface transportation.

Driver Attention Management

When is a driver overloaded with information? How successful will drivers be in managing their attention and cognitive resources to deal with multiple tasks? One can conceive of clear cases of multi-task information overload, such as controlling the vehicle, monitoring traffic, talking on the phone, revising the destination on the ATIS, loading a new CD, monitoring the ATIS visual and auditory information, and so on. This is not a new issue, but it is a difficult one that has implications for safety as well as legal issues of liability. It is also rooted in the American spirit of independence and freedom of choice. Users are not likely to appreciate "lock-out" designs that only allow the driver to access functions under certain circumstances. Few drivers would accept a car stereo that allowed the channel to be changed only when the vehicle was in PARK or at zero speed. The same spirit is likely to pertain to ATIS/CVO functions. Commercial applications face similar issues. Should CVO system design lock out the driver from accessing functions while moving? An interim position, but certainly not a solution, is to make all features and functions available at all times, but to warn and instruct drivers not to use them unless stopped.

Research on driver information management is important for the design of ATIS/CVO systems. It also is relevant to Advanced Vehicle Control Systems (AVCS).

Use of ATIS/CVO Systems by Older Drivers

One of the issues identified in the comparable systems analysis was that the use of ATIS/CVO systems by older drivers is relatively unknown and needs further research. The aging population of the United States, the "baby boomers," will result in an increasing proportion of older drivers. No information or insights were obtained on this important issue from the current analysis and it remains a topic for further research.

The Measurement Problem

The measurement of driver performance is difficult because it is multi-variate and dependent on a flux of changing tasks. The measurement of driver attention, workload, and situation awareness is even more difficult because these are hypothetical constructs that cannot be measured directly. The challenges of empirical measurement of the effectiveness of advanced systems, such as ATIS/CVO systems, should not be underestimated. Without reliable and valid measures, the impact of these technologies on productivity and safety will be difficult to assess. The development of good measures is an important and challenging research issue.

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