Development of Human Factors Guidelines for Advanced Traveler Information Systems and Commercial Vehicle Operations: Literature Review

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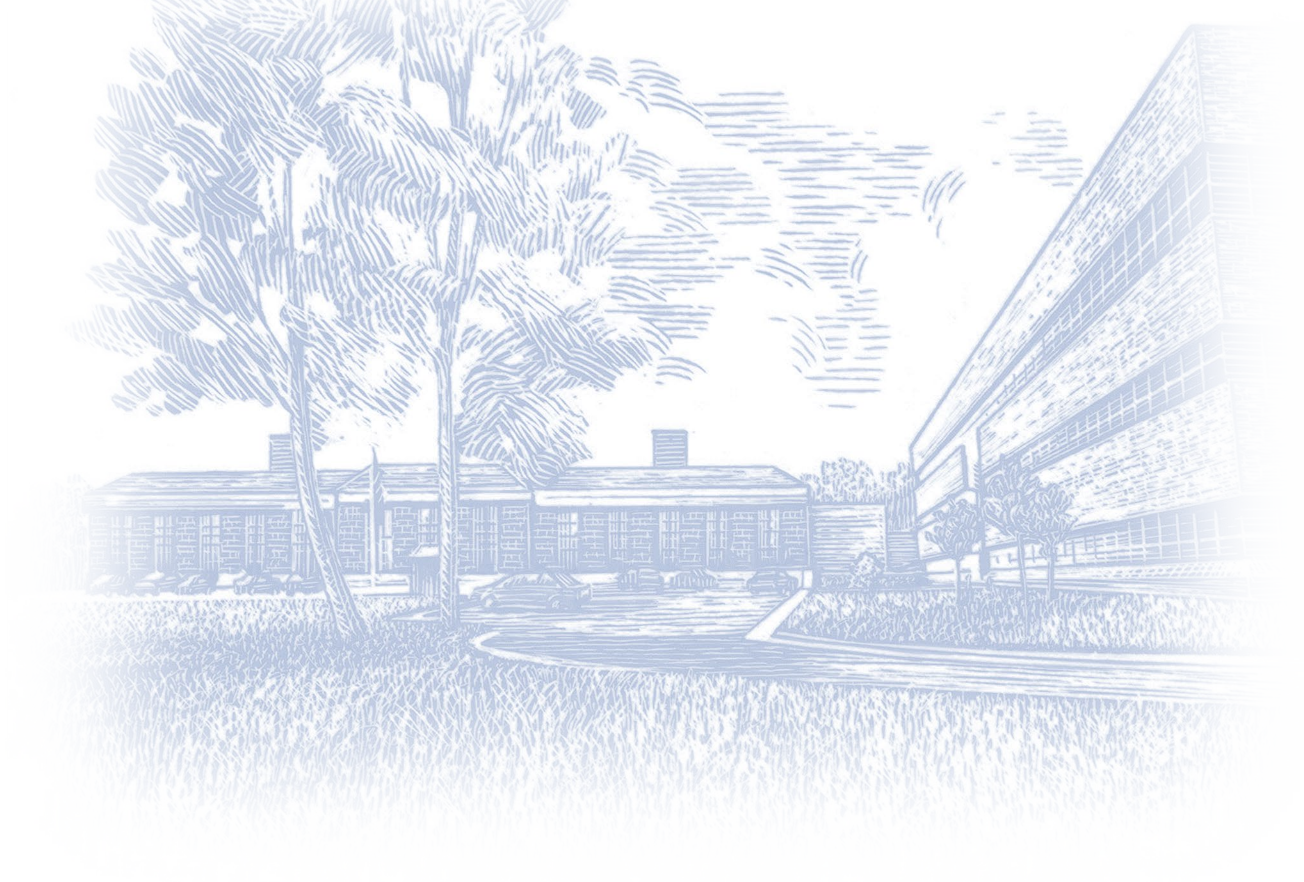

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Foreword

This report is one of a series of nine 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 other topics discussed in the series are functional description of ATIS/CVO, comparable systems analysis, task analysis of ATIS/CVO functions, alternate systems analysis, identification and exploration of driver acceptance, and definition and prioritization of research studies.

This report documents ATIS and CVO system objectives and performance requirements. It provides basic information regarding the range of ATIS and CVO operational capabilities, a survey of ATIS and CVO systems, a preliminary set of ATIS and CVO scenarios, and a summary of system performance requirements.

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

Jerry Reagan, Acting Director
Office of Safety and Traffic
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NOTICE

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16. Abstract The document type of resource materials. The purpose of Task A was to conduct a literature review of human factors–applicable articles associated with Advanced Traveler Information Systems (ATIS) and ATIS–related commercial vehicle operations (CVO) systems. Specifically, Task A was to assess existing human factors guidelines to determine their applicability to ATIS systems and identify research gaps that would be filled to establish complete and comprehensive ATIS guidelines. As with any literature review, the		

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EXECUTIVE SUMMARY

The Intelligent Transportation System (ITS) integrates the driver, vehicle, and the road to raise overall efficiency and driver safety. To this end, advanced technologies are being developed and applied. Two specific areas within the ITS framework are addressed in this report: Advanced Traveler Information Systems (ATIS) and Commercial Vehicle Operations (CVO).

ATIS is an important area for Human Factors and Safety research. Both urban and rural travelers will be provided real–time information on traffic and road conditions, vehicle location and navigation, safety warnings, and a host of motorist services. The inclusion of ATIS functions in the automotive environment changes the composite task of driving. If great care is not taken in designing this new task environment, performance and safety will suffer.

CVO's are vital to the movement of goods as well as providing services such as bus transportation and medical emergency response. Commercial vehicles, public service vehicles, and passenger vehicles fall into the category of CVO. Just about any endeavor that has a fleet of road vehicles is considered a CVO. The economic backbone of the country relies on timely and reliable delivery of products. The national roadway shipping infrastructure will benefit greatly from using technologies of ITS in general, and ATIS in particular.

The goal of this project is to develop human factors guidelines for the design of ATIS and CVO systems. Achievement of this goal will require the application of existing principles and guidelines to the ATIS/CVO domain, analysis and modeling of ATIS and CVO tasks using existing tools, and empirical research to fill gaps in the current base of knowledge.

The purpose of Task A was to conduct a literature review of human factors–applicable articles associated with ATIS and ATIS–related CVO systems. Specifically, the goal of Task A was to assess existing human factors guidelines to determine their applicability to ATIS systems and identify research gaps that would be filled to establish complete and comprehensive ATIS guidelines. As with any literature review, the conduct of Task A was treated as a foundation for subsequent tasks.

The methodology employed to complete Task A included a mass mailing (over 500 letters) to solicit articles, reports, and information from public and private sector organizations and individuals; advertising at the Human Factors Conference and the Human Factors Bulletin; and conduct of numerous database searches. Over 1000 articles were collected via this methodology. The articles were prioritized with respect to the potential value for human factors guideline development. Annotated bibliographies were then prepared for approximately 300 of the highest priority articles. Once the annotations were complete, they, as well as additional articles, were reviewed for the preparation of this final report.

As part of the Task A review, attempts were made to procure existing human factors guidelines of interest from several sources. These sources included existing ATIS/CVO research published in refereed sources, existing ATIS/CVO technical reports, articles describing comparable systems such as aircraft, and existing human factors guideline documents.

In attempting to compile applicable guidelines from these sources it became apparent that there are literally thousands of guidelines that apply to at least some degree to ATIS/CVO systems. Therefore, an effort was made to prioritize guidelines and report as part of this document only those guidelines that are particularly applicable.

The research status of ATIS applied to private vehicles and CVO is mixed. Both applications are relatively new, yet both already are involved in large–scale operational test programs. The Intelligent Vehicle Highway Society of America, tasked with advising the government on the development of ITS in the U.S., has outlined the development process of ITS over the next twenty years (Intelligent Vehicle Highway

Society of America, 1992b). Several projects have advanced to the demonstration project stage, yet basic aspects of ITS are still being defined. In the near–term (1992–1996) ITS research, development, and operational testing is planned (Intelligent Vehicle–Highway Society of America, 1992b).

The ATIS/CVO research to date has tended to be system–description oriented, with details of the organization of research that is or needs to be conducted. As such, there are many human factors research issues that still need to be addressed before a comprehensive set of guidelines can be developed. However, a number of issues have been resolved for ATIS systems or comparable systems and need not be re–addressed. It is apparent that, as the development of hardware progresses, the next few years will see a marked growth in the literature available from both U.S. demonstration projects and foreign sources. Therefore, as the research planning phase of this project progresses, it will be critical to continue vigilant review of current studies.

It is anticipated that the data from the initial U.S. operational tests and additional European and Japanese projects will serve to fill some of the largest gaps in the current human factors knowledge base. However, even with current knowledge and the promise of data from operational tests, it is apparent that many human factors research issues will need to be empirically addressed before a comprehensive set of guidelines can be developed.

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INTRODUCTION

BACKGROUND

Significant advances in sensor, electronic, and microcomputing technology during the past decade have led to the feasibility of functionally powerful, computer–based automotive and commercial vehicle information systems. Stephens (1986) estimated that more than 40 such systems are currently under development worldwide. Although these systems differ in objective and functionality, they all serve as an aid for the driver. The collective feasibility of developing this family of functionally powerful devices for road transportation has led to the conceptualization of the Intelligent Transportation System (ITS).

ITS integrates the driver, vehicle, and the road to raise overall efficiency and driver safety. To this end, advanced technologies are being developed and applied. Specific areas addressed in this report are Advanced Traveler Information Systems (ATIS) and commercial vehicle operations (CVO). Note that the acronyms ATIS and ADIS (Advanced Driver Information Systems, mentioned in much of the ITS literature) are used to refer to the same systems.

ATIS is an important area for human factors and safety research. Both urban and rural travelers will be provided real–time information on traffic and road conditions, vehicle location and navigation, safety warnings, and a host of motorist services.

CVO's are vital to the movement of goods, as well as providing services such as bus transportation and medical emergency response. Commercial vehicles, public service vehicles, and passenger vehicles fall into the category of CVO. Just about any endeavor that has a fleet of road vehicles is considered a CVO. The economic backbone of the country relies on timely and reliable delivery of products. Using technologies of ITS, the national roadway shipping infrastructure will benefit greatly. Most CVO research focuses on the trucking industry. Key technologies in CVO research are Automatic Vehicle Identification (AVI), Automatic Vehicle Location (AVL), Weigh in Motion (WIM), and navigation.

The research status of ATIS applied to private vehicles and CVO is mixed. Both applications are relatively new, yet both already are involved in large–scale operational test programs. The Intelligent Vehicle–Highway Society of America, tasked with advising the government on the development of ITS in the United States, has outlined the development process of ITS over the next 20 years (Intelligent Vehicle Highway Society of America, 1992b). Several projects have advanced to the demonstration project stage, yet basic aspects of ITS are still being defined. In the near term (1992–1996) ITS research, development, and operational testing is planned (Intelligent Vehicle Highway Society of America, 1992b). An outline of the near–term strategic plan appears in the following paragraphs (Mammano and Baxter, 1990).

ATIS research and development (R&D) will focus on navigational software, map and services data bases, and communication alternatives. Operational testing is now occurring on navigation route planning AVI/AVL and information delivery modes.

CVO R&D for the near term will focus on WIM, electronic toll collection, driver warnings, and electronic record keeping. Operational testing is now under way for AVI/AVL, electronic credential checking, and electronic permitting.

ATIS will provide services to motorists in four useful areas:

- Navigation.
- Road and traffic information.
- Roadside information.
- Personal communications.

The first of these areas, ATIS navigation, will provide useful and timely information, including landmarks and street names. It will also provide the optimum route and display current vehicle location to orient the driver. The second functional area, road and traffic information service, will provide valuable insight into current and future driving conditions. Some examples of conditions that require notification and rerouting are construction detours, accidents, foul weather, and traffic jams. Alternate routes can be provided and new arrival times can be estimated using ATIS. The third function of ATIS is to provide roadside information. This information might include the location of the nearest gas station, or the ability to tour a city without sightseeing information. A last function of ATIS will be person–to–person communication. This feature allows the driver to make and receive calls, including those for emergencies. Both data and voice modes of communication will be possible. If a traffic jam delays a meeting, business associates can reschedule en route as well as communicate to a central office from remote areas.

While these systems promise to serve a valuable function, they represent a new frontier in the automotive industry. This frontier could be hazardous if it interferes with the driving task. This non–interference requirement, in conjunction with requirements imposed by the environment (e.g., glare, night driving, high ambient noise), the user population (e.g., elderly drivers, various education levels), limited training opportunities, and system constraints (e.g., cost) make these systems one of the greatest consumer product human factors challenges to date.

An initial step in meeting this challenge is the development of comprehensive and useful guidelines for designers. Development of such guidelines is the goal of this project. In developing these guidelines, existing guidelines and other information sources will be reviewed to determine their applicability to ATIS and CVO systems. It was the goal of Task A to review these guidelines and this information as described in this report.

General Literature Review Findings

The majority of the ITS literature produced to date contains descriptions of research plans and proposed frameworks for evaluation of systems. These papers are key to the initial "information" phase of the ITS development. Some reports have arisen from early operational tests, part of the "advisory" stage of ITS designed to demonstrate the feasibility of different systems (Intelligent Vehicle Highway Society of America, 1992b). However, many of the initial operational tests are still under way as of the writing of this report, and no empirical findings are available.

Many of the ITS sources contain information that can be applied to both ATIS and CVO. In addition, "safety" and "human factors" are raised as very important design issues in much of the ITS literature. However, relatively few documents discuss specific design guidelines or empirical results relating to safety and human factors of ATIS and CVO systems.

While much of the available literature will not directly aid in the development of human factors guidelines, there is a significant base of information to aid in guideline development. This information is detailed in the following sections.

Two sources of information of particular interest to this project are reports from the TravTek and University of Michigan Transportation Research Institute (UMTRI) projects that are currently under way. Each of these projects is expected to generate considerable data concerning driver performance and behavior while using ATIS systems. Unfortunately, as of this report, no technical reports and little data specifying study results are available from either of these projects.

PROJECT SCOPE

The purpose of Task A was to conduct a literature review of human factors–applicable articles associated with ATIS and ATIS–related CVO systems. Specifically, Task A was to assess existing human factors guidelines to determine their applicability to ATIS systems and identify research gaps that would be filled to establish complete and comprehensive ATIS guidelines. As with any literature review, the conduct of Task A was treated as a foundation for subsequent tasks. The duration of Task A (3 months) was such that some of the literature of interest could not be obtained prior to publication of this report. Thus, the literature review does not, in effect, end with this report. Many article inquiries and orders are being completed as of this writing. Thus, valuable project information will continue to arrive in the next several months.

This report serves as a strong basis for additional reviews in subsequent tasks. Task A was completed in seven subtasks. The first six of these subtasks constitute six exclusive bodies of literature that were reviewed. Thus, these six subtasks were accomplished concurrently during the completion of Task A. The seventh subtask (reporting) serves to tie the results of the previous six subtasks together with a summary report of the findings and their impact on the overall project.

Description of the Method Employed to Complete the Literature

The initial groundwork for the project included a mass mailing (over 500 letters) to solicit articles, reports, and information from public and private sector organizations and individuals; advertising at the Human Factors conference in Atlanta and in the November 1992 issue of the Human Factors Bulletin; and conduct of numerous data base searches. The computerized data bases searched included Psychlit, Cougalog, Uncover, Applied Science and Technology, Intelligent Vehicle Highway Society of America, National Technical Information Service (NTIS), Engineering Index, Dialogue, Silver Platter, and the University of Idaho's main data base. Articles were obtained from the following open literature sources:

- Alcohol Drugs and Driving Abstracts and Review.
- American Society of Civil Engineers (ASCE) Transportation Journal.
- Automotive Displays and Industrial Illumination.
- Automotive Engineering.
- Automotive Industries.
- Aviation Week and Space Technology.
- Cognitive Science.
- Engineering Data Compendium.
- Ergonomics.
- Highway Research Record.
- Human Factors.
- Institute of Electronics and Electrical Engineers (IEEE) Transactions.
- IEEE Vehicle Navigation and Information Systems Conference.
- Information Technology Applications in Transport.
- International Journal of Man-Machine Studies.
- Institute of Transport Engineers (ITE) Compendium of Technical Papers.
- ITE Journal.
- Journal of Applied Behavioral Analysis.
- Journal of Applied Psychology.
- Journal of Dynamics Systems.
- Journal of Gerontology: Psychological Sciences.
- Journal of Studies on Alcohol.
- Journal of the American Society of Information Science.
- Journal of Transportation Engineering.
- Mechanical Engineering.

- Military Standards.
- National Aeronautics and Space Administration (NASA) Technical Paper Series.
- Nissan Technology Newsline.
- Perceptual and Motor Skills.
- Planning and Technology.
- Proceedings of Drive Conference.
- Proceedings of Human Factors Society.
- Proceedings of Institute of Mechanical Engineers.
- Proceedings of International Technical Conference on Experimental Safety Vehicles.
- Proceedings of ITS America.
- Proceedings of the International Congress of Transportation Electronics.
- Public Roads.
- Society of Automotive Engineers (SAE) Technical Paper Series.
- Safety News.
- Technology in Society.
- Technology Review.
- The American Cartographer.
- Toyota Technical Review.
- Traffic Engineering and Control.
- Traffic Safety.
- Transportation.
- Transportation Quarterly.
- Transportation Research.
- Transportation Research Board.
- Transportation Research Record.
- Vehicle Information Systems and Electronic Display Technology.
- Vehicle Navigation and Information Systems Conference Proceedings (VNIS).
- Vision in Vehicles.

In addition to computerized data base searches, three trips were taken to manually search through several libraries. One trip was taken to Seattle, Washington, to conduct a search at the University of Washington and Battelle. A second trip was taken to Detroit, Michigan, to conduct a search at UMTRI and General Motors. A third trip was taken to Washington, DC, to conduct a search at the Federal Highway Administration (FHWA).

Annotated bibliographies were generated for many of the articles collected as part of Task A. Due to time and resource constraints, annotations could not be completed for the 1000+ articles collected. Thus, the articles were prioritized based on the potential value for generating human factors guidelines. A copy of the annotations that were completed for this task–indexed by author, page number, and key words–appears as a supplement to the report working paper.

ORGANIZATION OF THE CONTENTS

The specific goals of Task A were to:

- Identify human factors research issues, hypotheses, empirical findings, principles, and guidelines applicable to ATIS/CVO systems.
- Identify relevant documentation describing comparable system objectives, functions, configurations, and guidelines.

- Identify present and likely near-term technological and cost constraints that will necessarily drive human factors-related ATIS/CVO issues.
- Present the reviewed information in a format that is usable for the remainder of the project tasks.

To achieve these goals, the organization of this report includes sections and subsections that provide information of interest to task leaders. In addition, the two major products of Task A are provided separately as part of the Conclusions and Recommendations section of this report, they include:

- Existing principles and guidelines of potential use.
- Research gaps that will be filled to complete comprehensive and useful guidelines.

The specific organization of this content is summarized in Table 1.

Table 1. Organization of objectives within this report.

Report Section	Objectives Addressed	Page
Description of ATIS/CVO system objectives, functions, and configurations	System/project description only	15
Review of ATIS/CVO empirical evaluations with human factors implications	Empirical findings	29
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Review of emerging technology and its impact on ATIS/CVO systems and human factors design	Technological and cost constraints	54
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DISCUSSION

ATIS/CVO SYSTEM CONFIGURATIONS, FUNCTIONS, AND OBJECTIVES

Overview of ATIS Systems

According to Perez and Mast (1992), the major goal of ATIS is to improve the information that is provided to travelers. This includes information for traveling in normal and poor weather, congested, and emergency conditions. In the early stages of ATIS development, the emphasis is primarily on providing travelers with information to improve their planning and decision making. In the later stages of ATIS development, the emphasis will be on supplementing static on–board information with dynamic traffic information that is collected and transmitted from other segments of the ITS to optimize individual travel time.

During our literature search, several papers were found that define major concepts and problems of ATIS systems (Rillings and Betsold, 1991; Haselkorn, 1992; Ratcliff and Behnke, 1991; Rothberg, 1990; Rutherford and Mahoney, 1989; Mast, 1991; Hancock and Caird, 1992). Rillings and Betsold (1991) discuss a 20–year plan for the evolution of ADIS developed at a series of workshops sponsored by Mobility 2000 (1990, 1991). The evolution of these systems is anticipated to progress through three stages:

1990 to 1995: This stage will focus on providing each driver with information to improve individual planning and decision making. Most of these systems will rely on the vehicle's own resources, such as dead reckoning, on–board data bases, and static route selection.

1995 to 2000: This stage will focus on supplementing the static information of the information stage with data obtained from the infrastructure. The vehicle information systems will advise the driver of the correct routes and guide the driver step by step over those routes.

2000 to 2010: This stage will focus on automatic exchange of information between the infrastructure and vehicles. Vehicles will be used to report traffic conditions and the infrastructure will combine the data from these reports and use it to control traffic signals and inform drivers of alternate routes.

Rillings and Betsold (1991) suggest that a major goal of the near–term advisory stage of ITS is to provide automatic minimum travel–time route selection and guidance using up–to–the–minute traffic information. During the middle–term coordination stage, the vehicle equipment and the infrastructure should also support an automatic mayday feature.

To accomplish the overall ATIS goal, there have been several classes of systems identified within the ATIS program: In–vehicle Routing and Navigational Systems (IRANS), In–vehicle Motorist Services Information Systems (IMSIS), In–vehicle Signing Information Systems (ISIS), and In–vehicle Safety Advisory and Warning Systems (IVSAWS) (Perez and Mast, 1992). Thus far in the evolution of ATIS, the vast majority of developed systems and empirical research has centered around IRANS applications. IMSIS functions are empirically represented in a few instances, and ISIS and IVSAWS are greatly under represented in early system development. A summary of the functions of recent ATIS projects provided by Rillings and Betsold (1991) illustrates the emphasis on IRANS to date. These projects include Pathfinder, TravTek, Advanced Mobile Information and Communication System (AMTICS), RACS, AUTOGUIDE, Acquisition par Télédiffusion de Logiciels Automobiles pour les Services (ATLAS), CARMINAT, Car Information and Communication System (CARIN), Media Intelligent pour l'Environnement Routier du Véhicule Européen (Minerve), Highway Assistance Readout (HAR), Army Research Institute (ARI), and Radio Data System (RDS). The basis functionality of the systems associated with each of these projects is summarized below:

- Pathfinder provides drivers with navigation and real–time traffic congestion information.
- TravTek provides drivers with navigation, route guidance, real–time traffic congestion information, general traffic information, trip services, pre–trip planning, and emergency communication.
- AMTICS provides drivers with navigation, real–time traffic congestion information, trip services, and personal and emergency communication.
- RACS provides drivers with navigation, real–time traffic congestion information, trip services, and personal communication.
- AUTOGUIDE provides drivers with navigation and route guidance.
- ATLAS provides drivers with general traffic information and personal communication.
- CARMINAT provides drivers with navigation.
- CARIN provides drivers with navigation and trip services.
- HAR provides drivers with general traffic information and trip services.
- ARI and RDS provide drivers with general traffic information.

These systems (and others) are described in greater detail in the following sections.

As illustrated above, existing IRANS systems and conceptual designs vary greatly with respect to functionality, driver information, and design. In fact, some systems (e.g., TravTek) incorporate IRANS and IMSIS functions into a single device. Although no determination has been made regarding available functions on most systems under development (Lunenfeld, 1990), a number of features will likely be useful and integrated as part of future systems. These features include the following:

- Route planning functions based on multiple criteria for route selection (e.g., fastest or fewest turns).
- Real–time display of traffic information and route replanning.
- "Yellow Pages" functions allowing selection of specific destinations based on several features (e.g., moderately priced Chinese restaurants within a given travel time).
- Emergency services functions (e.g., police, ambulance, towing).

The number of potential benefits and the perceived marketability of IRANS is a major reason for the development activity centered around IRANS applications. Navigation to an unknown destination without passenger assistance is a difficult task and, in most cases, is performed inefficiently or unsuccessfully. Outram and Thompson (1977) and Jeffery (1981) estimate that between 6 percent to 15 percent of all highway mileage is wasted due to inadequate navigation techniques. This results in a monetary loss of at least $45 billion per year (King, 1986).

A traffic delay can also be potentially reduced by widespread use of navigation systems. Several systems under development are designed to interface with advanced traffic management centers that will eventually be based in metropolitan areas. Once such systems are in place, real–time traffic delays can be broadcast to in–vehicle systems. These systems can then be used to continuously calculate the fastest route to a destination during travel. That capability, if widely used, could increase efficiency for an entire infrastructure network.

Given the level of development effort and the benefits of navigation systems, widespread development will continue. Thus, it will be critical that systems are required to be designed with human factors objectives to ensure system safety, efficiency, and usability. Dingus and Hulse (1993) specify human factors–related objectives for such systems. These objectives are listed below.

- *Navigate More Effectively.*

  The primary purpose of electronic automobile navigation assistance is to allow the driver to locate unknown destinations and assist in error–free planning and route following. In addition, systems will, in the near future, have the capability to provide detailed, relevant information about traffic, obstacles, and roadways. The driver will be able to navigate more effectively only if the system provides the information necessary for navigation in an accurate and timely manner.

- *Navigate More Easily.*

  Researchers have found that memorizing a route, either through lists or from maps, is difficult and not done well. Remembering spatial map configurations or mentally reorienting a map is also difficult for people and it conflicts with the spatial task of driving (Wetherell, 1979). Other navigation tasks are difficult because the information is not always available or is obscured (e.g., street signs). Therefore, providing drivers with an easy–to–use navigation system is a worthwhile design objective.

- *Navigate and Drive Safely.*

  Drivers should be able to navigate without jeopardizing driving performance. ATIS systems should be designed to minimize the demands imposed by the system and leave sufficient driver attention, information processing, and response resources for driving in all situations.

  In addition, information regarding upcoming obstacles or traffic congestion could warn drivers of potentially dangerous conditions. This feature could reduce risk, particularly in low visibility circumstances. Thus, with prudent design, navigation information systems could make driving safer and more secure.

- *Optimize Roadway Use Efficiency.*

  Since traffic congestion is a problem encountered by many drivers and is expected to get worse, some systems try to distribute traffic more evenly throughout a system using navigational assistance. If drivers are advised of congestion while planning their route, it is expected that they will avoid congested roadways. Thus, they would be able to avoid traffic congestion and not contribute further to the congestion problem. Also, if drivers are informed of obstacles or congestion that occur while they are en route, they may be willing to detour and avoid the congestion. The feasibility of this objective depends, in part, on the amount and detail of information provided to the driver while driving.

  While the majority of effort to date has been expended on IRANS development, the other ATIS subsystems, namely IMSIS, ISIS, and IVSAWS, hold promise for improving driving efficiency and safety. A paper by Green, Serafin, Williams, and Palke (1991) rated the relative costs and benefits of ATIS features. Based on ratings by four human factors ITS experts regarding the costs and benefits associated with accidents, traffic operations, and driver needs and wants, several IVSAWS features were found to be most desirable in future systems. Several in–car signing features were also highly ranked. In contrast, some IRANS features were ranked relatively low, primarily due to the potential safety cost of using such systems (Green, et al., 1991).

Description of U.S.–Based ATIS Projects/Systems

Most available reports of U.S.–based ATIS systems and projects are of a descriptive nature. With the exception of TravTek and Pathfinder, field or laboratory evaluations were lacking. Pathfinder was of limited scope (25 cars) and was the first domestic ITS project. Its main purpose was to demonstrate the feasibility of ITS and promote further study. The TravTek operational testing phase was completed in March 1993. By the third quarter of 1993, significant information on TravTek should be available from

Orlando testing. Therefore, the data that are currently available to support the development of human factors guidelines are limited, but will continually improve for the duration of this project.

A description of each of the planned or completed U.S. ATIS projects is presented below.

TravTek

"Travel Technology," a demonstration system developed by General Motors (GM) that involved the City of Orlando, the Florida Department of Transportation (DOT), the Federal Highway Administration (FHWA), and the American Automobile Association (AAA), is nearing completion. The TravTek system was a complete ITS infrastructure, including a Traffic Management Center (TMC), traffic monitoring and sensing, and route guidance information. The goal of TravTek was to reduce congestion and provide information on geographic attractions and services. The TravTek interface linked drivers of 100 test vehicles to real–time information via digital data broadcasts. Avis rental car customers and solicited subjects participated in the testing.

- The majority of ATIS reports discuss TravTek. If the constructs involved in TravTek are understood, the constellation of in–vehicle navigation systems is roughly represented. Using the latest technology, the driver is aided in various navigation tasks, route selection, route guidance, local information, and system interface. Human factors design considerations have been used since the inception of the system. The driver accesses information through three vehicle modes: pre–drive (park), drive (vehicle in motion) and zero speed, which are both visual and auditory sensory channels. Extensive research into the needs and functions of both driver interface modalities was accomplished prior to the start of data collection. In addition, two visual display formats were available to the driver (Fleishman, Carpenter, Dingus, Szczublewski, Krage, and Means, 1991):

– A turn–by–turn graphic "guidance screen."

– A color route map.

Several reports and publications are available describing the system. For system architecture, see the report by Rillings and Lewis (1991). Information on task analysis is in a paper by Krage (1991). Human factors design aspects are described by Fleishman, et al. (1991) and Carpenter, Fleishman, Dingus, Szczublewski, Krage, and Means (1991). Finally, the design of the auditory interface is described in Means, Carpenter, Fleishman, Dingus, Krage, and Szczublewski (1992).

ADVANCE

The largest operational test of ITS will be based in Chicago and its northwestern suburbs. The Advanced Driver and Vehicle Advisory Navigation Concept (ADVANCE) brings together the efforts of major ITS manufacturers Ford, Toyota, Nissan, Saab, Volvo, Peugeot, ETAK, Navigation Technologies, DonTech, Motorola, and Sun Microsystems. Institutions in Illinois are also involved, including Illinois Universities Transportation Research Consortium, City of Chicago, and the Illinois DOT.

This project is still in the planning stage, but is nearing operation. The ADVANCE operational test is very similar to TravTek, but it also focuses on reducing congestion on arterial roadways, as well as on highways.

Pathfinder

As the first in–vehicle navigation system project in the United States, Pathfinder involved Caltrans, GM, and FHWA. This project focused on a 20.9–km (13–mi) stretch of the Santa Monica Freeway, where 25 vehicles were equipped with ETAK–modified displays. Information on accidents, congestion, highway construction, and route diversion was presented to the driver, either on the map display or through digital voice. The final phase of evaluation took place in spring 1992.

Pathfinder is one of the few projects with a publication describing human factors aspects of system design. Mammano and Sumner (1989) make the following design observations:

- Voice messaging intelligibility was improved by digitizing common words and synthesizing less common ones. This also saved computer memory.
- Less critical information was filtered prior to being displayed (depending on the scale of the map) to avoid display clutter during peak traffic times.

Travelpilot

Travelpilot, a joint project of Bosch and ETAK, is an after–market navigation system. This device forms the core of the Pathfinder system and is also used in over 400 emergency vehicles in Los Angeles. The system consists of wheel sensors, compass, microcomputer with Compact Disc–Read–Only Memory (CD–ROM) map data base, and an 11.4–mm (4.5–in) vector–drawn monochrome display. In addition, Travelpilot can be linked to communication systems for real–time data display.

DriverGuide

Pre–trip out–of–vehicle route guidance is conducted using this system. Users enter origin–destination pairs and receive a printed set of instructions. The system was tested on French air travelers visiting San Francisco.

FAST–TRAC

The Ali–Scout system, developed as a joint project of the Federal Republic of Germany, Siemens, Volkswagen, Blaupunkt, and others, is used as part of the FAST–TRAC project in Oakland County, Michigan. The display is a simple Liquid Crystal Display (LCD) readout that shows driving instructions with arrows at appropriate intersections. Infrared communication occurs at beacons located at key intersections to update the vehicle information systems. FAST–TRAC is relatively low cost on a per vehicle basis, but requires intersections to be equipped with transmitting beacons.

ROGUE

Navigation Technologies Corp. has developed the route guidance expert system, ROGUE, for daily in–vehicle navigation. The ROGUE software draws on the NavTech digital street map data bases. Embedded in the CD–ROM data base is information that simulates human intuition about routing, such as time of day (e.g., rush hour). The system can run on a stand–alone basis or with an infrastructure updating its information. The stand–alone option is used as a selling point since the global positioning system (GPS) and communication infrastructures can be cost–prohibitive. Points of interest are also coded into the data base. ROGUE uses an in–dash cathode ray tube (CRT) display.

The expert system for the ROGUE in–vehicle route guidance is described in a report by Silverman (1988). There are six design concepts specified in the report. These concepts are:

- Providing route planning expertise (e.g., tell how to get to the nearest florist, not just where the florist is located).
- Providing effective and efficient directions (i.e., information about the street network, road and traffic conditions, and points of interest).
- Providing navigation guidance during travel. This is an analog of a knowledgeable passenger.

- Detecting driving errors (i.e., wrong turns need to be detected and corrective guidances need to be provided).
- Operating without external equipment (i.e., high cost and dependence on communications signals can be avoided; the ability to use external data sources should be built in, if available).
- Maximizing driver comfort and safety (i.e., the system must not distract or degrade driving safety; simple spoken and graphic directions, along with automated driving–error detection, achieve this goal).

The driver interface is also described in the Silverman report. A video display terminal (VDT) mounted in the instrument cluster delivers requested navigation information. The display is monochrome, but provides line graphics as well as text capability. Also, a speech synthesis unit aurally provides directions. The driver can toggle the system to give spoken directions or chime when directions are updated on the screen, beckoning the driver to glance at them. Driver input is provided via an alphanumeric keyboard.

CARIN

Philips Corporation's CAR Information and Navigation (CARIN) system is an early implementation of the Compact Disc–Interactive (CD–I) format of storing digital maps (Thoone, Dreissen, Hermus, and van der Valk, 1987). Vehicle location is accomplished by dead reckoning and map matching. Included in the system design is a radio data link for traffic information. The driver is guided with synthesized speech in conjunction with a pictogram display (similar to the Ali–Scout).

The system requires a keyboard for driver input, while a supplemental color touch screen is optional. A flat–panel display is used in the basic configuration, which shows stylized map graphics to supplement the audio. Maps are presented "heading up."

SmartRoutes

Liebesny (1992) discusses the SmartRoutes system that will service the Boston metropolitan area. The system will use real–time data from a traffic information center. Drivers will be able to access this information through the use of a land line, cellular phone, cable television, direct fax, or computer modem. Various automated mechanisms, such as interactive audiotext and video graphics, have been developed to disseminate the information. Liebesny (1992) recommends that the information be kept current and the system design updated continuously with a maximum acceptable aging period of 15 min. He also suggests developing a coordinated public/private partnership to handle the full aspects of incident management.

TRIPS

TRIPS includes dispatching of single–trip carpooling or parataxi systems, enabling drivers and riders to use touch–tone telephones, personal computers, and videotext terminals to obtain information on local traffic information and alternative route information (Ratcliff and Behnke, 1991).

Overview of ATIS Systems/Projects Outside the United States

Other countries are more advanced in ITS technology than the United States due, in part, to their traffic congestion. The traffic congestion in Europe, and especially Japan, is considerably worse than in this country. However, the United States should follow the rest of the world's example and implement a structured system of traffic management before its problems get worse. The systems in other countries were all formed as joint operations between government, industry, and research institutions. Without this collaborative effort, projects of this magnitude would have had little chance of success.

The reason for combining the operations of government, industry, and research institutions was to get a global perspective on current problems and solutions. In this way, resources could be put to use on citywide or country operational systems. This scale of organization has not been adopted in the United States. In addition to traffic flow and route navigation information, developments from other countries include driving aides such as collision avoidance and driving condition monitors. Human factors guidelines can be drawn by the study of these programs, their individual systems, and their direct research findings.

European ATIS Projects/Systems

Europe has several large–scale programs in progress under the umbrella of Road Transport Informantics (RTI), which is the equivalent of the U.S. ITS. Their main programs are dedicated road infrastructures for vehicle safety in Europe (DRIVE) and the program for European traffic with highest efficiency and unprecedented safety (PROMETHEUS). These two programs are separated by the organizations that formed them, but their goals are largely the same. DRIVE is under the control of the Commission of European Communities (CEC), while PROMETHEUS is part of the European Research Coordination Agency (EUREKA) platform, an industrial research initiative involving 19 countries and European vehicle manufacturers. While the projects are separate, close cooperation between the two is needed to reach a common goal. Actual system development is the primary goal of the PROMETHEUS project, while DRIVE tends to focus on human behavior issues and implementation of systems into the entire European community. Detailed program material can be found in: McQueen and Catling (1991), Kemeny (1990), Hellaker (1990), and Transport Canada (1992).

DRIVE

The intention of DRIVE is to move Europe towards an Integrated Road Transport Environment (IRTE) by improving traffic efficiency and safety and reducing the adverse environmental effects of the motor vehicle. It focuses on the infrastructure requirements, traffic operations, and technologies of interest to public agencies responsible for the European road transport systems. DRIVE also focuses on the human user and related issues that will be addressed in the implementation of in–vehicle systems.

DRIVE I was the first phase of the project and was started in 1989. It was funded for 3 years with an operating budget of $150 million. The pre–competitive research program consisted of 60 individual projects undertaken by members from the private sector, government agencies, and research institutions. The goal was to establish the overall work plan from which a European IRTE could be developed. The program has been highly successful and is now moving on to the demonstration phase.

The DRIVE program was seen only as a feasibility study in the beginning. However, as DRIVE progressed, it became apparent that there was a realistic opportunity for system development. This resulted in DRIVE II, which emphasized the implementation of pilot projects that had been developed as a result of DRIVE I. Funding was increased to about $250 million in order to construct and test hardware. DRIVE II is scheduled to end in 1995, and the release of products into the marketplace is expected at that time. The DRIVE II work plan identifies seven pilot project areas:

- Demand management.
- Traffic and travel information.
- Integrated urban traffic management.
- Integrated interurban traffic management.
- Driver assistance and cooperative driving.
- Truck fleet management.
- Public transit management.

For detailed individual project descriptions, see Keen and Murphy (1992).

PROMETHEUS

PROMETHEUS was started in 1986 and was initiated as part of the EUREKA program, a pan–European initiative aimed at improving the competitive strength of Europe by stimulating development in such areas as information technology, telecommunications, robotics, and transport technology. The project is led by 18 European automobile companies, state authorities, and over 40 research institutions. The budget for the project is over $800 million and the project is scheduled to last 7 years. PROMETHEUS is a pre–competitive research project, with the output being a common technological platform to be used by the participating companies once the product development phase begins. The overall goals of PROMETHEUS fall into four categories:

- Improved driver information – providing the driver with information from new sources of technology that were not previously available. Currently, the lack of information or the inability to assess a hazard is often the primary cause of accidents.
- Active driver support – when the driver fails in some way at the driving task, the system may aid the driver in an informative way or by active intervention.
- Cooperative driving – establishing a network of communication between vehicles in order to provide drivers with relevant information for areas en route to their destination.
- Traffic and fleet management – systems for the efficient use of the road network, ranging from highway flow control to fleet operations.

The emphasis of PROMETHEUS, however, is on systems having a large in–vehicle component to their design. The ultimate aim is for every vehicle to have an on–board computer to monitor vehicle operation, provide the driver with information, and assist with the actual driving task. A centralized communications network will also be a component of the system in order to provide two–way communication between each vehicle and a control center.

Within the PROMETHEUS program, there are seven subprograms; three are carried out by the motor industry, and four are carried out by the research community.

The industry subprograms cover the following:

- In–vehicle systems for vehicle monitoring and driver assistance.
- Vehicle–to–vehicle communications networks.
- Road–vehicle communications for traffic control.

The research subprograms cover the following:

- Development of required microelectronic components, including sensors and on–board computer systems by the PRO–CHIP researchers.
- Use of artificial intelligence in the vehicular system and software development by the PRO–ART research group.
- Communication within the system vehicle and driver, vehicle and vehicle, plus vehicle communications to the overall road network by the PRO–COM group.
- Vehicle change effects on the traffic environment will be studied by traffic engineers in the PRO–GEN group.

The research phase, covering the past 4 years, has largely been completed. The current move is toward the definition phase, where the emphasis has shifted to field tests and demonstrations. Ten common European demonstrations have been identified to evaluate systems in each of the following areas:

- Vision enhancement.
- Emergency systems.

- Proper vehicle operation.
- Commercial fleet management.
- Collision avoidance.
- Test sites for traffic management.
- Cooperative driving.
- Dual–mode route guidance.
- Autonomous intelligent systems.
- Travel information systems.
- Cruise control.

These demonstrations are scheduled to be completed by 1994; however, it is likely that PROMETHEUS will continue beyond that date. The second phase will be somewhat modified to reflect the near–market status of products under development, and will move away from the program's non–competitive origins.

In order to bring products to market more quickly in Europe, European Road Transport Telematics Implementation Coordination Organization (ERTICO) was created in November 1991. Its objectives are to pool the information from the many individual projects and identify strategies in order to exploit the results of DRIVE, PROMETHEUS, and other individual programs. ERTICO's goal is to create a climate for market–driven investment in order to ensure European dominance in advanced–vehicle technologies.

Individual system descriptions

Many individual RTI/ITS systems are now being tested throughout Europe. A short description of some individual systems is presented below to enhance the reader's understanding of developments taking place in Europe. System descriptions will be limited to the driver interface, as opposed to actual system hardware and communications network information.

Autoguide and the Ali–Scout are dynamic in–vehicle route guidance systems; that is, the system gives routing recommendations to drivers who are dependent upon real–time traffic conditions. The display unit is mounted on the dashboard of the car and controlled with a hand–held remote control (similar to a television remote). At the start of a journey, the driver can enter a grid reference or a preprogrammed destination. The system uses dead reckoning and roadside infrared–transmitter/receiver beacons to guide the driver to the selected destination. The beacons serve the system by correcting cumulative errors and updating traffic information. The navigation information presents directions to the driver through the use of icons and arrows. There is also a digitized speech unit that supplements visual directions. The Autoguide system has undergone extensive testing in London, while the Ali–Scout system has over 700 units being tested in Berlin. For more information, refer to one of the following articles: Catling and Belcher (1989), Jeffery, Russam, and Robertson (1987), Jurgen (1991), or Morans, Kamal, and Okamoto (1991).

TrafficMaster from the United Kingdom (U.K.) was the first commercially available in–vehicle system to provide dynamic traffic information to the driver. It is a map–based system that only provides traffic flow information; it does not actively suggest routes. The display screen is a 101–mm by 82–mm (3.9–in by 3.2–in) in–liquid crystal display that provides the map information. "Hard" push buttons for control of guidance functions are mounted next to the display (Jurgen, 1991).

TRAVELPILOT is a German autonomous navigation system based on the American ETAK Navigator sold by Blaupunkt Bosch Telecom. This system displays vehicle location on a dashboard–mounted CRT map that is stored on CD–ROM. The maps move relative to the vehicle's position, which is determined through the use of dead reckoning and map matching. A small CRT can display maps with highlighted routes or driving instructions that have intersection maps and street names. Hard buttons mounted on either side of the CRT are changeable function controls. The system has reportedly sold over 1000 units in its first year on the market and will be available soon in the United States for certain areas. For more information, refer to the following references: Suchowerskyj (1990), and Morans, Kamal, and Okamoto (1991).

Many other individual systems already exist or are in the prototype testing phase. Systems on the market currently tend to be navigation systems, but other driver information systems, such as collision warning systems, are nearing completion. These will most likely be marketed by the automobile manufactures and not by after–market suppliers.

Japanese Projects/Systems

Japan is leading all other countries in the implementation of a large–scale traffic control system that uses in–vehicle technology. The reason for their lead is due to their need for such systems. Over vast portions of metropolitan areas in Japan, the average speed is below 16.1 km/h (10 mi/h) during much of the daytime hours. The small geographic area and large population has led the Japanese government to install traffic control systems in all the large cities and on most urban and interurban freeways. These systems employ the latest technology, such as fiber–optic communications and in–color light–emitting diode (LED) changeable message signs displaying both text and graphics. Japan has invested in the development of driver information systems. Over 50 corporations have collaborated to develop in–vehicle systems that are marketed as units to be purchased by individuals who use the governmental road network system. The main ITS initiatives currently are road/automobile communication system (RACS), advanced mobile traffic information and communications system (AMTICS), and vehicle information and control system (VICS). Within RACS, the Ministry of Construction (MC) promoted and funded the Digital Road Map Association. This group was given the task of preparing and maintaining a national digitized road map data base. The results of this work are available on compact disc in a standard format. This format is used by both RACS and AMTICS, as well as by the various manufacturers of autonomous vehicle navigation systems (Ervin, 1991).

RACS

RACS is sponsored by the Public Work Research Institute of the MC, the Highway Industry Development Organization (HIDO), and 25 private companies. The system consists of vehicles equipped with dead reckoning navigation systems, roadside communication units (beacons) that are distributed throughout the road network (about 2 km (1.24 mi) apart), and a control center. There are three types of roadside beacons: Type 1 transmits location to the vehicle to zero–out cumulative navigation errors; Type 2 transmits, in addition to location, congestion and other traffic information; and Type 3 provides two–way communications with the vehicle so that information about the vehicle (e.g., location, automatic debiting of tolls, etc.), as well as emergency calls, can be transmitted to the control center. The MC recently announced a major beacon installation program, consisting mostly of Type 1. At present, there are about 1,000 beacons around Tokyo. Beacon installation is scheduled to proceed throughout Japan at a rate of about 10,000 beacons per year until 1994, with a gradual increase in the number of Type 2 and Type 3 beacons. Travel–time savings of 3 to 5 percent are expected, representing a significant reduction in fuel consumption and air pollution.

AMTICS

AMTICS is sponsored by the National Police Agency (NPA), the Ministry of Posts and Telecommunications (MPT), the Japan Traffic Management and Technology Association (JSK), and 59 private companies. It employs in–vehicle equipment similar to that of RACS, with the exception of the communication interface. The AMTICS data link is essentially a one–way means of broadcasting traffic data from a cellular system of terminals. It is intended to convey a wide variety of information, including congestion information, travel–time predictions, traffic regulations, railway timetables, and special events advice. This information is available at static terminals at railway stations, hotel lobbies, etc., as well as in the vehicle. A large–scale test of AMTICS was held in Osaka in 1990, and the results suggest that an individual travel–time reduction of about 7 percent could be achieved with in–vehicle navigation systems that provide congestion information to the driver. This would amount to individual travel–time savings of about $300 million if all cars were equipped in the Osaka area, with similar savings to the community because of reduced congestion. For more information on the AMTICS system, see papers by Okamoto (1988), Okamoto and Nakahara (1988), or Okamoto and Hase (1990).

VICS

VICS is a new program formed under the combined direction of the MPT, MC, and NPA, with the goals of resolving the competition between RACS and AMTICS and defining a common system using the best features of both. This venture is meeting with some opposition by those who feel that the competition between the two systems is improving both. A digital micro cellular radio system has been proposed to provide two–way road–vehicle communications and location information, essentially combining the tools used by each respective system. Although VICS may have a long–term future as part of an integrated driver information system for Japan, it will take some years to implement. In the meantime, a common RACS–AMTICS system using RACS Type 1 beacons and the broadcast of information to drivers via their FM car radios (like Radio Data System–Traffic Message Channel (RDS–TMC)) is the likely direction for further development.

Until now, traffic condition information was fed to drivers over the radio or through a supplemental system such as those mentioned above. However, most Japanese prefer to plan their own navigation routes rather than blindly follow directional arrows on an in–vehicle display (as is the case for the Autoguide systems used in the U.K.). The trend of opposition to blind direction following was researched by Schraagen (1990). The effect of "planning" routes while the vehicle is in motion on road safety has not yet been investigated in depth by the Japanese. This lack of investigation seems to be a trend in the development of Japanese systems.

Japanese systems tend to be put on the market with displays that are very detailed simply because the technology exists to do so. The litigation system in Japan gives some leniency for this type of system development and even for unsafe designs.

A Nissan system

A digital map–based system is sold with the Nissan Cedric, Gloria, and Cima models in Japan. It is similar in design to the ROGUE and TRAVELPILOT discussed in the previous section. A paper by Tanaka, Hirano, Nobuta, Itoh, and Tsunoda (1990) describes some of the interface aspects of this system. These aspects include:

- Three available scales of map display: 1/25,000 (street grid by blocks), 1/100,000 (default arterial roads), and 1/400,000 (macro).
- The ability of the map heading to be toggled either "north up" or "direction of travel" at the top.
- Vehicle location, which is always positioned in the center of the scrolling map display.
- The reduction of eye glance time by not displaying minor roads while the vehicle is in motion. Also, while driving, the system inhibits all switch operation, except for "changing of scale" and "display rotation mode." It is not clear what the "display rotation mode" feature entails from the research described.

DESCRIPTIONS OF CVO–SPECIFIC PROJECTS/SYSTEMS

CVO's include any motor vehicle of public or private ownership, regularly used to carry freight and passengers, used in commerce, or used to provide emergency response.

Functional areas that are currently being addressed for ITS CVO applications include the following:

- AVI.
- WIM.
- Automatic Vehicle Classification (AVC).
- Electronic Placarding/Bill of Lading (EP).
- AVL.
- Two–way Real–time Communication (TWC).
- Automatic Clearance Sensing (ACS).
- ADIS.
- On–board Computing (OBC).

These areas are being addressed to achieve three basic goals: (1) improved productivity; (2) improved efficiency and effectiveness of traffic management and administration by transit agencies, State, and local governments; and (3) improved safety for CVO's and others affected by them. The key technologies to improve local CVO are ADIS (similar in concept and functionality to ATIS) and TWC because of the increased productivity from real–time traffic routing and schedule information they will provide. Improvement of interstate operations requires AVI and use of the OBC concept to monitor vehicle systems and serve as an interface for communication between a vehicle system and external sources.

In general, ITS technologies are emerging as the key tools that carriers have available to reduce costs and improve productivity. New ITS technologies are making faster dispatching, fuel–efficient routing, and more timely pick–ups and deliveries possible. These ITS technologies will also have an impact on safety. Devices such as blind–side and near–obstacle detection systems can make highways safer and more productive. The cost to regulate CVO's can also be reduced with the use of AVI and WIM scales.

There are several special considerations that must be made when addressing ITS technologies and CVO's. These considerations include the following:

- Not all roadways are accessible to CVO's for reasons such as restrictive geometry and substandard bridges. Trucks carrying hazardous materials are also restricted to certain roadway use. Therefore, these vehicles must have accurate, detailed information about any proposed alternatives to the routes they normally travel. They will also require standardized electronic map data bases capable of covering the entire Nation.
- Equipment and communications standards are important to CVO's. For example, they must be able to access all tune–in traffic information broadcasts without having to carry several different kinds of radio receivers.

CVO research conducted to date focuses on three key technologies: AVI, displays, and communications. In general, as with automotive aspects of ATIS, CVO literature to date primarily includes planning and feasibility evaluations of proposed systems or projects.

One study that assessed promising areas of CVO research was a case study of trucking needs in Iowa (Midwest Transportation Center, 1992). Six of the "most promising" CVO applications are discussed in the Iowa study. Briefly, these applications are: (1) WIM using AVI, (2) pre–clearance for safety inspections, (3) "one–stop shopping" for regulatory compliance, (4) electronic toll and traffic management, (5) automated apportioned fuel tax administration, and (6) audits of apportioned fuel tax. Hazardous cargo identification and navigational aids are also promising.

Feasibility studies and assessments of specific AVI technologies have also been accomplished. Florida, in particular, is in the initiation phase of projects using AVI, WIM, and communications systems. Two Florida DOT reports describing these assessments are Assessment of Benefits of Advantage I–75 (Center for Urban Transportation Research, 1992), and Analysis of AVI Technology and Its Potential Application to Florida's Turnpike Summary (Center for Urban Transportation, 1992).

Displays are a major focus addressed in CVO assessment papers. A general assumption is that any in–cab device diverts valuable attention from the road and should be accepted with critical consideration of the safety impact. An internal memo from FHWA summarizes the weakening of the 1952 Federal Motor Carrier Safety Regulations on the location of a video display terminal (VDT) in the cab. These regulatory findings bode well for future use of in–cab displays. Another study inventoried over 50 supplemental in–cab devices (Burger, Smith, and Ziedman, 1989). Six categories of systems were discussed:

- Single/integrated displays.
- Vehicle information.
- Vehicle navigation.
- Vehicle positioning.
- Text communication.
- Vehicle safety.

Burger estimates that a broad proliferation of these devices could pose a significant safety problem. Plans to model current truck driver workload are presented as key to the safety evaluation of future systems.

Communication systems are also of significant interest for CVO applications. The University of Pennsylvania is conducting communication research on interdisciplinary topics ranging from signal bandwidth to artificial intelligence. A review of applicability of Advanced Vehicle Monitoring and Communications (AVMC) systems for bus transit has been done by the U.S. DOT. AVMC systems are projected to be cost–effective from both agency and passenger satisfaction vantage points. A method of AVMC feasibility evaluation is presented as part of the DOT report.

Evaluations of Existing CVO Systems

operate

Evaluations of Existing CVO Systems

In general, existing systems fall into the categories of AVI and related systems, WIM, and dispatching and routing navigation. A substantial review of existing AVI/AVL and WIM technologies is provided in the Florida DOT studies referenced in the preceding paragraphs. Two additional reports, Nakamura, Inoue, and Kanasaki (1984) and the Texas Transportation Institute (1989), also describe AVI and WIM issues and technologies. These reports, however, contain little information of direct interest to human factors design, particularly with respect to in–vehicle systems.

Several dispatching and routing navigation systems are in existence for CVO applications. A report by French (1987) summarizes various fleet management technologies, such as Loran–C AVL, Geostar Positioning, ETAK's Dispatch System, and Routeware's ARCS system (no longer in use). Most system designs are centered around ETAK's Navigator data base technology and have an ETAK–style user interface. The utility of vehicle navigation systems and an interface design using the ETAK Navigator for fleet management applications have been described by Honey, White, and Zavoli (1987). Interface aspects are summarized below:

- Destinations may be entered manually or received automatically from the dispatch center. The destination appears on the screen as a flashing star. Distance and direction are shown in case a map scale is chosen that does not include the destination. Status codes can be sent to the dispatch center at the press of a button; a hidden switch can be used as a mayday function for emergencies in the field.
- The display is oriented "heading up" as the driver sees the road out the window.
- Scale of the map is selectable from 0.2 to 64.4 km (1/8th mi to 40 mi).
- The dispatcher unit uses different colors to represent different street priorities (e.g., freeway, residential, and arterial).
- A mouse and on–screen menus are used on the dispatcher's station for map manipulation.

In addition to the interest in ITS technology for truck fleet applications, there has been some interest in public transit applications. A study by Morlok, Bruun, and Blackmon (1991) describes the usefulness of advanced monitoring and communication systems for bus transit. The authors list nine AVL technologies with potential transit applications. These technologies include:

- Loran–C.
- GPS.
- Radio Data System (RDS).
- Dead Reckoning.
- Radio Signposts.
- Passive ID.
- Infrared Detection.
- "Telerider."

CVO Operational Field Tests

"Advantage I–75" is the primary U.S. implementation of AVI. Over 3219 km (2000 mi) of roadway are encompassed by the Advantage network, including a stretch of HWY 401–20 in Canada from Montreal to Detroit. The I–75 portion ranges from Sault St. Marie, Michigan, to Miami, Florida.

The program testing data collection and WIM aspects of the Advantage project are called "HELP–Crescent." The States involved in research include Arizona, California, Idaho, Iowa, Minnesota, Nevada, New Mexico, Oregon, Pennsylvania, Virginia, Washington, New York, and New Jersey. The implementation is taking place along a highway "crescent" in the western United States.

Crescent program

The Crescent program is designed to:

- Evaluate one–stop shopping and transparent State borders to help reduce the number of required stops, and to use the OBC concept reporting capability to replace manual record keeping insofar as registration, fuel tax, and driver's hours–of–service requirements are concerned.
- Show that the technology applications, i.e., WIM, AVC, AVI, and on–board data management, will work reliably from a system standpoint in the highway environment.
- Demonstrate the potential for increased efficiency in governmental administration of selected motor carrier regulations and highway planning.

Crescent is expected to show that technology applications can be successfully combined into a system, institutional barriers can be minimized, and both commercial operations and public agencies can successfully share in the collection and use of data.

TRANSCOM

TRANSCOM (1991) is a coalition of transportation and traffic enforcement agencies in the New York–New Jersey region. These agencies conducted a study using CVO's working with 17 New York metropolitan area trucking companies from July 1989 to August 1991.

The study was conducted such that when an incident (e.g., accident or disabled vehicle) occurred, the affected agency would notify TRANSCOM. TRANSCOM sent messages concerning significant incidents to the affected CVO companies via pagers supplied as part of the project.

ATIS/CVO HUMAN FACTORS EMPIRICAL EVALUATIONS

When considering the implementation of new user–centered systems within an automobile, a number of issues must be addressed. According to Franzen and Ilhage (1990), these issues relate to driver mental workload, driver capacity, and the driving task analysis. Individual experiments have been accomplished worldwide, examining the implementation of in–vehicle systems in an environment where the user is already loaded with demanding tasks. These research findings often relate directly to the establishment of human factors guidelines for ITS. Researchers tend to study the differences in performance while using different systems or simulations. From this research, specific guidelines to support system design can be developed. In the following sections, specific research findings are reported in a format conducive to gleaning guideline material. Findings have been categorized based on the types of empirical studies reported and include driver information processing (i.e., attention and workload), visual display considerations (i.e., sensory and perceptual aspects), auditory display considerations, tactile displays, controls, user demographics, and user behavior and acceptance. While not all of the studies have findings that directly lead to guidelines, the majority are pertinent to future system design.

Driver Information Processing Demands: Attention and Workload

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

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

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

With respect to valuable functions present while the vehicle is in motion, all efforts must be made to limit the functionality of the in–transit mode to those tasks that:

- Do not significantly interfere with the driving task.
- Have convenience benefits that outweigh the cost (i.e., required driver resources) of including the function.
- Will be used relatively frequently.

Some navigation functions that meet these criteria include providing only necessary information (distance to next turn street, direction of next turn, and name of next turn street) and providing information regarding proximal traffic congestion or obstacles (Dingus and Hulse, 1993).

An option available to increase in–transit functionality without compromising driving safety is the allocation of functions to a "zero–speed" category (Carpenter et al., 1991). Zero speed refers to when the vehicle is stopped, but is still in "drive." The navigation system could allow a certain subset of functions (e.g., orientation information) to be accessed under these circumstances without concern for overload. However, once the vehicle is in motion again, the display and control configuration would return to its previous in–transit state.

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

Attention demands

Inquiries into the driver's ability to perform the driving task arise with any addition or change in the task, such as those associated with in–car ATIS systems. It is important not to overload the driver at critical times during the driving task (Perel, Brewer, and Allen, 1990; Smiley, 1989; Walker, Alicandri, Sedney, and Roberts, 1991). Walker et al. (1991) reported that subjects using complex navigation devices drove more slowly than those using less complex devices. These effects were also more prevalent in older drivers (55 years and older) than in younger drivers. If the driver is traveling at a faster speed or on a less complex road (i.e., fewer curves), shorter viewing time of any display will be required as compared to traveling at a slower speed or on less complex turns (Senders, Kristofferson, Levison, Dietrich, and Ward, 1967). Dingus, Antin, Hulse, and Wierwille (1989); Plude and Hoyer (1985); and Madden (1990) also report that driving attention demands for older drivers are increased due to decreased capacity.

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

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

Visual attention is particularly important to assess in driving since most information is gathered visually by the driver (Rockwell, 1972). Despite the almost sole reliance of driving on the visual modality, between 30 percent and 50 percent of visual attention, in most circumstances, may be devoted to tasks other than driving (Hughes and Cole, 1986). It is the availability of this spare resource that makes the inclusion of in–transit visual display information feasible. Designers must make displayed information usable to drivers even under extenuating circumstances, since the visual attention required by the driving task can change drastically at any given time (e.g., including a curve, the presence of traffic, or a change in type of roadway) (Dingus and Hulse, 1993). Therefore, displayed information must be usable under the most demanding circumstances.

A visual display that requires frequent and lengthy glances may prevent adequate monitoring of the driving environment. In fact, research has shown that deviation from the roadway lane center increases with longer eye–off–the–road time (Zwahlen and DeBald, 1986).

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

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

Workload

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

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

General Visual Display Considerations

Basic display characteristics

Information legibility, whether text or graphic, is a major design concern for automobile visual displays. A delineation of all appropriate display parameter options (e.g., resolution, luminance, contrast, color, glare protection) is a complex topic that is beyond the scope of this section. Actual guidelines for determining the proper color, contrast, and luminance levels to be used in CRT displays within vehicles can be found by using the formulas derived by Kimura, Sugira, Shinkia, and Nagai (1988). In addition, a number of legibility standards are in existence for visual displays, including those developed for aircraft applications (Boff and Lincoln, 1988). Several of these standards are reviewed for ATIS/CVO applicable design guidelines in the Conclusions section. Since the automobile has many of the same difficulties as the aircraft environment (e.g., glare), many of the same standards apply. However, note that the selection of an automotive display will be more constrained by cost and perhaps have limitations well below the state of the art.

There are minimum acceptable legibility standards that must be met or the display is unusable. It is critical that these minimum standards be met in spite of constraints for a given application. In addition, selecting display parameters is a problem, since viewing distance is limited due to the configuration constraints present for an automotive instrument panel. Driver constraints pose another problem. Older drivers with poorer visual acuity and/or bifocal lenses must be carefully considered during the specification of the display parameters. To overcome this combination of limitations, the display parameters must be optimized within practical control. For example, Carpenter et al. (1991) used a "special high–legibility font" in a color CRT application to ensure that drivers could glance at the display and grasp the required information as quickly as possible. Other design aspects that aid in legibility include the upright presentation of text information (even in map applications), maximizing luminance and/or color contrast under all circumstances, maximizing line widths to increase luminance (particularly on map displays), and minimizing the amount of displayed information, in general, to reduce search time (Dingus and Hulse, 1993).

Additional legibility design considerations include contrast, brightness, and character size. The greater the degree of contrast, the quicker the detection and identification time for any target (up to a point). The brightness of the instrumentation panel has been shown to have an effect on reading performance when character size is relatively small (1.5 and 2.5 mm) (Imbeau, Wierwille, Wolf, and Chun, 1989). Character size also plays an important role in response time. Imbeau et al. (1989) found that older drivers performed poorly when smaller character sizes were used. Schwartz (1988) suggested that further research must be considered on overall density and information grouping characteristics when evaluating displays where human performance is the paramount design criterion. Schaeffer and Campbell (1988) looked at vertical disparity of displays on performance accuracy. Vertical disparity ranging from 0 to 17.5 mrad did not show any effects on performance accuracy. However, large disparities did result in diplopia, double images, and possibly suppression of one of the visual images.

The use of color

Another basic visual display concern deals with the presence of color deficiency and color blindness. Approximately 8 percent of the male population have some degree of color deficiency or color blindness. It is, therefore, important in consumer product applications (including ATIS displays) to avoid reliance on color coding of critical information. Additional color issues include avoiding selected color combinations (Boff and Lincoln, 1988) (e.g., blue lines on a white background, since this combination causes the line to appear to "swim"). They also recommended using color coding of information sparingly, since too many colors create more information density and an increase in search time.

Brown (1991) found that color–highlighting techniques resulted in quicker and more accurate recognition of targets on a visual display. Although instrument panel color has been shown to have no significant effect on reading and driving performance (Imbeau et al., 1989), Brockman (1991) found that color on a computer–display screen can be distracting if used improperly. Brockman recommended several guidelines to avoid confusion when using color to code information. First, color codes should be used consistently. Colors from extreme ends of the color spectrum (i.e., red and blue) should not be put next to each other since doing so makes it difficult for the reader's eye to perceive a straight line. Second, familiar color coding, such as red for hot, should be used. Third, color alone should not be relied on to discriminate between items. Brockman recommends designing applications first in black and white, then adding color to provide additional information.

Display location

A major component of the driving task is scanning the environment and responding appropriately to unexpected events. Fortunately, humans are sensitive to peripheral movement. An object moving in the periphery often instantly gains attention. In fact, some human factors professionals believe that peripheral vision is as important as foveal vision for the task of driving (Dingus and Hulse, 1993).

Given the above considerations, the placement of an information display becomes critical. The information contained on even a well–designed display system will require a relatively large amount of visual attention. Therefore, if the display is placed far from the normal driving forward field of view, none of the driver's peripheral vision can be effectively used to detect unexpected movement in front of the vehicle. Increased switching time is another disadvantage of placing a display far away from the forward field of view. Typical driver visual monitoring behavior involves switching back and forth between the roadway and the display in question. Dingus, Antin, Hulse, and Wierwille (1990) found that while performing most automotive tasks, switching occurs every 1.0 to 1.5 s. The farther the display is away from the roadway, the longer switching takes, and the less time can be devoted to the roadway or the display (Weintraub, Haines, and Randle, 1985).

The position of a visual display was also studied by Popp and Farber (1991). It was found that a display positioned directly in front of the driver resulted in better driver performance than one mounted in a peripheral location. However, performance on a symbolic navigation presentation format was hardly affected due to the change in position, and results for peripheral location were still quite good. Tarriere, Hartemann, Sfez, Chaput, and Petit–Poilvert (1988) reviewed some ergonomic principles of in–vehicle environment design and agree that the CRT display should be near the center of the dashboard and not too far below horizontal. The paper suggested that the screen be mounted 15 degrees below horizontal, but should not exceed 30 degrees for optimal driver comfort.

According to the discussion above, the display should be placed as close to the forward field of view as is practical. The most desirable display locations are high on the instrument panel and near the area directly in front of the driver. There is, however, another automotive option that is currently just beginning to be explored: head–up displays (HUD's). Briziarelli and Allan (1989) tested the effect of a HUD speedometer on speeding behavior. Although no significant difference was found between a conventional speedometer and the HUD speedometer, most subjects (70 percent) felt that the HUD speedometer was easier to use and was more comfortable to read than a conventional speedometer. Subjects also reported being more aware of their speed when using the HUD speedometer. Campbell and Hershberger (1988) compared HUD and conventional displays in a simulator under different workloads. Under both low and high workload conditions, steering variability was less for drivers using a HUD display than for those using a conventional display (Campbell and Hershberger, 1988). Also, steering variability was minimized when the HUD was low and centered in the driver's horizontal field of view. In another simulator study, Green and Williams (1992) found that drivers had faster recognition times between a navigation display and the "true environment" outside the vehicle when the display was a HUD over a dash–mounted CRT.

Given the above arguments, a HUD providing navigation information on the windshield could be a good choice since it is the forward field of view. Besides the arguments described above, another advantage of a HUD (at least most HUD's) is that they are focused at (or near) infinity, thus eliminating (or reducing) the time required for the driver's eyes to adjust between the display and the roadway. However, a number of concerns have been raised by Dingus and Hulse (1993) about the use of HUD's:

- Luminance may be a limiting factor in the automobile due to the presence of glare and stringent cost constraints. A HUD that was too dim and hard to read could be worse than an in–dash display.
- Issues regarding display information density and distraction must be carefully addressed for HUD's and could result in a different set of problems.
- Issues regarding the division of cognitive attention with HUD's. The fact that a driver is looking forward does not mean that roadway/traffic information is being processed. The importance of this division of attention to driving task performance has yet to be determined.

Visual Information Display Research Specific to Navigation Systems

There is significant research being conducted on the use of visual presentation information and appropriate formats for that information. As previously discussed, the navigational display information should be limited to only that which is absolutely necessary. When following a pre–specified route, Streeter (1985) recommended that the necessary information should consist of the next turn, how far away the turn is, which street to turn on, and which direction to turn. Streeter found that people who are familiar with an area prefer to be given the cross street of the next turn, whereas people who are unfamiliar with an area prefer to be given distance information.

In addition to proximal (i.e., next turn) route–following information, notice of upcoming obstacles or traffic congestion would also be beneficial. Such information could conceivably make the composite task of driving safer, given that it can be displayed without requiring substantial driver resources (Dingus and Hulse, 1993).

The use of traffic information was studied by Ayland and Bright (1991). The study shows that drivers wanted reasons for suggested route changes. If an in–vehicle system tells a driver to deviate from a normal path, or take an unfamiliar turn, the driver wants information about the reason for the change, such as "exit left, accident ahead." The same conclusions were made in the Bonsall and Joint (1991) report with regard to reasoning for route changes. This study pointed out the need for accurate information. It was found that drivers would rather follow their own "best" route perceptions than the system's, especially if the user has experienced a high rate of inaccurate information.

Information provided to the driver should be timely. Sufficient time must be allowed for the driver to respond to any information. The driver needs time to hear and/or see the information, decide whether it is relevant, and act upon it. An above–average human response time is required–most (i.e., 95 percent or 99 percent) of the drivers should have ample time to respond under most driving circumstances. The time required by the driver to process information and respond is dependent upon a number of factors, including the task and the type of display format selected, which is beyond the scope of this paper. A discussion of driver response time requirements can be found in several sources, including the National Highway Traffic Safety Administration (NHTSA) Driver Performance Data Book (1986).

The value of automatic route selection in navigation

Several research studies (e.g., Dingus, Antin, Hulse, and Wierwille, 1989) have tested systems that do not provide a route to a destination. These systems provide a current location, area streets, and a pre–selected destination. There are several technological advantages to these systems, including less complex data base requirements and no route–algorithm requirement. However, such systems require the driver to perform trip planning tasks in transit instead of pre–drive (Antin, Dingus, Hulse, and Wierwille, 1990). Almost invariably, the information displays for navigation information systems are (and probably will continue to be) quite small. Thus, a requirement for non–route systems is to provide "zoom–in," "zoom–out," and pan features, in conjunction with prioritized streets, to avoid unreasonably high screen information densities. A person could "zoom in" to a small–scale map (e.g., 0.4 km (0.25 mi)) and see a detailed view of all area streets. However, if one "zooms out" (e.g., to a 32.2–km (20–mi) scale), many of the secondary streets disappear to maintain a reasonable perspective. Therefore, it is often difficult to see all of the secondary streets along a route, particularly if the route is long. A person must zoom in/out and pan to various locations in order to plan a route prior to starting the drive. However, particularly for complex or long routes, it is difficult and time–consuming to plan a route like this. After inputting a desired destination, what generally happens is that people drive immediately and plan the route as they travel. This strategy increases the driver's attention demand, since pre–drive planning has now been allocated as an in–transit task (Antin et al., 1990). Therefore, Dingus, Antin, Hulse, and Wierwille (1988) recommended that a provision for route selection be provided as part of the navigation and information systems.

Another advantage to providing a route–selection algorithm as part of navigation system features is that many more options are available for information presentation. If no route is provided, an area map must be displayed to navigate accurately. If a route is provided, the navigation information can be displayed aurally and/or visually, textually or spatially, in a turn–by–turn graphic format or an entire route graphic format.

Information format trade–offs for navigation systems

There are many information presentation formats that are being considered for navigation systems. Driver navigation behavior is a key consideration in format selection. Schraagen (1990) suggested that map–based displays do not give the driver information in a needed form. Drivers need to look for street names, landmarks, and road signs on the map to make navigational decisions. Verbal instructions such as "turn right" or "follow signs with directions to Amsterdam" would be the most usable format for the driver. Maps should be used only as an additional information source, not as the sole navigational tool.

Bartram (1980) tested subjects on planning a bus route using a list or a map. The results showed that subjects who used a map had faster decision times than those using a list. Another study conducted by Wetherell (1979) found that after subjects studied a driving route, either using a map or a linear list of turns, those using a map made more errors while en route. Wetherell concluded that these findings could have been caused by two factors: (1) the spatial processing demands of driving, seeing, and orienting interfere with maintaining a mental map in working memory; and (2) subjects had a harder time maintaining a mental model of a map learned in a north–up orientation when approaching an intersection going east, west, or south. In a study conducted by Streeter, Vitello, and Wonsiewicz (1985), subjects who drove a route through neighborhoods using a route list (i.e., series of verbal directions) were faster and more accurate than those who drove using a customized map with the route highlighted. Popp and Farber (1991) found that symbolic presentation of route guidance information was superior to other visual presentation modes, such as text or maps. Symbolic presentation had the lowest driver workload rating and best traffic safety behavior. Green and Williams (1992) compared the viewing perspective of different navigation displays, using either a map like "plan view," a forward "perspective view," or a combination of the two in an "aerial view." Green and Williams found that drivers recognized the presented display as matching the environment outside the car when an "aerial view" was used. The map like "plan view" was a close second.

The studies above indicate that either symbolic guidance displays or textual lists are easier to use than maps while navigating to unknown destinations. Note, however, that maps provide additional information (e.g., orientation information such as cross streets) that textual lists do not. Therefore, whether a map, symbolic guidance screen, or list is selected should depend on the desired task and required information. One approach to in–vehicle information display is to visually provide the information to the driver either in a graphical or textual format, depending on preference (Lunenfeld, 1989).

Dudek (1979) reported that information display format and style can affect driver's processing time and information perception. Familiarity of messages, messages arranged proportionally within the horizontal and vertical dimensions, and optimal message lengths (i.e., less than eight words for high speeds) have been shown to permit appropriate processing times for drivers. Drivers' familiarity with the locality and perception of such vague terms as "congestion" can affect the drivers' perception of the en route guidance system information. When dealing with local drivers, particularly commuters, studies have shown that drivers want to know the location of cross streets or landmarks; while non–local drivers prefer distances (Dudek, 1979).

Regardless of format type, an information display must be designed such that all in–vehicle information can be received in short glances and displays must not distract the driver (i.e., Lunenfeld, 1989). It is clear that less attention will be required for a well–designed turn–by–turn visual display format than for a full–route format. Little information is required for a graphic turn–by–turn screen, including only direction of turn, distance to turn, and turn–street name. Such information can be easily displayed in a legible, low attention–demanding format. McGranaghan, Mark, and Gould (1987) have characterized route following as a series of "view–action" pairs. A view–action pair refers to the sequential set of requirements where information is required for an upcoming event (i.e., turn), the event is executed, or the information for the next event is displayed. McGranaghan and his associates believe that only the information for the next view–action pair should be displayed for route following. In their view, any additional information is "extraneous" and "potentially disruptive" to the route–following task.

However, there are advantages to providing an entire–route display. One advantage is route preview. In circumstances of required low driving–task attention, the driver has the option to plan upcoming maneuvers in advance. While it is feasible and reasonable that pre–planning could alleviate the need for in–transit preview (i.e., map shown while the car is stopped, turn–by–turn configuration when the car is in motion), for complex routes, preview information may be valuable to recall and plan for upcoming maneuvers (Dingus and Hulse, 1993).

Route information provides a second advantage during circumstances of close proximity maneuvers. Many circumstances exist in the driving environment for which two (or more) quick turns are required. In the turn–by–turn symbolic screen case, the information for the second turn may come up too soon (and under circumstances where attention is needed for driving) to comfortably execute the second maneuver. In the route–map case, such an event can be planned in advance (Dingus and Hulse, 1993).

A trade–off must be made when selecting a route–map display format as to whether or not the map should be presented "heading up" (i.e., the direction that the vehicle is traveling is always up on the display) or "north up." The most significant issue regarding heading up versus north up is the speed and accuracy with which the displayed information is interpreted by the driver. With a north–up orientation, the driver must often mentally rotate the map image (e.g., if the heading is southeast) to determine whether to turn right or left. This additional operation requires additional attention and processing time and results in more errors for the population as a whole (Dingus and Hulse, 1993).

One advantage to north–up map presentations is that they do not "move" (Dingus and Hulse, 1993). For a heading–up format, the map must constantly rotate as the vehicle heading changes to maintain heading–up. This rotation, particularly when presented in the visual periphery, can be somewhat distracting. Antin et al. (1990) found that driver visual scanning behavior was adversely affected by a moving–map system. The authors stated that the novelty of the display (the subjects were novices and therefore interested in the display) had the effect of pulling spare driver resources toward the display. However, other factors, such as distraction induced by movement in the periphery, probably contributed to this finding. It should be noted, however, that a study by Hulse (1988) indicated that although visual scanning patterns are affected by the introduction of a moving–map system into the automobile, drivers can adapt their visual scanning behavior to account for changes in driving–task attention demand when required. Hulse found that the probability of a glance to the roadway center increased from 0.51 in light traffic conditions to 0.61 in heavy traffic conditions. Therefore, while some degree of distraction occurs because of these displays, apparently drivers are able to ignore it (at least to some extent) if required by the driving situation.

In a study of the ETAK Navigator, Antin et al. (1990) found that it took, on–average, approximately twice as long to plan a route using a paper map. They also noted that a moving–map display was more intrusive to driving behavior than the paper map, but it was still within driver capabilities. Several studies evaluating the general effectiveness of in–vehicle information systems have been reported (Al–Deek and Kanafani, 1989; Dingus et al., 1988; Dingus, Hulse, Krage, Szczublewski, and Berry, 1991; King, 1985; Lineberry and Martin, 1990; van Vuren and Watling, 1991).

Auditory Display Considerations

Auditory information, including voice–based systems, is an alternative medium to visual information display. Turnage and Hawthorne (1984) found that drivers did not respond as well to synthesized speech as to natural speech. Thomas, Gilson, Ziulkowski, and Gibbons (1989) found that the processing of synthetic speech can produce increased demands on the short–term memory as compared to human speech. They noted that the performance decrements observed were attributed to memory capacity and not to misperception of synthetic speech. Davis and Schmandt (1989) also reported that driving instructions are more helpful when modeled after natural language. The Back–Seat Driver system (Davis and Schmandt, 1989) and the DIRECT system (Gilbert, DeFrain, and Underwood, 1991) have examined the use of voice–based in–vehicle information systems.

Walker et al. (1991) reported that drivers using auditory navigation devices drove more safely than those using visual devices. Subjects using visual devices missed more gauge changes, had longer reaction times, and drove more slowly than subjects using auditory devices. Presenting the same information both aurally and visually was also suggested.

Additional research assessed the workload differences between visual and auditory information. Labiale (1990) found that workload is lower when using auditory presentation of navigation information as opposed to a visual presentation. This study also showed that drivers preferred auditory information because they felt it was a safer system.

Despite the apparent advantages of voice systems over visual displays for in–vehicle applications, Dingus and Hulse (1993) pointed out that aural information may not be a panacea for attention and workload concerns. The workload required to process auditory messages increases as the intelligibility of those messages decreases. Low–cost systems will be required for automotive navigation systems due to marketing considerations. This cost constraint requires the selection of digitized speech that does not provide any street name information to the driver (due to data–base constraints) or synthesized speech that is less intelligible than digitized speech. Although the quality of low–cost synthesized speech is constantly improving, factors such as tonal quality and inflection limit its relative effectiveness (Sanders and McCormick, 1987).

Even though numerous research studies have been conducted testing forms of synthesized speech, the state–of–the–art technology is not yet to the point where intelligibility/

comprehensibility can be predicted in all situations or environments. However, it is known that a number of factors influence intelligibility, including speech rate, message length, message content, message complexity, background noise, pitch, and loudness (Van Cott and Kincade, 1972; Marics and Williges, 1988).

Background noise is an intelligibility factor that is particularly important in an automobile and affects both digitized and synthesized speech. Noise in an automobile sometimes reaches 90 dB (A), making voice intelligibility virtually impossible in some circumstances (Bailey, 1982). The noise in an automobile also comes from many sources with different masking properties (e.g., citizens band (CB) radio, cellular telephones, stereo systems, conversation, and road noise), making alleviation of the noise problem somewhat difficult. Although hearing is not a primary sensory mode for driving, there are situations when in–vehicle auditory displays could mask other important signals (i.e., railroad grade crossings or emergency vehicles on the road) (Lunenfeld, 1990). Therefore, in such situations, the loudness and frequency components, and the spectral content of the voice would have to be carefully considered.

In addressing some of the intelligibility concerns discussed above, Labiale (1990) recommended that the amount of aural information presented be restricted (seven to nine bits) or the aural cue be used as a prompt for a simple visual guidance presentation. Also recommended is the ability to repeat the aural message, especially if information is complex, to aid in intelligibility and recall.

A driver's prioritization of a voice message is an additional and potentially negative issue related to the presentation of aural commands. A study conducted by a Japanese automobile manufacturer indicated that drivers apparently respond instinctively to verbal information to a greater degree than visual information. This behavior was manifested in a tendency to follow the in–vehicle instructions even if they conflicted with traffic regulatory information (e.g., turning the wrong way onto a one–way street) (Noy, 1991).

Although voice presentation can alleviate visual attention–demand problems associated with navigation information, it is not without problems. Dingus and Hulse (1993) recommended that the auditory modality be used to: (1) provide an auditory prompt (e.g., a tone) to signal the driver to look at a visual display for changing or upcoming information (thus lessening the need for the driver to constantly scan the visual display in preparation for an upcoming event), or (2) have some type of simple visual information presentation to supplement the auditory message (so that a message that is not fully understood or remembered can be checked, or later referred to, via the visual display).

Tactile Display Research

There are some methods of information presentation that can be used to bypass the use of visual and auditory information. Janssen and Nilsson (1990) conducted a simulator study looking at the different methods of presentation for a collision warning system. They investigated auditory, visual, and tactile warnings. A system that gave tactile feedback seemed to be a unique concept. The experiment was a simulator study that used a "smart" gas pedal that would pulsate if the driver was to get too close to the car in front. This method of information presentation could be compared to a visual light or an audible buzzer. The warning systems that used lights or buzzers showed increased negative behavior that could prove to be dangerous. Negative behavior was defined as an increase in driving speed, increase in acceleration and deceleration levels, and an increase in left–lane driving (passing behavior). Janssen and Nilsson (1990) found that the "smart" gas pedal suffered none of these negative side effects and reduced following distance.

Nilsson, Alm, and Janssen (1991) continued this research to look at driver reaction to intervention factors using the "smart" gas pedal. Three conditions were compared to evaluate the level of vehicle intervention a driver would find unobtrusive. A "warned" subject would receive only the vibration of the pedal if they were to follow another vehicle too closely. A driver in the "suggested" condition would feel resistance on the gas pedal, but could override the resistance by applying more pressure. The final condition was that of "intervention," where the "smart" pedal would automatically slow the car to a 4–s following distance. While the "intervention" was the safest with regard to behavior, it was met with the least acceptance; drivers preferred the "warned" and "suggested" systems.

The above described research could potentially have implications for IVSAWS applications.

Manual Control Research

Many control–related technological advancements are available for use with computers and, therefore, are available for potential use as part of ATIS and CVO systems. Sears and Shneiderman (1991) found no performance differences between the mouse and touchscreen for targets ranging from 32 to 4 pixels per side. Stabilization of touchscreens reduced error rate for smaller character size.

The trade–off between "hard" buttons and "soft" CRT touchscreen push buttons has become a concern of the ITS human factors community (Dingus and Hulse, 1993). With the use of CRT's and flat–panel automobile displays, there has been a strong temptation to use touchscreen overlays for control activation. While this can be a good method of automobile control for pre–drive or zero–speed cases, research has shown that this is not true for in–transit circumstances. Zwahlen, Adams, and DeBald (1987) looked at safety aspects of CRT touch–panel controls in automobiles as a function of lateral displacement of the centerline. This study found an unacceptable increase in lateral lane deviation with the use of touch–panel controls. This study found the touchscreen control panels visually demanding, as demonstrated by the relatively high probabilities of lane deviations. Zwahlen et al. (1987) suggested that use of touch–panel controls in automobiles should be reconsidered and delayed until more research with regard to driver information acquisition, information processing, eye–hand–finger coordination, touch accuracy, control actions, and safety aspects has been conducted and the designs and applications have been improved to allow safe operation during driving.

Monty (1984) found that the use of touchscreen keys while driving required greater visual glance time and resulted in greater driving and system task errors than conventional "hard" buttons. There are two reasons for this performance decrement: (1) the controls are non–dedicated (i.e., change depending on the screen), and (2) soft keys do not provide tactual feedback. For a "hard" button, the driver must (depending on the control and its proximity) glance briefly at the control and then find the control using tactile information to accomplish location "fine–tuning." For the soft keys, the driver must glance once to determine the location, and glance again to perform the location "fine–tuning" (Dingus and Hulse, 1993).

One way to minimize control use while in transit is to severely limit control access. Therefore, as with the display information previously discussed, it is important to assess the necessity of every control in terms of both in–transit requirements and frequency of in–transit use to minimize driver control access. Those controls that are not absolutely necessary for the in–transit environment can then be allocated to pre–drive or zero–speed circumstances (Dingus and Hulse, 1993).

Control location has been shown to be important in automotive research. The farther a control is located from the driver, the greater the resources needed to activate the control. This has been demonstrated by Bhise, Forbes, and Farber (1986) and Mourant, Herman, and Moussa–Hamouda (1980), who found that the probability of looking at a control increased with increased distance. Therefore, controls present on the steering wheel, or otherwise in close proximity to the driver, are easier to use.

Control activation complexity and steering interference have also been shown to be important issues. Monty (1984) has shown that continuous controls or controls requiring multiple activations are significantly more difficult to operate. Therefore, limiting controls to single, discrete activations provides fewer resource requirements.

Driver Demographics

The older driver

The most prevalent user demographic issue is driver aging. Parviainen, Atkinson, and Young (1991) studied both the aging population and the handicapped with regard to in–vehicle systems development. Parviainen et al. (1991) stated that the number of aging drivers will double by the year 2030, and that systems must be designed to accommodate these special populations. According to Franzen and Ilhage (1990), the driver population over age 65 will soon consist of one out of every seven drivers on the road. Older drivers constitute the most rapidly growing segment of the driving population in number of drivers licensed, distance driven, and proportion of the driving population. However, there continues to be problems associated with an aging driver population, including discrimination and lack of highway traffic engineering to accommodate older drivers (Waller, 1991).

Research has shown that older drivers spend significantly more time looking at navigation displays than younger drivers (Pauzie, Martin–Lamellet, and Trauchessec, 1991; Dingus, et al., 1989). Experiments comparing the visual glance frequencies of both elderly and young drivers toward a CRT screen with navigation information were conducted. It was found that younger drivers spent 3.5 percent of the driving time looking at the display, while elderly drivers spent 6.3 percent of the time looking at the display. Consequently, when navigation systems are involved, this group devotes less time directed toward the roadway. This dictates that special consideration must be given to this segment of the population, and that minimizing in design of a navigational information display glance time is critically important.

Older drivers perception of risk is increasing (Winter, 1988). Winter suggested that more older drivers are "running scared," frightened away from traffic situations they can probably handle, as well as those they cannot. Psychologically, some of them experience fear and anxiety about their vulnerability in a fast, complex traffic world, and in relation to citations, insurance, and licensing examinations. Winter suggested that older drivers may develop compensatory attitudes and behaviors, some of which are positive and contribute to safety and some of which are negative and promote unsafe practices. On the positive side, they become more responsible and law–abiding. However, older drivers may deny that their skills are decreasing and continue to drive under conditions highly unsafe for them. Winter reasoned that a prime factor in elderly attitude toward driving is the fear of an accident or a violation that would lead to reexamination for licensure and end in a possible loss of both the license and of the independence it affords. Another threat is the cancellation of insurance or the rise in premiums that would make driving too costly.

Many traffic engineering controls designed for older drivers have been suggested in recent research. Lerner and Ratté (1991) suggested that older drivers have a need for advanced signing of upcoming exits. According to Bishu, Foster, and McCoy (1991), older drivers favor larger signs, lower speed limits, and more stop signs and traffic signals. Garber and Srinivasan (1991a) suggested that an increase in amber time or the protected phase for left–turn lanes would help reduce the large percentage of involvement in left–turn lane accidents by elderly drivers.

Research has indicated the existence of many age–related performance problems. Walker, Alicandri, Sedney, and Roberts (1990) found that older drivers (55 years of age and older) drove slower, had larger variability in lateral placement, had longer reaction times to instruments, were more likely to be in another lane after a turn, and were more likely to make navigational errors compared to middle–aged drivers (35 to 40 years of age) and younger drivers (20 to 25 years of age). Women appear to be at risk from age–related changes in cognitive functioning, particularly those with less driving experience and after 75 years of age. Men appear to be at risk for both accidents and citations as a result of sensory and psychomotor function problems. However, there are no significant differences in the rates at which males and females reported either accidents or citations (Bishu et al., 1991; Laux, 1991). For drivers over age 74, slowing of reaction time has a strong association with overall driving performance and with specific driving measures, especially those related to vehicle control (Ranney, 1989). However, Olson and Sivak (1986) found that older drivers, ages 50 to 84, had relatively the same perception–response time to unexpected roadway hazards as younger drivers, ages 18 to 40. Further research in this area has been reported by Chang, 1991; Greatorex, 1991; Ranney and Pulling, 1990; Reynolds, 1991; Stelmach and Nahom, 1992; Vercruyssen, Carlton, and Diggles–Buckles, 1989.

Several studies have been conducted to determine the driving habits, safety, and accident rates of older drivers (Evans, 1988, 1991; Garber and Srinivasan, 1991a, 1991b; Jette and Branch, 1992; Kostyniuk and Kitamura, 1987; McKelvey and Stamatiadis, 1989). Evans reports that although accident rates for drivers 65 years old is greater than that for drivers who are 40 years old, both groups have substantially lower accident rates than for drivers at age 20.

Why grandpa wears glasses

It is generally acknowledged that vision plays a vital role in safe and proficient driving (Kosnik, Sekuler, and Kline, 1990). However, the aging process does bring about a variety of changes in drivers' visual functions and their cognition, which may gradually affect their interaction with vehicle environment. Older drivers report problems with visual processing speed, visual search, light sensitivity, and near vision (Kosnik et al., 1990). Older drivers reported a higher frequency of visual problems, but generally do not have unusual visual problems.

Research has shown that older drivers' visual performance improves with the use of specific display characteristics. Babbitt–Kline, Ghali, and Kline (1990) reported that the use of icons improves user visibility in both distance and lighting conditions (e.g., daylight versus dusk). Hayes, Kurokawa, and Wierwille (1989) reported that many performance problems in viewing visual displays can be eliminated by increasing the character size of textual labels. Yanik (1989) observed that for color displays, drivers had better visual responses to yellows, oranges, yellow–greens, and whites on contrasting backgrounds. Yanik also found that analog displays (i.e., moving pointer) were preferred over digital or numerical displays. Other studies involving older drivers' visual abilities are reported by Mortimer (1989); Ranney and Simmons (1992); and Staplin and Lyles (1991).

Designing for the older driver

Designers of transportation systems will have to consider the needs of older drivers. Mast (1991) stressed a greater need for transportation system research and development for older drivers in areas of traffic control devices, changeable message signs, symbol signing, hazard markers, night driving, sign visibility, intersection design, traffic maneuvers, left turns against traffic, and merging/weaving maneuvers.

Lerner and Ratté (1991) reported that focus groups identified the following needs and generated ideas and countermeasures for the safe use of freeways by older drivers:

- Lane restrictions, time restrictions, separate truck roadways, and other methods to reduce interaction with heavy trucks.
- Greater police enforcement, new enforcement technologies such as photo radar, new traffic control technologies, and other methods to reduce speed variability in the traffic stream.
- Better graphics, greater use of sign panels listing several upcoming exits, and other methods to improve advance signing so that it better meets the visual and information needs of the elderly.
- Wide high–quality shoulders, increased patrol, brightly lit roadside emergency phones, promotion of citizens band radio use, better night lighting, more frequent path confirmation, and other methods to overcome concerns about personal security.
- More legible maps, map–use training in older–driver education courses, in–vehicle guidance systems, and other pre–trip planning aids that are designed to be used by older drivers.
- Appreciation for the safety benefits, on–road "refresher" training for those who have not used high–speed roads recently, training in recovery from navigational errors, and other older–driver education specific to freeway use.
- Eliminating short merge areas and other methods to improve the interchange geometries that the focus groups identified as contributing to anxiety.

Learning and training effects

Groeger (1991) discussed the learning process of the driving task and a proposed intelligent vehicle system that could continue to teach drivers as their skills mature or deteriorate. The Personalized Support and Learning Module (PSALM) is a concept derived as part of the DRIVE project. It would use the sensors in many ITS–equipped automobiles to monitor driver performance. Individualized and task–specific instruction will be possible with PSALM.

Fatigue effects

Another topic addressed in the new vehicle technology research is fatigue detection. Systems are being developed that measure driver performance through steering wheel input by the driver. If patterns suggesting fatigue are recorded, then audible alarms awaken the driver or suggest taking a rest break. Several research studies and specific systems are discussed in Tarriere, Hartmann, Sfez, Chaput, and Petit–Poilvert (1988). A similar Japanese system was developed by Nissan and is discussed in detail in the report by Senoo, Kataoka, and Seko (1984). These systems could be considered ATIS.

Driver Acceptance and Behavior

Acceptance research

When developing components of ITS, it is important to consider the attitudes of system users. Is the system acceptable, usable, and affordable? A good review of the issues associated with ITS acceptance is presented by Sheridan (1991). Lunenfeld and Stephens (1991) also discussed the specific issues of night–vision enhancement systems.

A survey by Marans and Yoakam (1991) found that most commuters felt that ITS was a plausible solution to traffic congestion. The highest approval of ITS (48 percent) came from commuters whose work commute was from suburban to suburban localities. The survey also reported that 86 percent of the commuters drove their own car to work.

A UMTRI focus group study (Green and Brand, 1992) elicited attitudes on 11 types of in–vehicle electronics. Drivers were cautious about the navigation systems. Most indicated that the systems were good for someone else to use, in certain situations. It was noted that men preferred maps and women preferred directions. Both genders preferred left/right turning directions rather than compass north/south.

A survey by King (1986) analyzed self–reported navigation and map–reading skills. King found that 27.6 percent of all travel represented non–familiar trips, and that the majority of respondents felt confident in their own navigation and map–reading skills.

In a survey by Barfield, Haselkorn, Spyridakis, and Conquest (1989) (see also Haselkorn, Barfield, Spyridakis, and Conquest, 1989 and 1990; Haselkorn and Barfield, 1990; Spyridakis, Barfield, Conquest, Haselkorn, and Isakson, 1991; Wenger, Spyridakis, Haselkorn, Barfield, and Conquest, 1990), commuters rated commercial radio as the most useful and preferred medium from which to receive traffic information both before and while driving, as compared to variable message signs, highway advisory radio, commercial TV, and telephone hotline systems. Commuters also indicated that departure time and route choices were the most flexible commuter decisions. Most commuters indicated that they could not be influenced to change their transportation mode.

Driver acceptance of technology was assessed by McGehee, Dingus, and Horowitz (1992) while studying a front–to–rear–end collision warning system. They reported that drivers often follow at distances that are closer than brake reaction time permits for accident avoidance. This close driving behavior may be due to the lack of previous bad experiences. A front–to–rear–end collision warning system (whether it is visual, aural, or a combination of both) had the potential of providing added driver safety and situation awareness and was generally accepted as a worthwhile device by the subjects tested. According to a study by Erlichman (1992), subjects showed a preference for text– and voice–warning message systems that were demonstrated in a study on safety advisory and warning system design. The results of these studies apply to IVSAWS.

Route selection and route diversion

A major component of ITS systems includes navigation aides. These devices can provide the user with current traffic conditions, alternate route selections, and guidance over the alternate routes. The effectiveness of these systems in alleviating traffic congestion has been reported in studies by Dingus and Hulse (1993); Halati and Boyce (1991); Hamerslag and van Berkum (1991); and Knapp, Peters, and Gordon (1973).

Drivers have been shown to resist diverting from their present route to avoid congestion (Dudek, 1979). Dudek showed that 50 percent of drivers were willing to avoid a 20–min delay, but only 8 percent were willing to avoid a 5–min delay. According to this report, congestion would have to be moderately severe before people divert. This may be due to lack of information known by the driver. A key to persuading drivers to use an alternate route is appropriate and timely information. For example, if drivers know they can save time by using an alternate route, but do not know how much time, the drivers may be hesitant to change routes. In addition, drivers tend not to take the shortest or fastest route if it is less pleasant. Cross and McGrath (1977) found that drivers select routes based on the following factors: efficiency (fastest route 54 percent, shortest route 53 percent), problem avoidance (safest route 43 percent, more familiar with route 36 percent), more miles of multiple lanes (31 percent), roads in better condition (30 percent), less chance of getting lost (24 percent), less traffic (18 percent), and pleasure and personal convenience (most scenic route 25 percent). Factors such as road quality, number of junctions, and average speed are also important in route selection. Streeter and Vitello (1986) had 33 women rate what was most important to them in terms of navigational preferences. For short trips, they wanted to avoid road construction/bad roads and traffic. For long trips, they also wanted to avoid road construction/bad roads. Other areas that were important to the drivers for long trips were use of major roads, scenery, few stoplights, and travel time.

Allen, Stein, Rosenthal, Ziedman, Torres, and Halati (1991) looked at driver route diversion and alternate route selection using in–vehicle navigational systems. Overall, the study showed that navigation system characteristics can have a significant effect on driver diversion behavior, with better systems providing more accurate traffic congestion information. Navigation systems equipped with congestion monitors effectively changed driver behavior; however, not all drivers exited to the alternate route suggested by the computer. Older drivers (55 years of age or older) were more reluctant to choose alternate routes.

Research has shown that drivers have difficulty planning optimum routes from their origin to their destination (King and Rathi, 1987). These travel inefficiencies lengthen travel time. King and Rathi asked subjects to plan three relatively long trips in unfamiliar areas by using only a road atlas. The routes selected by the subjects were compared with the routes recommended by the American Automobile Association (AAA) for both distance and approximate driving time. Analyses of the data indicated that the routes selected by the subjects on average increased trip length by 12.1 percent.

Tong, Mahmassani, and Chang (1987) found that commuters combine their last experienced travel time with the supplied travel time to predict travel time for their next trip. When commuting to work, this value was adjusted by a margin that was governed by the last experienced schedule delay in order to protect against an unacceptably late or early arrival time. Tong et al. (1987) noted that additional information supplied to commuters reduces the importance of relying on their memory or accumulated experience in the prediction of travel time.

Shirazi, Anderson, and Stesney (1988) studied commuters' attitudes toward traffic information systems and route diversion. Overall, commuters wanted timely and accurate information, more frequent reporting, and better uses of electronic freeway message signs. Most were in favor of continuous radio traffic reporting (68 percent) and traffic information phone numbers (53 percent). In general, males were more likely to change routes than females. Females (38 percent) were less likely to know alternative routes than males (62 percent). Drivers commuting for short periods (less than 45 min) were more likely to change routes to work than those with longer travel time. Nearly 70 percent of commuters said they would leave the freeway if more accurate information regarding their commute was available, and if they knew that surface streets offered a shorter route to work. The most frequently cited factor for route change was radio traffic reports (30 percent), followed by personal experience (20 percent).

Khattak, Schofer, and Koppelman (1991) found that most commuters changed their routes based on radio traffic reports. Khattak et al. (1991) also found that commuters used traffic information more when they were en route, compared to when they were planning their trips. Drivers reported a preference for information on near–term prediction of traffic conditions for congested and unreliable routes as opposed to current traffic conditions. Drivers considered current conditions as unstable with the potential for rapid change. Overall, radio traffic reports were attributed to reducing en route anxiety and frustration of drivers even if drivers did not modify their trip decisions. Commuters who are more likely to change their departure time in comparison to their route selection wanted long–term prediction of traffic conditions.

Barfield et al. (1989) (see also Haselkorn et al., 1989 and 1990; Haselkorn and Barfield, 1990; Spyridakis et al., 1991) used cluster analysis to show that four commuter subgroups exist with respect to their willingness to respond to the delivery of real–time traffic information:

- Route changers, those willing to change routes on or before entering Interstate 5 (20.6 percent).
- Non–changers, those unwilling to change time, route, or mode (23.4 percent).
- Time and route changers (40.1 percent).
- Pre–trip changers, those willing to change time, mode, or route before leaving the house (15.9 percent).

Bonsall and Parry (1991) tested drivers' compliance with route guidance advice by asking subjects to make several "journeys" from specified origins to specified destinations using an IBM computer–based simulator, Interactive Guidance on Routes (IGOR). The quality of the advice IGOR provided varied. Overall, about 70 percent of the advice was accepted. Acceptance declined as the quality of advice decreased. Participants' perception of the advice was dependent upon the physical layout of the network. Generally, if previous advice had been very good, then even bad advice was likely to be accepted; and if previous advice had been very bad, then a bad item of advice was almost certain to be rejected. Acceptance of advice generally decreased as familiarity with the network increased. Visible presence of traffic congestion or a road sign apparently confirming advice increased acceptance of advice. Women were found to be significantly more likely to accept advice, particularly non–optimal advice, than were men. Subjects who normally had high commuting distances were less likely to accept advice.

To analyze the effectiveness of route–guidance systems, Abu–Eisheh and Mannering (1987) developed a route and departure time choice modeling system where departure–time was a continuous variable. The models were estimated using a sample of people commuting to work, and the resulting coefficient estimates were significant. This study also found that males have a tendency to drive faster than females, that safety belt users tend to drive faster, and that younger commuters drive faster than older commuters.

Alcohol impairment

Alcohol impairment needs to be considered in the design of ATIS/CVO systems since about half of all fatal accidents involve drunk drivers. The use of alcohol is believed to cause 25,000 deaths a year on U.S. highways. A recent study by Zador (1991) estimated that a driver nearly doubles the risk of being in a fatal, single–car crash with each increase of 0.02 in the blood alcohol concentration (BAC). The risk is higher for younger drivers than for older drivers, and females had higher relative risk than males. At higher BAC's (at or above 0.15 BAC), the risk of crashing was 300 to 600 times the risk at zero or near–zero BAC's.

Alcohol has many documented effects on the human body (Meier, 1990). Studies have suggested that subjects tend to ignore instructions and traffic rules after drinking (Linnoila and Mattila, 1973). A study by Farrimond (1991) suggested that alcohol affects visual constancy values. Subjects saw familiar objects as larger than actual size and saw hazards as smaller and farther away than they actually were. According to a study by Moskowitz, Burns, and Williams (1985), skilled tasks were impaired at low BAC's. These impairments lead to accident–causing driver errors.

A recent study by Holubowycz, McLean, and McCaul (1991), conducted in Australia, suggested that there are two to three times as many drivers on the road who were over the legal BAC limit than previously believed by police data. However, in a study by Lund and Wolfe (1991), data indicate that the incidence of alcohol–impaired driving on weekend nights fell by one–third or more in the United States between 1973 and 1986, and that the decline affected most population subgroups. This study attributes the decline to an increase in public awareness brought about by such national groups as Mothers Against Drunk Driving (MADD).

CVO-Specific Human Factors Research

Acceptance research

Several major surveys addressing the use and acceptability of advanced technology have been performed using CVO's as respondents. The results of these surveys are summarized below.

A Survey of the Use of Six Computing and Communications Technologies in Urban Trucking Operations. A survey performed by the American Trucking Association (Willis, 1992) was conducted on the use of six kinds of advanced telecommunications and commuting technologies by truck operators in urban areas. The technologies investigated were computer–aided dispatch (CAD), two–way text communication, AVL, in–vehicle navigation, AVI, and traffic information services. A total of 69 companies were surveyed.

The results showed that 35 out of 69 firms used CAD. Two–thirds of those that used CAD employed dynamic routing (i.e., rerouting of vehicles in response to changing patterns of demand during the day).

Two–way communication was the second most widely used technology (21 companies). The survey found that two–way text communication is viewed as having both safety and operational advantages over voice communication. For example, text messages can be stored until it is safe for the driver to assess them.

Automatic vehicle location is ranked third and was being employed by 15 of the 69 companies. Management and dispatchers liked AVL as a means of better managing drivers and vehicles. Drivers' views were mixed or negative. Thus, drivers' needs must be addressed in order for AVL to work.

The survey found that in–vehicle navigation systems are seldom used by truck operations. Such systems are used more often by fire departments and ambulance services (5 out of 69 companies).

The AVI results were not as useful since most of the surveyed users were participating in an AVI toll collection study. However, those subjects using AVI were pleased with the technology.

Fleet management is the key task that ITS offers to streamline for both commercial carriers and public transit. As with ATIS for private vehicles, improved routing and communications will be key components for fleet management. Regulatory compliance is also promising. Operational field tests involving many State agencies are currently under way, such as Heavy–vehicle Electronic License Plate (HELP) program and Advantage I–75.

Institutional Barriers and Opportunities for IVHS in Commercial Vehicle Operations: An Iowa Case Study (Midwest Transportation Center, 1992). This survey of commercial vehicle operators was undertaken to determine the most feasible and desirable ITS features for CVO applications. The following are summarized results of this survey.

The most promising CVO applications are:

- Weigh–in–motion using AVI.
- Pre–clearance for safety inspections.
- "One–stop shopping" compliance with all truck regulations at a central place.
- Electronic toll and traffic management.
- Automated apportioned fuel tax administration.
- Audits of apportioned fuel tax.

Other promising applications include:

- Hazardous materials identification.
- Navigation aids due to cost.

Survey of the Trucking Industry's Preferences for IVHS (Stone and Ervin, 1990). This survey of commercial truck drivers reported the following findings:

- Seventy percent of the sample preferred a two–way conversation link for communicating instructions and messages.
- Current users of advanced technology rated text messages equal in value to the conversation link.
- Larger carriers rated AVI for WIM higher than the smaller carriers did.
- Warning and control systems were rated highly. Sixty–five percent of the sample rated impending rollover warning as "very important." Seventy–nine percent rated collision warning as "very important." Overwhelming interest was seen in "mayday" alert systems.
- Rural carriers preferred video maps for routing.
- Urban carriers rated voice routing and video routing as equal in value.
- Urban carrier dispatchers preferred electronic map presentation of vehicle location, whereas rural dispatchers thought text and map were equally desirable.
- Truck location updates should be accomplished every 1 to 4 h.

The TRANSCOM project (described in the previous section) reported the following results:

- Real–time traffic incident notifications were valuable to trucking companies. The participating companies stated that the information helped them to avoid incidents, thus saving time.
- Dispatchers had a very hectic job and were often too busy to relay information to drivers.
- Those drivers with limited route options did not always benefit from real–time incident information.
- Incident notification was most valuable when sent only to those drivers affected by the incident. Receiving information on every incident in the area caused many firms to ignore their pagers used for notifications since it provided information that typically did not affect them.
- A good indicator for judging the usefulness of a feature was the time value placed on the commodity and the ability to use alternate routes. It was recommended not to judge the usefulness of the indicator based on the type of carrier.
- A weekly traffic and transit advisory of lane closings and major traffic–generating events was beneficial to all truckers for planning routes.
- Two–way communications between drivers and dispatchers on how to enhance the pager's usefulness was not necessary, but it helped.

HELP and Crescent Demonstration project. The HELP program involved the use of AVI, WIM, AVC, satellite data links, and data communication networks, including on–board computers. This research is intended to design and test the integration of selected technologies, including AVI, AVC, and WIM equipment, computer integration, and communication linkages.

The program involves 14 U.S. States, a Canadian Province, a U.S. port authority, national transportation agencies, and a trucking industry representative from both Canada and the United States. It was originally started in 1983 and called Crescent, but by 1985 the overall program was changed to HELP. The demonstration project itself is called Crescent, and it was started in 1991 and completed by 1993.

There were four goals for the HELP program. They were as follows:

- Assess the viability of the technologies in the highway environment (e.g., reliability, accuracy, etc.).
- Improve institutional arrangements (e.g., one–stop shopping, pre–clear at weight stations and ports of entry, border transparency).

- Measure efficiency and productivity (e.g., improved safety, enforcement, reduced administration, data collection, etc.).
- Identify additional applications of the technology (e.g., public/private sector applications) (Walton, 1991).

No specific results were found for Crescent as of the initial writing of this report. As with TravTek and other projects, results should be available during the duration of this project.

Additional CVO research findings

There are very few empirical and review studies that involved advanced technology and commercial vehicles in addition to the studies mentioned above. The few findings that were available are summarized below.

ITS America called attention to the differences between automotive and CVO populations. The IVHS America Strategic Plan (IVHS America, 1992b) stated that the average commercial driver differs from the average automobile driver in terms of such demographic characteristics as size, age, sex, and health, as well as such performance characteristics as information processing and response abilities in a multi–channel information system. The report stated that it is critical to examine driver characteristics specifically in the context of CVO (IVHS America, 1992a). In addition, the report stated that human factors considerations are important in developing CVO technologies. Areas that need to be studied include:

- Information requirements issues.
- Display issues.
- Driver performance issues.
- Driver behavior issues (IVHS America, 1992a).

Boehm–Davis and Mast (1992) specified that CVO systems designers must also consider identifying the information needed by the driver, the vehicle, and the control agencies (e.g., ATM's, fleet managers). Once the information has been identified, researchers need to identify the best means of presenting that information to users (Boehm–Davis and Mast, 1992).

HUD concepts for commercial trucks

HUD's allow the operator to access vital information without having to look down at the instrument panel. HUD's are currently used in many applications, including aircraft, automobiles, and trucks, and they have many potential advantages.

HUD's in trucks, however, require modifications due to windshield designs. Truck windshields are nearly vertical. Therefore, Greenland and Groves (1991) recommended using a separate combiner element as part of the HUD package and not using the windshield. This would avoid potential ray interference and low brightness. A separate combiner element would also allow the HUD to be a completely self–contained unit. So the HUD may be placed in any convenient location in the vehicle.

The application of ITS technology to hazardous material transportation

The regulations for transporting hazardous material lie in three areas:

- Adequate packaging.
- Communication of hazard information.
- Operational requirements pertaining to the particular mode of transportation.

ITS will have the greatest potential for improving communications.

Allen (1991) suggested using "smart cards" that convey information for emergency response. These are similar to the existing diamond placards with numbers and symbols. He also suggested real–time tracking (AVL, TWC, and OBC), electronic manifest (AVI, AVC, TWC, and OBC), and smart package (TWC and OBC). "Smart package" would monitor the physical condition of high–hazard, volatile hazardous material cargo and packaging.

AVI research for commercial vehicle operations

Tests were conducted by Davies, Hill, and Siviter (1991) on current AVI systems that performed well with regard to height, offset, temperature, attenuation, speed, multi–lane, multi–tag, placement, accuracy, reliability, and interference. The results found that although none of the commercially available systems performed without significant operational problems, those based on radio–frequency technology showed the most promise. A prototype was then built using the results obtained in the first study. Davies, Hill, and Siviter (1991) outlined principal features of the final specifications for the AVI beacon system.

Ferlis and Aaron (1977) described an AVI system that incorporates a transponder that carries a unique vehicle identification number and an interrogator that extracts the vehicle identification number from the vehicle; a communication system that transmits the vehicle information to a central computer for processing; and a computer that manages, stores, edits, and analyzes incoming data. The technologies that could be used for AVI systems are broad. Radio–frequency (RF), microwave, radioactive, magnetic, license–plate scanning, and visible–optical scanning are all potentially viable. Koelle (1991) indicated that the technology employed in the Ametech AVI system is powered by either RF or built–in battery.

AVI technology, as outlined in the literature, has several potential applications (Ferlis and Aaron, 1977; Koelle, 1991; Larson, Colton, and Larson, 1977). Koelle (1991) described how Ametech Systems Corporation has used AVI systems technology in electronic toll collection. Various toll roadway systems have used Ametech's AVI systems, which have proven to be both reliable and cost–effective. Koelle noted that in mid–1991, there were in excess of 120,000 in use. According to Koelle, public acceptance of this technology was highly favorable.

Ferlis and Aaron (1977) described other potential AVI applications. In addition to toll collection, access control can be managed. Based on the vehicle's identification number, vehicles' access to outlined locations can be determined. For example, "cordon control" (which prohibits certain motorists from traveling during certain times or locations) can be facilitated by AVI systems. Another potential application is data collection. As vehicles are identified at particular points, traffic measures, including volumes, vehicle classification, travel times, and travel paths can be collected. Traffic signal control is another application of AVI technology. By identifying traffic flow, control of the offset relationship of a series of signalized intersections could potentially decrease congestion.

Automatic vehicle monitoring

An extension of AVI technology is Automatic Vehicle Monitoring (AVM). In addition to providing vehicle identification information, AVM provides both status and location information. Fleet management has been identified as a potential application of AVM technology. Ferlis and Aaron (1977) outlined three benefits that AVM technology could have on fleet management. These included reducing or eliminating manual data collection through automatic passenger counts, reducing scheduled layover time because of improved schedule adherence, and freeing buses by enabling schedules to lengthen headways without increasing passenger's perceived waiting time. AVM has also been used by police department dispatchers. Larson, Colton, and Larson (1977) described a system that has been tested by the St. Louis Police Department. Results of the testing suggested that there is potential for implementing an AVM system that may decrease response time, increase officer safety, and decrease the voice–band congestion that presently exists.

Follow–up studies on the success of AVI and AVM technology are absent from the literature. Ferlis and Aaron (1977) examined the feasibility of this technology. Results of a feasibility study indicated that due to the high cost of technology, it may not be feasible. Note that this examination is dated. Further examinations of AVI technology, including its feasibility, effectiveness, safety implications, and attitudinal factors, are required.

COMPARABLE SYSTEM EMPIRICAL FINDINGS APPLICABLE TO ATIS/CVO

This section outlines several ATIS/CVO comparable systems. Comparable systems include display and control interfaces for military ground vehicles, ships, submarines, air-traffic control, nuclear and conventional power plants, rail vehicles, and aerospace crafts. Background information on each of these comparable systems will be provided. In addition, existing guidelines derived from the literature and their potential applicability to ATIS/CVO will be examined in the next section. Finally, research questions required to determine the ATIS/CVO applicability of these outlined comparable systems will be discussed in the Conclusions section of this report.

Nuclear Power Plant Systems

Within nuclear and conventional power plants, systems that could potentially have ATIS/CVO applications are in existence. O'Hara and Brown (1991) examined the problems and issues with nuclear power plant alarm systems–specifically, the human factors issues associated with the design. From this study, a number of recommendations and guidelines were outlined.

The proper application of advanced technologies to alarm systems, and an improvement in operator performance are recommended. Potential guidelines for using this with ATIS/CVO applications include the following:

- Use tile or window displays superior to CRT–based presentations during high alarm density conditions.
- Organize conventional alarms by system and function to improve performance.
- Require instructional alarm information due to their infrequent and low–probability nature.
- Use auditory alarms with caution since they may be startling and distracting.
- Use voice warnings rather than visual warnings since operators respond faster.

These human factors–related recommendations work well with ATIS applications that require advanced display and alarm systems.

Richards, Gilmore, and Haney (1986) performed a case study of human factors guidelines on a user–computer interface design at EG&G National Engineering Laboratory. In a systematic approach to display integration, a number of areas requiring human factors input were outlined. These included workstation and equipment arrangement; the CRT display organization; the window system, menus, and information packaging; color coding; labeling; and text formatting. Some of these areas, depending on the ATIS/CVO system in question, may be relevant to ITS system design.

Literature is available that describes conventional and nuclear power workstation interfaces, and the guidelines involved in the design process. However, research that examines the effectiveness of the systems post–design is limited. Casey, Dick, and Allen (1984) conducted human factors and performance evaluations of the Emergency Response Information System (ERIS). This system is in place at a full–scale Boiling Water Reactor simulator. The ERIS was designed to support control room operators during emergency management situations, and specifically for "detecting abnormal operating conditions, assessing the safety status of the plant, executing corrective actions, and monitoring the plant response." Although the design seems to be beneficial to operators during emergency conditions, given the small subject size, it is difficult to make assumptions about the success of the ERIS design. A more thorough examination of the ERIS and similar workstations is required to determine the effectiveness of these designs. From this, the most effective design in terms of increased performance can be determined. Only when this work has been accomplished can the design guidelines used to develop the most successful workstations be noted and their applicability to ATIS/CVO (as well as other applications) be determined.

Armored Vehicles

The armored ground vehicle is of potential value to ATIS/CVO applications, although there is little published research available. The task of driving an automobile is different than operating an armored vehicle in many respects. However, the two environments are quite similar when compared to other available comparable systems (e.g., aircraft). Ruisseau, Gorzerino, Moscato, and Papin (1988) noted that differences in armored vehicle environments included operators wearing specialized equipment, limited interior vehicle space, and the high level of nuisances including noise and vibration.

In addition to the differences in the operator's environment, the technology that must be employed in armored vehicles is quite specific. In addition to designing a control or visual system to meet the goals of these specialized tasks, the designs used in an armored vehicle must be able to withstand extreme temperatures, shock, and vibration, and must be undetectable to the enemy. Also, due to confined work spaces, designs must be comfortable to use and must have minimal controls.

Hudson (1986) outlined the specialized armored vehicle display technology involved in "night sight" devices and noted that a large field of view and good resolution are two prime design goals. To meet these goals, image intensifiers are required. Hudson described the technological development, including earlier designs that used "cascade" tubes and later designs that incorporated improved photocathode materials.

In terms of potential ATIS/CVO applications, the technology developed for the specialized task technology involved in armored vehicle operation should be considered. For ATIS/CVO applications that require night–vision displays, the technology outlined by Hudson (1986) may be relevant. Because tasks performed by automobile drivers and the armored vehicle operator are quite different, adapting armored vehicle technology to automobile technology must be done carefully. Depending on the desired ITS application, this specialized technology may require further consideration.

Aircraft Glass Cockpits

Within the glass cockpit literature there are several categories of systems. Each of these categories is summarized below. For an overview of glass cockpits, see the report by Jennings and Hannert (1987).

Head–up displays

A well–examined topic in current research literature is HUD's (Deaton, Barnes, and Lindsey, 1989; Deaton, Barnes, Kern, and Wright, 1990; Ercoline and Gillingham, 1990; Naish and Miller, 1980; Sorkin, Kistler, and Elvers, 1989; Weinstein, Ercoline, and Bitton, 1992). Though the bulk of this literature deals with the development of HUD technology in aerospace environments (i.e., cockpits), there is a potential for ITS applications. Before applying these to automotive applications, it should be explored further.

Deaton et al., (1989) investigated pilot performance using windscreen bows as a type of HUD format. Different HUD formats were examined, including a "standard" format that used dotted lines at negative pitch attitudes, and an "enhanced" format that used sawtooth lines at negative pitch attitudes and horizon–pointing tails at the inner ends of the pitch lines. The results of a simulator study indicated that the "enhanced" format increased pilot performance, particularly at severe negative pitch altitudes.

In a study that examined the effects of HUD variations in airspeed and altitude display, Ercoline and Gillingham (1990) examined five different symbol set presentations. These included rotating pointers, rotating pointers with dots, moving vertical tapes, boxed digits, and trend bars. Results of a simulator study indicated that displays with less clutter increased pilot performance in terms of airspeed and altitude performance errors. Note that one of the purposes of this research was to provide data in order to add to the HUD symbology design standardization effort. This investigation, along with other similar empirical studies, examined areas of HUD symbology that could be incorporated into a set of design guidelines. If HUD technology is to be used in ITS, a similar type of standardization effort will be required.

Naish and Miller (1980) also examined and evaluated HUD formats. Three detectors were presented in HUD format. The displays were evaluated in terms of pilot performance in tracking, speed error, and workload. As in the Ercoline and Gillingham (1990) study, the results were developed into a set of design guidelines. Given the newness of HUD technology, it is essential that research of this nature be conducted. It is possible that many of the guidelines defined in these investigations may be applicable to the automotive environment. However, much research will need to be conducted to develop a new set of guidelines that takes into consideration the specific tasks of automotive driving.

Sorkin et al. (1989) investigated the usability of Auditory HUD's (AHUD's). AHUD's are defined as "systems that provide data about signals or events occurring at different spatial locations relative to the aircraft." The investigation examined the effectiveness of AHUD's in providing azimuth and elevation information. Results of the investigation suggested that a stereophonic display integrated properly with a head position sensing system may usefully improve an observer's information processing. This investigation illustrates that HUD technology is quite diverse and all of its applications have not yet been realized.

A relevant question regarding ITS research is, "Can HUD technology be adapted for use in ATIS/CVO applications?" Research needs to be conducted that examines the driving task in detail and outlines the incorporation of a HUD that would affect driver performance and safety. HUD technology has been shown to decrease pilots' response times (Deaton et al., 1989). If drivers' response or reaction times can be decreased without increasing the safety risks, HUD technology may be a good alternative. As illustrated in the aerospace study examples, the presentation of different HUD formats has been examined. In terms of an ATIS/CVO application, the type and format of displayed information should be explored in detail.

Map displays

Airplane traffic information displays have been actively researched. There appears to be a problem with the orientation and vantage point of the traffic display view. Williams and Wickens (1991) and Aretz (1991) studied this by comparing north–up and track–up alignments in maps. Both experiments showed that optimum orientation is task–dependent. For navigation tasks requiring a track–up alignment (e.g., localization), an Ego–centered Reference Frame (ERF) was best; and for tasks requiring a north–up alignment (e.g., reconnaissance), a World–centered Reference Frame (WRF) was best. Williams and Wickens (1991) state that a north–up alignment does provide a stable alignment and could be used in situations where precise control is not critical.

Another orientation experiment was done comparing a map that employed the principle of visual momentum with the two traditional approaches–track–up and north–up (Aretz, 1991). A visual momentum display places a wedge in a map corresponding to a pilot's field of view. Results of this experiment indicate that a visual momentum display captures north–up alignment benefits in tasks that require an ERF.

Ellis, McGreevy, and Hitchcock (1987) studied the potential of using a perspective display instead of a plan view display (top down, two–dimensional). They concluded that the perspective display was preferred over a plan view display and it provided improvements in decision time and avoidance performance.

According to this research it appears that some type of perspective display with inherent track–up alignment would be best. However, the conditions inherent in an ITS/CVO application are somewhat different. Thus, the same benefits may not be realized by the addition of the third dimension in this application. If, in fact, perspective displays prove to be superior for ITS/CVO applications, then factors including the location of the computer eye, color coding, and the best vertical and horizontal scaling factors should be investigated. (See Green and Williams (1992) for a discussion of perspective display variations in vehicle applications.)

Warning displays

Reising and Hartsock (1989) studied the effectiveness of checklists and pictorial switch layouts (i.e., showing the location of a switch to be pressed) on a CRT screen. Results of this experiment indicate that pilots react to an emergency much quicker when the complete title of the emergency (versus just an abbreviated title) and the checklist are provided. Providing the pictorial display of switch layout, however did not provide any additional improvement in performance.

In other warning display research, an evaluation was made to find the effects of different symbol designs on search time and error rate (Blackwell and Cuomo, 1991). It was found that such factors as filling symbols, simplified shapes, and enhancing critical features decrease search times. This research contained some good design principles, but lacked any investigation of the meaning that is implied by different shapes and symbols.

Traffic displays

Kelly (1983) studied the increments used to display a lead aircraft's speed (i.e., ground speed quantization). According to the study, 5.1–m/s (10 knots) supplied all of the information necessary for satisfactory performance, but performance dropped at the 10.3–m/s (20–knot) ground speed quantization level. However, pilots reported that their confidence in what the lead aircraft was doing increased when the lead aircraft's speed was displayed in smaller increments.

Landing guidance

Mann (1987) performed an experiment augmenting forward visibility and autonomous landing guidance system concepts. The variables included:

- Determining the rate at which video information must be updated in order for the pilot to control the dynamic behavior of the aircraft.
- Determining the effects of sensor resolution on pilot performance.
- Determining the accuracy requirements for the Inertial Navigation System (INS).

This data is useful in defining the video and symbology dynamics required to reduce pilot disorientation and augment the low–visibility real–world visual scene.

Acceptance of technology

McClumpha, James, Green, and Belyavin (1991) studied automation acceptance by commercial airplane pilots who used high–technology cockpits in the United Kingdom. Results identified four factors reflecting pilot attitudes toward glass cockpits–understanding, workload, design, and skills. These may also be applicable toward ITS/CVO technology. In addition to these four factors, they found that increased hours on new technology were associated with less favorable attitudes toward the design. Young pilots reported that they were concerned with the possible loss of flying skills, while older pilots were less concerned with this.

Judge, Smith, and Beaudet (1991) described a pre–mission flight interface designed for fighter pilots. They reported that giving pilots the ability to tailor their individual system to their own personal preferences paid high dividends in pilot acceptance, trust, and human/electronics teamwork. Using this information in ITS/CVO design may present some safety and practicality problems. For example, can the general public, or even CVO operators, be trusted to use such freedom in an effective and responsible manner?

Aircraft Auditory Display Formats

Because of the visual demands that are sometimes placed on drivers, auditory display information may play an important role in ITS/CVO technology. One trend in cockpit displays is to use synthesized speech to present secondary information. In a comparison between speech and pictorial displays in a cockpit environment (Robinson and Eberts, 1987), it was found that pictorial displays with an omni–directional auditory cue were preferred. In a similar system, voice communication with the control tower was compared to the Data Link system. Data Link provides visual display communication information on a CRT screen. Results of this study indicate that the Data Link system reduced the strain on short–term memory, which in turn, reduced operational errors.

This research suggests that because of the limitations of short–term memory, pictorial/CRT displays of information may be preferred over auditory–speech displays in some circumstances. However, in ITS/CVO applications, the limitations on short–term memory may be less important than increasing the visual demands of the driver. This design trade–off should be further investigated.

Ships

Collision avoidance system

A ship collision avoidance system, that facilitates threat assessment and provides some indication of avoidance maneuvers (i.e., does not prevent maneuvers) was compared to visual lookout and conventional radar (CAORF Research Staff, 1978). In high-traffic conditions, performance degraded and became erratic when using visual and radar systems. The aiding component of the collision avoidance system was effective in making the maneuvers more predictable. This same result may occur in ITS/CVO applications. However, environmental differences must be recognized when making this generalization.

Other research (Mestre, Cavollo, and Peruch, 1986) has focused on using perspective displays for navigation in shipping lanes (similar to those used in the aerospace industry) and a rate-of-turn indicator. Results of this research indicate that these displays are beneficial as navigation aids.

Caution is required when using this data in ITS/CVO applications since the dynamic nature of ships is different from those of automobiles. For example, because of their great size, inertia, and slow speeds, ship control inputs have large time lags. As such, predictor and other informational displays make navigation tasks significantly easier.

Monitoring and guidance system

A paper by Breit (1981) described a system that provides information on vertical and lateral acceleration, hull stresses, and bow flare in ships. The system also demonstrated the best vehicle operator conditions to minimize damage to the ship's cargo. An interesting aspect of the system is that it allows the operator to pre-set the alert criteria. These values are then used in the prediction algorithm to determine the best maneuver in any given circumstance. This idea of having the operator input the pre-set criterion deserves further consideration. With this, there is potential to control for much of the variability that exists between individual drivers and within the environment. Research will be required to determine the parameters of variability between drivers and within the environment. It will also be important to investigate just how the driver should be allowed to manipulate an ITS/CVO system in order to account for this variance.

THE IMPACT OF EMERGING TECHNOLOGIES ON ATIS/CVO SYSTEMS AND HUMAN FACTORS DESIGN CONSTRAINTS

The purpose of this section is to provide an overview of applicable emerging technologies for ATIS/CVO applications. Much of the technology of today and tomorrow is being focused on providing drivers with information on road conditions, navigation, warning systems, vehicle controls, and personal communications. In order for information to get to the driver, it must be sent to the automobile, interpreted, and displayed. This section covers current, near–term, and future forms of communication devices, displays, and navigation technology that have the potential to impact the human factors design of ITS systems.

Communications

As more motorists take to the road and driving tasks become automated, drivers need a way to communicate with a system to optimize travel time and safety. Citizens band and amateur radio are outdated due to the need for faster and more reliable devices that can also transmit and receive data. Today's mediums of data and voice communications include infrared, frequency modulation (FM) sideband, mobile–satellite services, cellular, radio frequency (RF) data networks, inductive–loop systems, and Shared–Trunked Radio Systems (STRS) (Weld, 1989; Kirson, 1991).

Infrared

Infrared systems use roadside beacons to transmit and receive information to and from equipped automobiles. They provide an excellent rate of data transfer and have a low cost. However, they must be in proximity to the car and environmental conditions can disrupt the signal.

Infrared beacons could be used to support AVI systems with either one– or two–way communications. Beacons can also be used as navigational aids. The beacons can update an automobile's position on the map data base as the car passes by. Information about upcoming intersections can also be provided.

FM sideband

FM sideband technology takes advantage of sideband radio and TV frequencies and broadcast information. This format is inexpensive and requires no additions to the automobile. The United States has used a highway advisory system on the amplitude modulation (AM) dial since the 1970's. Several European companies have developed more complex systems that broadcast a code at the start of the message so that only cars affected by the information will receive it. Other advances allow drivers to listen to non–critical information at their leisure and have critical information mute their radios or tape players (Davies, Hill, and Klein, 1989). These more advanced systems require a device to decode and present the information. Possible display formats include in–dash information displays and speech synthesis. Usability of this system is limited since it provides only one–way communication and some areas are not suitable for receiving FM transmissions.

One possible short–term use of sideband technology would be to provide up–to–date traffic information to all drivers in a local area. For example, units could be sold in varying degrees of complexity. The low–end model would intercept all information and display it on a small monitor. More expensive models could use coded signals to present information that is only relevant to the driver in the area. These systems would be ideal for the traveler who does not need route guidance or trip planning, but needs to know current traffic and road conditions.

Satellites

Mobile satellite services are advantageous because they transmit and receive information directly to and from an automobile regardless of geographic location. Relative costs for satellite systems are low and transmission speeds are high (about 2400 bits/s). A disadvantage of satellites is that they require several cities to use the same channel, which limits the total usage.

The next major milestone in communications will be the capability to transmit and receive voice or data from land, air, or sea from hand–held terminals. The iridium system is composed of 77 low–earth–orbit satellites. A major advantage of this system is the ability to switch between the satellites as the user moves across the country with no loss of data between links. The satellites will be able to simultaneously cover all populated areas of the earth. Motorola plans on having all 77 satellites in orbit by 1997, with initial launchings in 1995. Their primary use will be to back up terrestrial stations of cellular communications. Because the area of the earth that each satellite will cover at any one time is large, each satellite would not be able to handle as many calls at once as a ground station. For IRANS, the satellites will be able to track a user with much greater accuracy than the current Global Position System (GPS). A possible shortcoming of the system could be a lack of cooperation between cellular companies. Since it would be possible for anyone to "dial direct" to a satellite, local dispatches would have to regulate calls and provide billing.

Cellular

Cellular technologies use land–based centers, each with several cells capable of transmitting information. A mobile unit uses the strongest cell to communicate and can be handed off to another cell when a stronger one comes into range. Newer digital cellular links are being formed that will improve the reliability and transfer rate of information. Approximately 2 percent of Americans use cellular technology and cells are already becoming overloaded. This problem, plus the fact that many areas are not cellular equipped, suggests that cellular technology as it exists today will not be beneficial to large–scale ATIS uses. In order for cellular communications to be a useful source for communications in the future, cells will have to accept more users at one time and will need a greater range.

Radio Frequency (RF)

RF data networks may prove to be an expandable resource for ITS applications. The system operates in a manner similar to the cellular communication links, but does so at a much lower cost. This cost is lower on both the user's and the transmitter construction ends. Each new location of coverage requires its own antenna. RF technology has proven to be successful. An application of radio transmission, called Packet Access Radio (PAR), uses short spikes of data sent through either normal RF nodes or bounced off satellites or meteor scatter (Williams, 1989). Williams claims that meteor bounce could be an excellent low–cost data communication medium. The biggest drawback of PAR is its transmission speed; some transfers can take several minutes. For non–time critical information, meteor bounce should be investigated further for ITS communications.

Inductive loop

Inductive–loop systems are mounted under the roadway surface and are mainly used to track and detect vehicles. An alternate use would be to allow communications between the loop and the automobile. The major drawbacks of this system include low data rate and a range limited to the length of the loop. Installation costs are also high, since each loop must be buried under the road surface.

ATIS/CVO uses of this technology include AVI and areas that constantly change status. For example, commercial drivers entering an area may need to follow a specific path to avoid dangerous areas. Loop systems could be used to guide the vehicles in the right direction and inform a control center when a vehicle has entered a dangerous area.

Shared–Trunked Radio Systems

Shared–Trunked Radio Systems (STRS) operate in the same way as cellular radios, but use a 300–MHz band. Mobile units either lock onto a control channel or scan channels available for transmission. The major difference between cellular and STRS is that cellular units need enough dedicated cells to cover all users, where STRS users share cells that are not being used. STRS only covers about 30 percent of the United States, and adding more transmission units would be expensive.

Regulations

Regulations determining ownership and responsibility of areas and bands of communication are important communication concerns. In order for any of the above systems to work, an agreement must be reached between existing companies and the Government to provide data communications standards (Chadwick and Patel, 1992).

In–vehicle data transfer

The current and traditional method of getting information from one part of the automobile to another is wrapped metal wire. At least two new methods have been proposed: plastic optical fiber and Spread Spectrum Transmission (SST).

Optical fibers have proven to be very effective in sending data at high speeds. The typical fiber used today is glass, which is more expensive and more fragile than plastic. Plastic fibers, when stretched over several miles, do not have the same performance as glass fibers. However, for the relatively small confines of an automobile, plastic fibers offer excellent data transfer at a low cost and weight. Another advantage of plastic optical fibers is that when encased in a molded shell, they can withstand the rigorous environment (including shock and temperature) of the automobile in transit. Advances in connections have also made plastic fiber easier to work with and install (Ueda and Yamaguchi, 1990). Plastic optical fibers can also be used in a passive network system that allows shared system information within the car to be received by all systems at the same time with only one transmission (DiLiello, Miller, and Steele, 1990).

SST is a wireless system used to connect local area networks (i.e., several computers sharing the same hardware). SST has been used by the military for several years, but its specifics were not known until recently. The greatest advantage of SST is its ultra–high security and accuracy in data transfer. This is accomplished by diffusing a radio signal over a large band and then decoding the signal at the other end. Any attempts to intercept the signal with normal radio interception will only get part of the spread signal. Uses of SST technology are widespread, from inter–automobile communication to networks of ATIS support stations. On–board computer systems could be wireless. The system is already being used for sending real–time data from test vehicles to portable computers on site. As of 1989, only one company had received Federal Communications Commission (FCC) authorization to use SST without a radio license (Zenko, 1989).

Display Technology

In–vehicle display requirements

As automotive–compatible technologies increase, the need to present information quickly and saliently has become more important. According to Akiba, Davis, Kato, Tatiyoshi, Torikai, and Tsunesumi (1991), the automotive requirements for displays are:

- Operating temperature and humidity from –40° to 80°C at 0 to 95 percent relative humidity (RH).
- Resistance to vibration and shock of 10 to 100 g's.
- Compactness.
- Low power consumption.
- Ease of legibility (day and night).
- Long life and high reliability.
- Low cost.

The major categories of current displays are Vacuum Fluorescent Displays (VFD's), CRT's, LCD's. Those for near–term and future displays are HUD's, and Helmet/Head Mounted Displays (HMD's) respectively.

Vacuum Fluorescent Displays (VFD's)

VFD's are currently the most common type of displays found in automobiles. They are used in clocks, digital speedometers, message centers, audio systems, and temperature control systems.

VFD's are produced by exciting a phosphor–coated anode. The current colors available are blue, green, yellow–green, green–yellow, yellow–orange, orange, and red–yellow. With filters, the color combinations increase. VFD's provide high luminance at low voltage cost, are highly readable, and have a life span of more than 10,000 h. Recent advances in VFD technology have increased display area size, created a greater range of colors, and reduced the voltage use to half–duty cycle. Future advances will provide full–color displays larger than the current 127 by 178 mm (5 by 7 in), use graphics, increase luminance for HUD technology, and will run at a one–third duty cycle. See Akiba et al. (1991) and Iwasa (1991) for more detailed information on VFD's.

Cathode Ray Tube displays (CRT's)

CRT's are now being used in some automotive applications. CRT's are more commonly seen in computer displays and television screens. They can present full colors; have high resolution; and because of their maturity, are currently the least expensive of the major display technologies. The major disadvantages of CRT's for automotive use are their large size, weight, and power consumption. Another disadvantage is that as the screen size gets bigger, the image gets dimmer, a critical factor in the glare–ridden vehicle environment.

Liquid Crystal Displays (LCD's)

LCD's are currently receiving the most display research attention. According to Nordwall (1989), "LCD's generally offer savings of about 60 percent in volume, 70 percent in weight, and 80 percent in power compared with cathode ray tubes." LCD's can also display color using built–in filters. However, LCD's are non–emissive, have a narrow viewing angle, and some types have difficulty operating under high and low temperatures (Erskine, 1988).

There are several different types of LCD's available. The current type used in automobiles today is the Twisted Nematic (TN) configuration. In its simplest form, an LCD works by applying voltage to a "sandwich" cell consisting of a polarizer, a glass substrate, a transparent conductor, and an alignment layer on either side of the twisted nematic liquid crystals. When voltage is applied to the cell, the conductors cause the alignment layers to "untwist" the liquid crystals. When this happens, the polarizers line up and let light through. An obvious disadvantage of LCD's is brightness. With this basic TN configuration, the more cells (pixels) you have, the more voltage it will take to drive them. If too much voltage is applied to a row or column, other unwanted pixels may open (called "bleeding"). A second disadvantage is that it takes a set amount of time for the voltage to "spread around" the network of cells. One solution to these problems is the use of "switches" on each pixel that can either allow the appropriate energy through the cell or store the charge until the cell is needed. These switches are most commonly Thin Film Transistors (TFT) or Thin Film Diodes (TFD). This type of display is called an active matrix LCD. A good general description of LCD's and active matrix LCD's is presented in Firester (1988). A more recent type of LCD, called a Double–Layered Super–Twisted Nematic Liquid Crystal Display (D–STN LCD), has also been developed. Its major benefits are a wider range of temperature operation, lower voltage usage, and increased contrast ratio (Matsumoto, Nakagawa, and Muraji, 1991). D–STN LCD's can also be manufactured at a lower cost than other active matrix displays (Itoh, 1991).

Although the technology exists to create large flat panel displays, they are expensive. Close to half the cost is in the fabrication process. Much of the current research today is focused on creating cheaper and larger panels on which to build displays (see study by Takeda, Ezawa, Kuromaru, Kawade, Takagi, and Suzuki (1989), for an example). A large flat–panel LCD would allow one large panel to replace the several smaller gauges and dials in most current automobiles. These displays could be made the same size for each manufacturer's models and could be programmed to have different appearances. The displays could also include the displays users want to see.

Since LCD's are non–emissive, they need an external source to light them. The two most common types of back–lighting lamps are the Cold–cathode Fluorescent Lamp (CFL) and the Hot–cathode Fluorescent Lamp (HFL). The HFL provides a higher luminance than the CFL, but has a higher operating temperature and shorter life (i.e., approximately 3,000 h). A newly developed lamp is the Warm–cathode Fluorescent Lamp (WFL). The WFL offers twice the intensity of the CFL and 10,000 h of operation equal to that of the CFL. The WFL also operates at a lower voltage level and can be constructed with a thin film heater to help the liquid crystals operate better at temperatures below 20° C (68° F) (Itoh, 1991).

Head–Up Displays (HUD's)

The HUD can use one of several projection sources to project an image (e.g., mi/h, warning indicators, etc.) onto the windshield. This information appears to be floating in space in front of the vehicle. The HUD allows drivers to keep their eyes forward, without glancing to the dashboard. HUD's have been successfully used in aircraft by giving the pilot a "window" to fly through. An automotive HUD is different from an avionic HUD in that the scenery behind the display is more complex for the driver than for the pilot. A second difference is that automotive HUD's are displayed not at optical infinity, as in an aircraft, but at a closer distance, somewhere between 1.8 and 7.3 m (6 and 24 ft) (Stokes, Wickens, and Kyte, 1991).

HUD's are commonly produced by either reflecting an LCD off of the windshield by means of a half–mirror or direct reflection, or by using a light source to illuminate a holographic element on the windshield. Proponents of both systems claim success with each of these systems, and much research is currently being conducted to create the best optical picture at the lowest cost. For detailed information, see Patterson (1988), and Wood (1988). A high–luminance VFD has also been proposed as an alternate HUD projector because it needs no back–lighting and is resistant to shock and temperature conditions.

Helmet/head–Mounted Displays (HMD's)

HMD's are currently used in military aircraft. The current technology places a HUD on a monocular "tube" that is clipped onto a helmet and placed directly in front of one of the subject's eyes. The advantage of having a HUD on your head is that it moves with you as you pivot your head. The AH–64 Apache helicopter uses a monocular HMD for night flying and targeting. In the near future, HMD's will cover both eyes.

A second type of HMD uses a small CRT display mounted on a helmet that fills the field of view of the pilot. The image can be either computer–generated or manipulated real–time video footage of the outside world. For example, a helicopter pilot could land a craft in rough terrain by "looking" via the floor through a remote camera.

It is probably safe to assume that in the near future, the typical driver will not want to wear either system of HMD in normal driving situations. However, the CVO driver who needs to travel in low–visibility conditions could use a monocular HMD with a night–vision device to navigate to a delivery location. Law enforcement officers could also benefit from night–vision HMD's. Navigation and warning controls could also be put on the display. It is feasible that monocular displays could be put on a hat or some type of glasses so they would be easy to put on and take off.

Navigation Technology

According to French (1988), there are three basic types of navigation systems. Autonomous navigation systems are capable of operating without the need for external sources such as satellites or road beacons. Most autonomous systems use dead reckoning to track the distance and angles traveled. Dead reckoning uses wheel rotations and directions turned to estimate the current position of the car. The Japanese Multi–Advanced Vehicle (AV) system uses a new optical fiber gyroscope to more accurately sense vehicle turns (Oshishi and Suzuki, 1992; Harrell, 1991). Dead–reckoning systems have historically been relatively reliable, but periodically get out of calibration. The result is that the driver is given incorrect information about location and/or route status. Therefore, provisions for out–of–position information and simple location adjustment are necessary. These features use route–map displays.

Radio navigation systems use satellites to keep track of an automobile's position. Each vehicle to be tracked has a unique code that can be "seen" by the satellite and reported to a base station. The most commonly used satellite is the GPS, but there are many companies around the world competing for the market. Most systems that use radio navigation also use dead reckoning to account for areas where signals may be blocked. Currently, the GPS system of satellites is incomplete over the United States. In addition, satellite signals are often blocked by tall structures in major cities. Therefore, it appears likely that many ITS systems will always require backup navigation systems if GPS is used.

Proximity beacon systems use short–range transmitters to send signals to passing cars with receivers. These beacons are also usually combined with dead reckoning and satellite signals. The beacons have a correction factor that updates position from the other methods. A drawback to beacon technology is its cost of construction and maintenance.

Navigation interfaces

The most common method of presenting information to drivers with navigation systems is through video monitors that display a map of the area and the automobile's current position. Some systems also use voice synthesis to convey messages to the driver. Much research needs to be conducted to determine which properties of voice are most salient in the driving situation. The Back–Seat Driver, a Massachusetts Institute of Technology (MIT)–based navigation system, uses only speech to guide drivers (Davis and Schmandt, 1989). Davis also provides a good explanation of some potential problems with speech–based directions.

Synthesized speech is not as intelligible as digitized speech (Marics and Williges, 1989). Intelligibility is particularly important in vehicle environments due to the high noise levels often present. It may be some time before the intelligibility of low–cost synthesized speech systems required for in–vehicle use are of any quality. Unfortunately, for many ITS applications, synthesized speech is desirable because large data bases are sometimes required for communication of certain information (e.g., next street name in a large city) (Dingus and Hulse, 1993).

Motorola has developed a voice recognition system that will be available in automobiles. The system is user–dependent (i.e., a user must "train" the system prior to use) and a new driver cannot effectively use the voice commands. The reliability of this system in the automotive environment is unknown; however, it is apparent that advances in speech recognition technology could make this control technique viable for ITS applications.

Summary

The information presented in this section is the result of a broad literature review. Because technology advances at such a rapid pace, this report is by no means comprehensive. The technologies reviewed are the next advances that will probably occur. Specifically, LCD technology, digital cellular voice and data communications, and speech synthesis and recognition may impact ATIS/CVO system design in the near to middle term.

CONCLUSIONS AND RECOMMENDATIONS

The previous sections discussed products of primary interest for the initial literature review of this project. These products summarize existing guidelines applicable to ATIS/CVO systems, and a preliminary list of human factors research needs for guideline development.

PRELIMINARY GUIDELINE SUMMARY

Attempts were made to procure applicable human factors guidelines from several sources, including:

- Existing ATIS/CVO research published in refereed sources.
- Existing ATIS/CVO technical reports. These sources are kept separate because they have not undergone the scrutiny of a peer review process in all cases.
- Comparable systems.
- Existing human factors guidelines.

Each of these sources appears as a separate section.

In attempting to compile guidelines from these sources, it became apparent that there are literally thousands that apply to ATIS/CVO systems (particularly from existing guidelines). Therefore, the guidelines were prioritized and only the most applicable are discussed. As part of the final guidelines developed for this project, it will be necessary to pay close attention to a number of sources. The guidelines summarized below are provided in a list format by category of applicability.

Guidelines From Published ATIS/CVO Research

Driver attention and workload

Designers should allocate as many tasks as possible to "pre–drive" as opposed to "in transit" in order to minimize required driver attention. "Pre–drive" consists of the complex planning and attention–demanding tasks. "In transit" consists of a relatively small subset of tasks that are necessary for efficient system usage while the vehicle is in motion (Lunenfeld, 1990). Designers should limit in–transit functions to necessary tasks and those of major convenience. Tasks can successfully be completed without substantial driving task interference by properly selecting and designing in–transit functions (Dingus and Hulse, 1993).

Effort must be made to limit the functionality of the in–transit mode to those tasks that:

- Do not significantly interfere with the driving task.
- Have benefits that outweigh the cost (i.e., in terms of required driver resources) of including the function.
- Will be used relatively frequently.

All other functions should be allocated to the pre–drive case or carefully considered (and tested) based on the above criteria (Dingus and Hulse, 1993).

Allocating functions to a "zero speed" category increases in–transit functionality without compromising driving safety (Carpenter, Fleishman, Dingus, Szczublewski, Krage, and Means, 1991). Zero speed means a vehicle is stopped and in drive. Once the vehicle starts to move again, the display and control configurations return to the previous in–transit state.

Selection of ITS interfaces nomenclature and labeling is critical to system usability. Nomenclature and labeling should be subjected to usability testing prior to final design of the system (Dingus, et al., 1991).

Pre–drive functions involve human–computer interaction for the computer illiterate. Three critical aspects generally apply to the automobile:

- The number and complexity of functions should be minimized so that all available functions are "transparent" from a top level or "main" menu.
- Control devices must be carefully considered for use in the automobile.
- The screen size must be carefully considered in conjunction with desired functions.

It is important to assess visual attention in driving since most information is gathered visually by the driver (Rockwell, 1972). Visual attention can change quickly, especially in certain circumstances (e.g., the presence of a curve, traffic, or a change in type of roadway), and can consume 100 percent of a driver's resources. To reduce attention demands on the driver, short display viewing times are necessary for driving at faster speeds and on more complex roads. Research has shown that gender and previous driving experience affect attention demands. Age also affects demands; older drivers spend significantly more time looking at displays than younger drivers (Pauzie, Marin–Lamellet, and Trauchessec, 1991; Dingus, Antin, Hulse, and Wierwille, 1989). Consequently, it is important to design information displays so that only the minimum glance time is required.

The display should be limited to only the necessary information, which, according to Streeter (1985), would only include the next turn, how far away the turn is, which street to turn on, and which direction to turn on a pre–specified route. Streeter found that people who are familiar with an area prefer to be given the cross street of the next turn, whereas people who are unfamiliar with an area prefer to be given distance information. In addition to proximal (i.e., next turn) route–following information, notice of upcoming obstacles or traffic congestion would also be beneficial. Such information could make the task of driving safer, given that it can be displayed without requiring substantial driver resources (Dingus and Hulse, 1993).

Traffic information, such as minimum travel time, route selection, and guidance, should be updated at least every 15 min. Information should be available to users in as many pre–drive options as possible to reduce in–transit workload. Options include telephone (including cellular phone), personal computer, videotext terminals, television, fax, and eventually on–board computer systems.

Voice presentation (particularly in situations of high visual–attention demand) can make driving easier and safer if designed properly (Dingus and Hulse, 1993). Dingus and Hulse (1993) recommended that:

- Auditory modality be used to prompt the driver to look at a visual display for changing or upcoming information (thus lessening the need for the driver to constantly scan the visual display in preparation for an upcoming event).
- The system have some type of simple visual information to supplement the auditory message (so that a message could be checked, or later referred to, via the visual display).

As the quality of auditory messages decreases, the workload to process the messages increases. Although the quality of low–cost synthesized speech is constantly improving, factors such as tonal quality and inflection limit its effectiveness relative to digitized speech (Sanders and McCormick, 1987).

Even though research studies have been conducted to test forms of synthesized speech, the state–of–the–art knowledge is not yet to the point where intelligibility/comprehensibility can be predicted in all situations or environments. However, it is known that a number of factors influence intelligibility, such as speech rate, message length, message content, message complexity, background noise, pitch, and loudness (Van Cott and Kincade, 1972; Marics and Williges, 1988). Therefore, voice loudness, frequency, and spectral content must be carefully considered. Given the noise variation for in–vehicle environments, a voice volume control is essential (Dingus and Hulse, 1993).

In addressing some of the intelligibility concerns discussed above, Labiale (1990) recommended that designers restrict the amount of information presented (i.e., seven to nine bits) in aural messages, or use the aural cue as a prompt to a simple visual guidance presentation. Labiale also recommended that aural messages be repeated to aid in intelligibility and recall, especially if the information is complex.

Messages must be worded carefully so that drivers do not misinterpret them. A study conducted by a Japanese automobile manufacturer indicated that drivers tended to instinctively respond more to verbal information than visual information. Drivers tended to follow the in–vehicle instructions even if they conflicted with traffic regulatory information (e.g., turning the wrong way onto a one–way street) (Noy, 1991).

Route algorithms should display navigation information whenever possible. Without a planned route, drivers must plan trips in transit instead of pre–drive (Antin et al., 1990). Almost invariably, information displays for navigation information systems are (and probably will continue to be) quite small. Therefore, it is important to require that non–route systems provide "zoom–in," "zoom–out," and pan features in conjunction with prioritized streets to avoid unreasonably high screen information densities. This strategy, although necessary to make a display legible, increases driver attention, since pre–drive planning must (due to the difficulty of panning and zooming to plan many routes) be accomplished as an in–transit task (Antin et al., 1990). Dingus et al. (1989) therefore recommended that a provision for route selection be provided as part of navigation and information systems.

Another advantage to providing a route selection algorithm as part of the navigation system feature is that many more options are available for information presentation. If no route is provided, an area map must be displayed to navigate accurately. If a route is provided, the navigation information can be displayed aurally and/or visually, textually or spatially, as well as in a turn–by–turn graphic format or an entire route graphic format.

The issue of whether to use maps, turn–by–turn graphics, or textual direction lists is somewhat task–dependent when presenting visual navigation information. Studies (e.g., Streeter, Vitello, and Wonsiesicz, 1985) indicate that textual lists are easier to use than maps when navigating to unknown destinations. Note, however, that maps provide additional information (e.g., orientation information such as cross streets) that textual lists do not. Therefore, whether a map or list is selected should depend on the desired task and required information. Popp and Farber (1991) found that symbolic presentation of route guidance information was superior to other visual presentation modes, including text and maps. Symbolic presentation had the lowest driver workload rating and best traffic safety behavior. Depending on the requirements of the system under design, the inclusion of both a graphic display format (instead of a map) and textual lists displayed in different situations may provide the most usable overall system (Lunenfeld, 1990).

If a textual direction list format is used, it is critical that in–vehicle information can be received in short glances, so as not to distract the driver from the driving task. The recommended optimal message length for text format is less than eight words. Vague terms should be avoided and nomenclature should be tested (Dingus and Hulse, 1993). Messages should be standardized to enhance familiarity of messages and shorten retrieval time. Systems should be able to give information both in terms of cross streets or landmarks and distances to incidents or destinations.

Less attention is required in a well–designed turn–by–turn visual display than in a full–route format. Little information is required for a graphic turn–by–turn screen, including direction of turn, distance to turn, and turn–street name. This information is easily displayed in a legible, low attention–demanding format. Any additional information may be extraneous and potentially disruptive to the route–following task

(McGranaghan, Mark, and Gould, 1987). Therefore, turn–by–turn graphic displays are recommended over full–route maps in most circumstances.

In selected circumstances, a more complex screen graphic may be required. One such circumstance, is that of close–proximity maneuvers. Many circumstances exist in the driving environment for which two (or more) quick turns are required. In the turn–by–turn format case, the information for the second turn may come up too quickly (and under circumstances where attention is needed for driving) to comfortably execute the second maneuver. Therefore, a graphic depiction of all maneuvers within a certain time envelope should be displayed.

Selecting either a turn–by–turn or route visual display requires careful consideration to ensure that the information is displayed in a usable and safe manner. If a turn–by–turn configuration is used, close proximity and preview must be considered; and if a full–route map is used, it is necessary to minimize the information present so that drivers are not overloaded. Even with the minimization of full–route map information, it is not clear from the literature whether or not drivers will become overloaded in high attention–demanding circumstances (Dingus and Hulse, 1993).

The north vs. heading–up display is another issue inherent in route–map presentation, especially if the speed and accuracy with which the display information can be interpreted by the driver is important (Dingus and Hulse, 1993). With a north–up orientation, the driver must often mentally rotate the map image (e.g., if the heading is southeast) to determine whether to turn right or left. This operation requires additional attention and processing time and results in more errors for the population as a whole.

One advantage to north–up map presentations is that they do not "move." For a heading–up format, the map must constantly rotate to maintain heading up as the vehicle heading changes. This rotation, particularly presented in the visual periphery, can be somewhat distracting, although most drivers seem to be able to ignore it (i.e., at least to some extent) if required to do so by the driving situation (Hulse, 1988).

According to Dingus and Hulse (1993), heading up is a better option than the north–up trade–off. However, they emphasized that both methods have disadvantages and recommended that an appropriately designed verbal direction list or turn–by–turn spatial option is more desirable than a route–map using either presentation rule.

When developing advanced information systems, the problem of "out–of–the–loop" loss of familiarity needs to be considered (Dingus and Hulse, 1993). Presently, the driver is required to obtain most information from the driving environment (i.e., street signs, stop lights, etc.). As more information is presented within the car in a readily accessible manner, the less likely the driver will need to obtain that information from the driving environment. However, any problem, deficiency, or inconsistency that requires the driver to shift attention to the driving environment could result in a delay and increased effort since the driver has become accustomed to having the information provided within the car. Therefore, it is important that all information provided in–vehicle be accurate and reliable. If the accuracy of critical information cannot be reasonably guaranteed, then that information should not be provided.

Information provided to the driver should be timely and sufficient time must be allowed for the driver to respond to it. The driver needs time to hear and/or see the information, decide whether it is relevant, and act upon it. More than an average human response time is required; most drivers (i.e., 95 percent or 99 percent) should have ample time to respond under normal driving conditions. The time required by the driver to process information and respond to it is dependent upon a number of factors, including the task and the type of display format selected. This information is beyond the scope of this paper. A discussion of driver response time requirements can be found in several sources, including the NHTSA Driver Performance Data Book (1986).

Visual display considerations

A delineation of appropriate display parameter options (e.g., resolution, luminance, contrast, color, glare protection) is a complex topic that will be somewhat task and situation specific. There are a number of legibility standards that exist for visual displays, including those developed for aircraft applications (Boff and Lincoln, 1988). Since automobiles and aircraft have many of the same difficulties, (e.g., glare), these standards are applicable. However, note that the selection of a display in the automotive domain will be more constrained by cost and have limitations well below the state of the art.

In any event, display parameters have a minimum acceptable level and anything below that level is unusable. It is therefore critical to ensure that these minimum standards have been met in spite of the constraints for a given application. In addition, the problem of selecting automobile display parameters is more difficult, since viewing distance is limited due to instrument panel configuration constraints.

The user population also has difficulties in determining display parameters. Older drivers with poorer visual acuity and/or bifocal lenses must be carefully considered when specifying display parameters. To overcome this combination of limitations, the display parameters must be optimized within practical control. For example, Carpenter et al. (1991) used a "special high–legibility font" in a color CRT application to ensure that drivers could glance at the display and grasp the required information as quickly as possible. Other design aspects that aid in legibility include presenting text information in an upright orientation (even in map applications), maximizing luminance and/or color contrast under all circumstances, avoiding selected color combinations (Boff and Lincoln, 1988), using color–coding of information sparingly (since too many colors create more information density and increase search time), maximizing line widths to increase luminance (particularly on map displays), and minimizing the amount of displayed information to reduce search time (Dingus and Hulse, 1993).

Color deficiency and color blindness is another basic visual display concern. Approximately 8 percent of the male population has some degree of color deficiency or color blindness. Therefore, it is important not to color–code critical information in consumer product applications (including navigation systems).

Although instrument panel color has been shown to have no significant effect on reading and driving performance (Imbeau et al., 1989), Brockman (1991) found that color on a computer display screen can be distracting if used improperly. To avoid confusion, Brockman recommended several guidelines when color–coding information. The first guideline was to be consistent in the use of color codes. Designers should avoid using colors from extreme ends of the color spectrum (i.e., red and blue) next to each other since it is difficult for the reader's eye to perceive a straight line. Second, familiar color coding (e.g., red for hot) should be used. Third, color alone should not be relied upon to discriminate between items. Brockman recommended designing applications first in black and white, then adding color to provide additional information.

Display location

The placement of an information display is critical. The information contained on even a well–designed display system requires a large amount of visual attention. Therefore, if the display is placed far from the normal driving forward field of view, none of the driver's peripheral vision can be used to detect unexpected movement in front of the vehicle. Another disadvantage of placing a display far away from the forward field of view is increased switching time. The farther the display is away from the roadway, the longer the switching takes, and the less time that can be devoted to the roadway or the display (Weintraub, Haines, and Randle, 1985). Green and Williams (1992) found that navigation displays were recognized at a faster rate when using a HUD over a dash–mounted display. Tarriere, Hartmann, Sfez, Chaput, and Petit–Poilvert (1988) reviewed some ergonomic principles of designing the in–vehicle environment and suggested that the screen be mounted at least 15 degrees below horizontal, but should not exceed 30 degrees, for optimal driver comfort.

A HUD that provides information on the windshield is a good choice since it is in the forward field of view. HUD's are also advantageous because they focus at (or near) infinity, thus eliminating (or reducing) the time required for the driver's eyes to adjust between the display and the roadway. However, a number of concerns have been raised by Dingus and Hulse (1993) about the use of HUD's:

- The luminance may be a severely limiting factor in the automobile due to the presence of glare and stringent cost constraints. Certainly, a HUD that is too dim and hard to read could be much worse than an in–dash display.
- Issues regarding display information density and distraction must also be carefully addressed for HUD's, and could result in their own set of problems.
- An issue exists regarding the division of cognitive attention with HUD's. Just because a driver is looking forward does not mean that roadway/traffic information is being processed. The importance of this division of attention to driving task performance has yet to be determined.

Therefore, the design of a HUD must be carefully developed and tested.

Manual control guidelines

A system that requires too many of a driver's resources may not leave enough resources to allow the driver to drive safely in all circumstances. This means that both navigation displays and navigation system controls need to be designed to minimize driver attention and processing of resource requirements.

One way to minimize control requirements while in transit is to severely limit control access. Therefore, it is important to assess the necessity of every control in terms of both in–transit requirements and frequency of in–transit use to minimize driver control access. Those controls that are not absolutely necessary for the in–transit environment can then be allocated to pre–drive or zero–speed circumstances.

Several other specific control issues are also present with respect to ATIS applications. First, control location is important since the farther away a control is located from the driver, the greater the number of resources needed to activate the control. This has been demonstrated by Bhise, Forbes, and Farber (1986) and Mourant, Herman, and Moussa–Hamouda (1980) who found that the probability of looking at a control increased with increased distance. Therefore, controls present on the steering wheel, or otherwise in close proximity to the driver, are easier to use.

Complexity is a second important control factor to consider. Research (Monty, 1984) has shown that continuous controls or controls requiring multiple activations are significantly more difficult to operate. Therefore, limiting controls to single, discrete activations will provide fewer resource requirements.

A third control factor is the trade–off between "hard" and "soft" push buttons. With the use of CRT's and flat–panel displays, there has been a strong temptation to use touchscreen overlays for control activation. While this can be a good control method in the automobile for pre–drive or zero–speed cases, this is not the case for in–transit circumstances. Monty (1984) found that the use of touchscreen keys while driving required greater visual glance time and resulted in greater driving and system task errors than conventional "hard" buttons. The reasons for this performance problem are twofold:

- The controls are non–dedicated (i.e., they change depending on the screen).
- Soft keys do not provide tactual feedback.

For a "hard" button, the driver must (depending on the control and its proximity) glance briefly at the control and then find the control using tactile information to accomplish location "fine–tuning." For the soft keys, the driver must glance once to determine the location and glance again to perform the location "fine–tuning." Therefore, while soft keys are often convenient, they require greater driver resources and are not recommended for navigation information system in–transit application.

Providing information to convince drivers to avoid congested routes

Several papers (e.g., Allen et al., 1991b, 1991c) suggested guidelines to help improve route selection and route diversion. Advisory systems should provide anticipated traffic congestion information. Current conditions can be viewed as unstable and subject to rapid change. Advisory systems should target information that allows commuters to change their departure time and route choice. This information should be accurate and visually confirmed by the use of road signs or on–board congestion monitors. Information should give projected commute times of both alternative and present route choices.

Design guidelines to accommodate age and alcohol effects

ATIS design should include alcohol–impaired drivers and drivers from all age groups. Both alcohol–impaired and older drivers need advanced roadway hazard warning systems due to their slower reaction times. These drivers would also benefit from advanced signing of upcoming exits. Information systems should use icons to improve user visibility and increase character size of textual labels to improve performance problems experienced by elderly drivers. Older drivers have shown that they respond better visually to the use of yellows, oranges, yellow–greens, and whites on contrasting backgrounds. Moving pointers are also preferred over digital or number displays.

Guidelines From ATIS/CVO–Related Technical Reports

The following statements have been taken from various technical reports. Those guidelines applicable to an ATIS/CVO guideline document are presented in an outline (list) format. The title and author of the technical report that the information was taken from are cited with an underlined heading.

Human Factors Issues Surrounding the Implementation of In–Vehicle Navigation and Information Systems.

Moffit, Roger, and Cincinelli (1986) stated that color CRT use is accompanied by problems of visibility and discriminability in daylight.

Zwahlen and DeBald (1986) studied the use of cellular phones. They found that dialing long numbers resulted in unacceptable lane deviations.

Improving Motorist Information Systems: Toward a User–Based Motorist Information System for the Puget Sound Area (Haselkorn and Barfield, 1990).

Haselkorn and Barfield made the following recommendations for the categories specified:

Pre–Trip Information. Place a high priority on home delivery of motorist information, particularly information that will impact departure time.

Target home–delivered motorist information for specific types of commuters, based on the driving decision to be impacted.

Reliability of Motorist Information. Include a feedback mechanism in any motorist information system to assess information reliability.

On–Road Information. Place a high priority on improving on–road information delivery mechanisms.

When designing and delivering on–road motorist information, target those commuters who tend to change routes while driving.

Through the use of integrated information systems, coordinate home and on–road messages based on delivery location and motorists' needs for feedback and reinforcement.

Improve on–road message content. Balance the trade–offs between generality and specificity of the message, and between reason and task information.

Keep on–road messages relevant to particular driver decisions, or to feedback and reinforcement of those decisions.

Incorporate the timeliness messages into on–road motorist information.

Integrate on–road delivery mechanisms more closely with real–time gathering of traffic data.

Design rules for CRT displays in vehicles (combined from two reports: Zwahlen et al., 1987; Streeter and Vitello, 1986).

A maximum of two consecutive looks should be required to operate a CRT touch–panel control system.

Two to four seconds (although shorter ranges are best) is the acceptable time range for interrupting the driver's scanning of the road to operate a CRT panel.

HUD's are an alternate display method to be consider since information is displayed directly in the field of view on the windshield.

The placement of the navigational instrument display should maximize the driver's use of near–peripheral vision, so other driving tasks are possible while attending to the instrument.

Navigation information should be presented vocally even though computer–generated graphics are also effective.

Crucial design issues in audio message systems (Michaelis, 1990).

Vocabulary. Drivers should not be alienated by the use of unfamiliar words.

Intonation and Inflections. Synthesized speech needs to be tailored to be intelligible. Strategically placing pauses between words can simulate inflection.

Cues. The speaker should sound sincere, helpful, and friendly, not condescending or threatening.

Training. Drivers should be exposed to synthesized speech prior to using a system in order to get accustomed to it.

Highway advisory radio message guidelines (Dudek and Huchingson, 1986).

A terse message style is better than a verbose style when route information is delivered.

The chunking capacity of the short–term memory for navigational directions is seven words. Drivers have the capacity to remember a maximum of four turns and four street names.

Repetition of auditory route instructions improves recall. Repetition can be achieved by external or internal means.

Using the number of traffic lights as landmarks between turns should be done carefully and should be avoided when flashing lights are present.

The level of detail for a route change should be tailored to the user. Less detail is required for those familiar with the route.

The instruction "you have come too far" is helpful for those that mistakenly change course, yet Streeter et al. (1985) indicated otherwise.

Effects of Variations in Driving Task Attentional Demand on In–car Navigation System Usage (Wierwille, Hulse, Fischer, and Dingus, 1988).

The visual display should be high on the dash, with a minimum viewing angle from a straight ahead position to allow peripheral vision. This peripheral vision would be used for driving while attending to the navigator.

Future In–car Information Systems: Input from Focus Groups (Green and Brand, 1992).

Drivers learned by reading manuals, listening to cassettes, and playing with the systems. Cassette tapes were well–liked, while manuals were noted to have shortcomings.

Drivers wanted advance, early information on failing vehicle systems.

Drivers complained about the operability of entertainment systems. Reach distance, too many controls, and controls that were too small were cited. Illegible labels were also a problem.

Drivers wanted directions for local trips and maps for long trips.

People preferred "left/right" turning directions rather than "north/south" directions.

For long trips, people wanted to know which direction they were heading.

For turns, landmarks were desired in addition to heading direction.

Laboratory Assessment of Driver Route Diversion in Response to In–vehicle Navigation and Motorist Information Systems (Allen, Ziedman, Rosenthal, Torres, and Halati, 1991).

More information about upcoming traffic conditions led to greater compliance to taking alternate routes.

Older drivers were less likely to change route regardless of congestion. Perhaps this was because older drivers were recruited from a retirement home and may have been less confident in their independent abilities as compared to older drivers who live in their own homes.

Human factors design of the TravTek driver interface (Fleishman, et al., 1991).

Limiting of ATIS functions while driving. Given the visual attention demands of driving, researchers permitted only traffic update information and navigational information to be displayed while the vehicle was in gear. These displays were categorized as "drive" functions. When the vehicle's transmission was placed in park, the other features were made available. These features were called the "pre–drive" functions. In addition, only the hard keys on the steering column were engaged during driving. The touchscreen soft keys on the CRT were only operable while the vehicle was in park or at zero speed, at which point touchscreen keys to control the map displays were engaged.

Steering wheel buttons. Buttons mounted on the steering wheel should be used for simple and important "drive" functions.

Map choices. An overview (route) map should be available to drivers to recover from navigation errors. The system allows switching between route and guidance maps from a steering wheel button.

Updating CRT display. An auditory signal should be used to indicate updated visual information in order to reduce operator's vigilance requirements for CRT display monitoring.

Design of the TravTek Auditory Interface (Means, Carpenter, Fleishman, Dingus, Krage, and Szczublewski, 1992).

Minimize "chattering" by avoiding unnecessarily long voice messages.

Minimize "nagging" by limiting voice to high–priority information and make its role a supplement to the visual interface.

Maximize voice intelligibility by:

- Using a distinctly non–human, pseudo–male voice.
- Careful correction and smoothing of synthesized words (vs. digital recordings).

Make information timely and useful if conveyed by voice.

Allow the user to control voice functions, such as volume and repeat message, and to choose the types of messages to be enunciated.

Avoid auditory "clutter." Use the voice for the most important messages. Do not use voice for positive feedback since status quo assumes all is well.

How Important is Mobile Communication for a Truck Company? (Huiberts, 1989).

Truck companies prefer visual data over voice as a mode of communication.

There needs to be a way to signal drivers while they are out of the truck (e.g., during loading).

Due to language differences, a printer is desirable for the driver to refer to.

Guidelines From Comparable Systems

Using guidelines that originate from a comparable system could pose problems. The guidelines for any system reflect the user's information needs, sensory and mental capabilities, and physical characteristics. Only those guideline characteristics that are the same may be applied to ATIS/CVO applications.

Comparable systems guidelines may, in many cases, simply provide a basis from which to research and develop a set of guidelines that are unique to ATIS/CVO systems. Some of the guidelines that provide insight into design of these systems are summarized below:

- For navigation tasks that require a track–up alignment (e.g., localization), an ERF is best; and for tasks that require a north–up alignment (e.g., reconnaissance), a WRF is best (Williams and Wickens, 1991; Aretz, 1991). Williams and Wickens (1991) stated that a north–up alignment provides a stable alignment and could be used in situations where precise control is not critical.
- A visual momentum display can capture the benefits of a north–up alignment in tasks that require an ERF (Aretz, 1991).
- In many cases, a perspective display is preferred over a plan view display. In general, "natural" displays provide improvements in decision time and crash avoidance performance (Ellis et al., 1987).
- Pilots reported being concerned about losing their flying skills when using automated technology (e.g., automated cockpits). Older people were less concerned with this loss than younger people (McClumpha et al., 1991).
- Giving pilots the ability to tailor their individual systems to their personal preferences pays high dividends in pilot acceptance, trust, and human/electronic teamwork (Judge et al., 1991).
- Pilots react to and handle emergency situations much quicker when the complete emergency title (versus an abbreviated title) and checklist are provided (Reising and Hartsock, 1989).
- Researchers found that filling warning symbols, simplifying shapes, and enhancing critical features decreases search time (Blackwell and Cuomo, 1991).
- When a 10.3–m/s (20–knot) ground speed was displayed for the lead aircraft in formation flying, it was discovered that too much guessing occurred. A ground speed of 5.1 m/s (10 knots) appeared to supply all of the information necessary for satisfactory performance. However, pilots reported that they were more confident in the lead aircraft when the lead aircraft's speed was displayed in smaller increments (Kelly, 1983).
- Pictorial displays with an omni–directional auditory cue were preferred over speech displays in an aircraft application (Robinson and Eberts, 1987).
- A ship collision avoidance system that facilitates threat assessment and provides some indication of avoidance maneuvers (i.e., does not prevent maneuvers) was effective in making the maneuvers more predictable (CAORF Research Staff, 1978).
- Though the AVM benefits in support of multiple–fleet management cannot be determined with certainty, the broad signpost and triangulation methods seem to offer the best benefit/cost ratio (Ferlis and Aaron, 1977).
- AVI systems technology should be implemented now, even in the present–generation simple systems. AVI technology will develop best through evolutionary, rather than revolutionary, developments. That is, AVI designers will gain experience by installing and operating actual systems, and better understand needed developments (Koelle, 1991).
- A rotating pointer format for the display of altitude and airspeed information should be incorporated into a standard set of HUD symbols (Ercoline and Gillingham, 1990).
- Novel formats, such as trend bars, should also be considered for future standard HUD symbols (Ercoline and Gillingham, 1990).
- Image intensification offers the best and most cost–effective solution to the needs of armored fighting vehicle drivers during poor visibility conditions (Hudson, 1986).

Guidelines From Human Factors Guideline Documents

When developing new systems, experimental testing of every design aspect is expensive, time–consuming, and unnecessary. Rather than testing every feature separately, engineers rely on guidelines, principles, and "rules of thumb" to aid in their design decisions.

Existing applicable human factors guidelines for developing ATIS/CVO systems will be discussed in detail in the following paragraphs.

This section will not cover those areas where human factors guidelines, such as information processing, are not given or are vague. Although information processing contributes a useful model of human cognition, research does not contain many "cut–and–dried" facts that are useful for ATIS/CVO designers.

Anthropometry

Anthropometry is defined by Kantowitz and Sorkin (1983) as "the application of scientific physical measurement methods to the human body in order to optimize the interface between humans and machines and other manufactured products." People come in a wide variety of sizes and shapes. Therefore, designers must try to accommodate the widest range of human physical dimensions possible in their designs. By doing so, they will maximize the number of people who can use the equipment.

There are three strategies given by Kantowitz and Sorkin (1983) for using anthropometric data in design:

- Design for the average individual. This technique should be used when no adjustments can be made to the system. An example of this is the standard 0.91–m (3–ft) high kitchen counter top.
- Design for extreme individuals. This technique should be used when either an upper or lower anthropometric limit must be specified. An example of this strategy is designing the height of a door.
- Design for a specified range of individuals by providing adjustments. This technique should be used whenever economically feasible. The most common adjustable equipment is designed to fit between the 5th and 95th percentile of people. An example of this adjustability is the height adjustment on an office chair.

When designing an ATIS system, anthropometric data can be helpful in providing guidelines for three important considerations.

First, manual controls should be located so that all drivers can easily reach them. One anthropometric measurement, the *arm reach envelope*, provides information on how far people can reach with their hands in an entire range of vertical and horizontal directions. Specific parameters for this type of measurement can be found in NASA's *Man–Systems Integration Standards* (1989).

Second, visual displays should be placed so that they are easily readable for all drivers. In NHTSA's *Driver Performance Data Book* (1986), studies of drivers' eye positions were measured in relation to the car–body inch lines. The distribution of eye positions for the 2,300 subjects sampled was represented as a series of concentric ellipses that can be used to determine what drivers can and cannot see from their eye positions.

Fortunately, seating is adjustable to some extent for most automobiles and commercial vehicles. This feature might eliminate the need for adjusting the position of some ATIS controls and displays.

Third, controls should not be placed so that they are inadvertently activated by the driver's natural body position. For example, a driver's right knee might lean against the dashboard and disturb controls. Also, visual displays should not be located where they will be blocked by the user's body.

Human–Computer Interaction (HCI)

In many respects, an ATIS/CVO system is similar to a typical desktop computer. Designers of the HCI interface for an ATIS system need to design an interface for a heterogeneous population with varying skills, experience, and appreciation for computers.

The following is a general list of HCI guidelines by Williges, Williges, and Elkerton (1987).

Compatibility. Language used in a software interface should have clear and unambiguous meanings to users. It is important that the meaning of the language be compatible with user population stereotypes, given the diversity of language use and the imprecision of language application by humans.

Controls and displays should also be highly compatible. An example of stimulus–response compatibility is a HUD signaling a driver to turn right using an arrow located on the right side of the display, as well as pointing to the right. Research has also shown that auditory input and speech responses are more compatible with verbal tasks, and that visual input and manual responses are more compatible with spatial tasks. This suggests that speech controls might be beneficial in an ATIS/CVO system when they become economically and technologically feasible. The research also shows that visual displays are more compatible with manual responses. However, this research must also be reconciled with studies showing that a driver's visual capacity is already taxed by the driving task, and that further demands on the visual channel could have safety risks.

Consistency. User input and system output should be consistent between screens and software modules. For example, the help button on a touchscreen display should be in the same position, regardless of the current functions of the screen.

Memory. In the design of human–computer dialogues (i.e., question and answer, menu selection), it is important to minimize the amount of information users must store in short–term memory, especially if other information processing is simultaneously required. The maximum number of items a person can remember is between five and nine. However, this number also depends on the complexity of the items, the sequence of presentation, the length of time they must be remembered, and the amount of competing information to be processed. Since using an ATIS system will often be a secondary task (driving being the primary task), there will often be a significant amount of competing information to be processed. Therefore, the demands on memory should be minimized.

Structure. Providing structure to the system's functions will help a user form an internal representation of the system. For example, by describing a word processor as analogous to a typewriter, users are able to use their existing knowledge of a typewriter in order to help them understand the functions of a word processor. Moreover, by providing users with the system structure (e.g., a hierarchical tree of software functions and modules), the user will be able to perform better in unfamiliar sections of the software. In ATIS/CVO systems, giving users a tutorial hierarchical overview might help them acquire knowledge.

Feedback. Whenever users make a system input, such as requesting traffic information, the system should give a response or feedback to users to acknowledge receipt of this input. If the system cannot give the information back in a timely manner, it should advise users when the output will be given. By doing this, users realize that the input has been received, and they understand that the delay in the system response is not an error on their part. A system should also supply feedback if the input made was an error (e.g., a distinctive "beep" if users try to select a more detailed route map when none exists). It should also inform users why the input was an error and suggest alternative choices.

Workload. Because users' performances suffer if the mental workload of a system is too high, every effort should be made to minimize the complexity of the ATIS/CVO system, especially the density of the information displayed, in order to reduce workload. Furthermore, extra information should be removed if not needed. These recommendations suggests that users should have control over the rate of information displayed, especially if it is auditory information, since it cannot be scanned or ignored.

For a more extensive list of HCI guidelines, designers should consider Smith and Mosier's *Guidelines for Designing User Interface Software* (1986). This report gives 944 HCI guidelines, many with examples, comments, conditions of applicability, and cross–references to other guidelines. As stated by the authors, the goals of these guidelines are to provide consistency, minimize user input, minimize user memory requirements, maximize compatibility, and maximize user flexibility with the computer. These guidelines are broken down into six categories summarized below. Note that several of the categories apply to ATIS/CVO systems.

Data entry. Data entry refers to user actions involving computer input and computer responses to this input. Most of these guidelines are not applicable to ATIS systems due to the limited nature of data input necessary for ATIS use. An example of a guideline from this section is entitled "Storing Frequently Used Text: Allow users to label and store frequently used text segments, and later to recall stored segments identified by their assigned labels." This guideline might, for example, prompt designers to allow all destinations that an operator has previously keyed in (e.g., "454 Main Street") to be accessed by a menu number, instead of having the operator retype the entire destination.

Data display. Data display refers to computer output to a user and assimilation of information from such outputs. This category includes guidelines on map displays–a valuable resource when developing a navigational (IRANS) system. However, many of the listed guidelines were derived from full–size CRT screens and are not applicable to the smaller screens found in vehicles. An example of a guideline from this section is entitled "Aiding Distance Judgments: When a user must judge distances accurately on a map or other graphic display, provide computer aids for that judgment." Using this guideline, designers might put mileage scales on ATIS maps.

Sequence control. Sequence control refers to user actions and computer logic that initiate, interrupt, or terminate transactions. An example of a guideline from this section is entitled "Logical Ordering of Menu Options: List displayed menu options in a logical order; if no logical structure is apparent, then display the options in order of their expected frequency of use." Such a guideline might prompt designers to place an "emergency roadside service" option after other more frequently used options, such as "display restaurants/motels."

User guidance. User guidance refers to error messages, alarms, prompts, and labels, as well as more formal instructional material provided to help users interact with the computer. An example of a guideline from this section is entitled "Task–Oriented Help: Tailor the response to a help request to the task contents and current transaction." This guideline might prompt designers to offer specific destination information in a navigational task, if requested during the task.

Data transmission. Transmission refers to computer–mediated communications among system users, and also with other systems. This category is applicable to vehicle–to–infrastructure and infrastructure–to–vehicle communications. An example from this category is entitled "Automatic Feedback: Provide automatic feedback for data transmission confirming that messages have been sent or indicating transmission failures, as necessary, to permit effective user participation in message handling." Designers might use this guideline to provide feedback on whether an emergency roadside assistance message has been sent, or if there is a problem with transmitting the message.

Data protection. Protection is necessary for security from unauthorized use, potential loss from equipment failure, and user errors. Guidelines for this subcategory may be more applicable to CVO systems where sensitive business information might require more data protection than an individual's travel itinerary. An example of a data protection guideline is entitled "User Confirmation of Destructive Actions: Require users to take an explicit extra action to CONFIRM a potentially destructive control entry before it is accepted by the computer for execution." The designer of an ATIS system might use this guideline to require users to confirm that they want to delete a destination entry in a navigational task.

Another resource for HCI guidelines is the Military Standard (Mil–Std) 1472D (1989, pp. 247–278), which provides 30 pages of guidelines, although it does not give any conditions of applicability or cross–references. Mil–Std 1472D covers only the critical and general guidelines. An example of a guideline from this report is shown below:

"Page numbering: Each page of a multiple–page display shall be labeled to identify the currently displayed page and the total number of pages, e.g., page 2 of 5."

ATIS designers could use this guideline for numbering pages of on–line help text.

Another article that deals exclusively with linguistic guidelines for HCI is an article by Harris (1990), which provides a list of 10 guidelines for proper use of the English language in a computer interface. Many of these guidelines are similar to those mentioned previously. However, the article is informative.

General display issues

The most common types of ATIS displays use the visual and auditory modalities to display information. The sections below look at each of these two modalities separately, as well as compare and contrast their benefits in an ATIS/CVO system. Finally, tactile displays are briefly discussed.

Visual vs. Auditory Displays. To decide whether information should be displayed visually or aurally, a designer must consider the user, the system, and the environment. Sorkin (1987) presented a list of conditions and considerations to aid in this decision:

Use auditory presentation if:

- The message is simple.
- The message is short.
- The message will not be referred to later.
- The message deals with events in time.
- The message calls for immediate action.
- The visual system of the person is overburdened.
- The receiving location is too bright, or dark adaptation integrity is necessary.
- The person's job requires him/her to move about continually.

Use visual presentation if:

- The message is complex.
- The message is long.
- The message will be referred to later.
- The message deals with location in space.
- The message does not call for immediate action.
- The auditory system of the person is overburdened.
- The receiving location is too noisy.
- The person's job allows him/her to remain in one position.

Sorkin also pointed out that the omni–directional nature of auditory displays makes them suitable for alerting and warning messages, such as for IVSAWS applications.

There is significant evidence to support the use of auditory displays in vehicles in addition to or instead of visual displays. First, many authors have found that giving turn–by–turn directions on the auditory channel leads to quicker travel times, fewer wrong turns, lower workload, and more attention given to the primary task of driving than does route information displayed on a visual map (Labiale, 1990; Parkes, Ashby, and Fairclough, 1991; Streeter, Vitello, and Wonsiewicz, 1985; McKnight and McKnight, 1992). Second, there is evidence to support the notion that driving performance suffers when drivers are simultaneously looking at in–vehicle displays. Drivers tend not to react to situations on the road (McKnight and McKnight, 1992), and they deviate from their course (Zwahlen and DeBald, 1986).

On the other hand, there is also support for use of visual displays in navigational tasks. Aretz (1991) stated that if drivers are not presented with some sort of north–up map, they cannot construct an internal cognitive map of their route. This means that drivers might arrive at a destination with no navigational problems, but not have any idea where their destination is located in relation to their route origins or other landmarks.

According to Williges, Williges, and Elkerton (1987), another problem is that for a spatial task such as navigating, performance is optimal when using visual stimuli and manual responses. If the task is verbal, an auditory stimulus should be coupled with a verbal response from the person. These results suggest that for a navigational task, a visually displayed "arrow" indicating travel direction would be more beneficial than encoding the information verbally, as in an auditory speech display.

Visual displays

The guidelines presented here were constructed with several goals in mind. First, users should be able to identify visual stimuli. Second, they should be able to discriminate among visual stimuli. Third, the visual stimuli should not be contaminated with other "noise" in the environment.

The guideline's scope primarily includes the physical nature of the stimuli, rather than the cognitive aspects. For cognitive considerations, see the section on "Human–Computer Interaction." Furthermore, many guidelines concerning mechanical gauges and other mechanical displays are not included here because ATIS systems have to display many different types of data. As a result, it is not practical to use dashboard space for fixed–function mechanical displays.

The following visual display guidelines are given by Helander (1987).

General

Distance Between Displays – The larger the distance between displays, the slower the reaction time, and the more errors a user will make. Therefore, in–vehicle displays should be located close to the front windshield for optimal driving and ATIS performance.

Grouping Display Information – Display information that should be considered simultaneously by a driver should be presented in accordance with the Gestalt principles of proximity, similarity, continuity, and closure. For example, in an ATIS navigation screen, the Gestalt principles of proximity would suggest that origin information and destination information should be physically separated on a screen by at least one or two blank lines in order to avoid confusion over whether information should be categorized as origin or destination.

CRT Displays

Contrast Ratio – This is the ratio of the object luminance over the background luminance. A high contrast ratio will result in better perception. One of the more accurate and popular measures of this is the Modular Transfer Function Area (MTFA). For a high–contrast display, an MTFA value of 10 or greater is recommended. For more information on this measure and its calculation, see Snyder (1985).

Character Resolution – For high screen resolution, a dot matrix of 5x7 pixels is required, but 7x11 and 9x11 matrices are preferred. In addition, because square pixel dots take up more space, they are a better choice than round dots.

Font – Character legibility depends on font. Basically, the closer the font approximates regular stroke characters, the higher the legibility. For 5x7 pixel matrix characters, the Huddleston font is the best, and for 7x9 and 9x11 matrix sizes, the Huddleston and Lincoln/Mitre fonts are equally good. Woodson (1981) recommended that fonts that avoid character confusion be selected. For example, the letters C and G can be confused if the horizontal stroke in the G is too short.

Font Size – Researchers recommend a size of 14 to 22 minutes of arc, with 18 minutes being an optimum size for reading. For visual search tasks, such as looking for a street name on a map, 22 or 24 minutes is recommended. Note that measurements are given in terms of the observer's visual angle, since this corresponds to the retinal image and eliminates the need to give both object size and distance from object measurements.

Screen Reflections – There are many sources of screen reflections in a vehicle, including the sun, headlights from another vehicle, and reflections from another vehicle. In order to reduce screen reflections, a tiltable screen or screen filters should be used. Another technique is to display the characters in reverse video–dark characters on a white background. However, reverse video may cause problems with screen flicker, since the illuminated area is so large. For a detailed list of measures to reduce screen reflection and their advantages and disadvantages, see page 529 of Helander's study (1987).

Color

Discriminating Among Colors – Observers should be able to discriminate among colors on a CRT. Formulas to determine discrimination performance are based on color saturation, color hue, and the contrast ratios of different colors. These formulas can be found on pages 538–539 of Helander's report (1987).

Coding – No more than five colors should be used on a display for high–accuracy identification. Colors should be used to convey information–not for aesthetic value. In an ATIS map display, categories of roads, such as highways or secondary roads, should consistently be given a specific color.

Uses of Color – Color is useful if operators must search for information. For example, in a display of upcoming restaurants along a particular route, those restaurants with take–out service could be shown in a particular color.

Conventional Meanings of Color – Research suggests that red, yellow, and green be reserved for "danger," "caution," and "safe," respectively. IVSAWS warnings could be coded in this manner for dangerous environmental conditions, such as ice or snow, and for heavy traffic caused by accidents.

Colors in Text – In alphanumeric displays, red and yellow colors against a black background are the most legible, while blue and green are the least legible.

Color and Object Size – Smaller objects lead to poorer color recognition than larger objects. Therefore, color–coding is more effective for entire words than for individual characters or small symbols.

Alerting Signals

The following alerting signal guidelines are from the report by Boff and Lincoln (1988).

Dual–Modality Alert – Present high–priority alerting signals both visually and aurally. Maximize the probability of detection of each mode of the warning signal.

Location of Alert – Place visual alerting signals as close to the operator's line of sight as possible. The maximum deviation of 15 degrees should be allowed for high–priority alerts and 30 degrees for low–priority alerts.

Size of Alert – Visual alerting signals should subtend at least 1 degree of visual angle.

Contrast Ratio – Visual signals should be at least twice as bright as the other displays.

Flashing – Visual alerting signals should be flashing against a steady–state background.

False Signals – False signals should be minimized, and a method of canceling the signal should be provided.

Note that the source of alerting signal information is originally from an aircraft study, and should be approached with caution. For example, slight deviations from an aircraft's direction of travel is rarely hazardous, unlike ground–based transportation. Therefore, an alert that startles operators so they temporarily go off course for a minute is an acceptable risk in an airplane, but not in a car. For a more in–depth look at visual display image quality and visual information portrayal, designers should consult pages 2216–2310 of the report by Boff and Lincoln (1988).

Auditory displays

As mentioned earlier, there are many advantages to using auditory displays rather than visual displays. However, there are also more potential problems with noise interfering with the auditory channel than with the visual channel. Typically, designers only have to worry about the "noise" of screen reflections for visual displays. Unfortunately, just as auditory signals are omni–directional, noises and competing signals in the system or in the environment are also omni–directional.

Designers of an ATIS/CVO system must be particularly aware of the sounds in an automobile or a commercial vehicle. Road noise, noise from one's own vehicle, noise from other vehicles, competing speech communication from passengers in the vehicle, competing signals from the vehicle's entertainment system (e.g., radio, compact disc (CD) player), and other communications equipment (e.g., cellular radio, CB radio) must be taken into account when designing in–vehicle auditory displays.

The following guidelines are given by Sorkin (1987).

General

Signal Levels – Signal levels of 15 to 16 dB above masking threshold are sufficient for situations requiring a rapid response to a signal (e.g., a warning signal). (Note: masking threshold is defined as the sound level required for 75 percent correct detection of a signal when presented to the observer in a two–interval task. In a two–interval task, the observer reports which of two defined observation intervals randomly contains the signal. Both contain noise.)

Maximum Signal Levels – The level of an auditory signal should be less than 30 dB above masking threshold in order to minimize operator annoyance and disruption of communication.

Alarm Signals

Minimum Duration – The minimum duration signal burst should be at least 100 ms to ensure reliable detection, but not much longer, since other communication could be disrupted.

Pitch – The pitch of warning sounds should be between 150 and 1000 Hz.

Signal Spectra – Signals with harmonically regular frequency components should be used instead of inharmonic components. For lower priority warning signals, most of their energy should be in the first five harmonics. For high–priority signals, more of the signal's energy should be in harmonics 6 through 10. These high–priority signals can also be made distinctive by incorporating a small number of inharmonic components.

Onset and Offset Rates – Since fast onset rates for the pulse shape of a warning tone may produce a potentially dangerous startle response from the operator, the onset and offset rates should be limited to 1 dB/ms.

For an in–depth look at auditory signal characteristics and perceived urgency, see the Edworthy, Loxley, and Dennis (1991) report.

A major problem with using only simple auditory signals is that operators must be able to not only distinguish between signals, but properly associate the particular signal with its meaning. Technology has permitted the development of artificially produced speech displays that are capable of communicating with an operator in his/her own language. Such displays allow for a much higher rate of information transmission than do simple auditory warnings.

Sorkin and Kantowitz (1987) discussed two general factors that determine the quality of speech. First is articulation, which is measured by how well individual syllables and phonemes are recognized. This is determined by how distinct the speech is from the noise. The second is its intelligibility–the comprehensibility of the words, sentences, or the total message. Intelligibility is determined by the size of the message set and the relative probability of a message being chosen from the set. More specifically, the larger the message set, the poorer the comprehension. Also, intelligibility is poorest when all messages have an equal probability of being presented.

It is important to note that understanding speech is not just a bottom–up process, but a top–down process as well. Measurement of speech articulation–sonic characteristics–is insufficient to determine how well a person will understand it. Comprehension is measured by intelligibility, where peoples' expectations (i.e., probability of a message being presented), as well as other cognitive factors, determine their understanding.

The following speech display guidelines are presented and referenced according to their source.

Speech Characteristics

Signal–to–Noise Ratio – Speech intelligibility increases as the signal (speech)–power–to–noise–power increases (Boff and Lincoln, 1988).

Voice Type – Select a voice type according to the source of the speech messages. For machine messages to the operator, use machine–sounding voice quality; when simulating human speech, use human–sounding voice quality (Simpson, McCauley, Ronald, Ruth, and Williges, 1987). Bertone (1982) recommended using only a female voice, based on a military helicopter in which only males were flying. Therefore, the female voice might be more distinctive among male communication. However, in an ATIS/CVO system, gender distribution will be about equal and will eliminate the distinctiveness of a female voice.

Prosodics – Prosodics are the natural pitch undulations in human speech. Regardless of voice type, use the best approximation of natural prosodics (Simpson et al., 1987).

Rate of Speech – For warning messages, use a speaking rate of approximately 150 wpm. A slower rate may be desirable for training listeners who are unfamiliar with the speech accent. Pending further research, the best rate for a given application will have to be determined experimentally (Simpson et al., 1987).

Alerting Tones – When a machine–quality voice is used exclusively for warnings, do not put any alerting non–speech sound before the speech warning message. When a machine–quality voice is used for warnings and for other functions (e.g., advisories, responses to user queries, etc.), incorporate an alerting characteristic into the voice warnings. Possible alerting features may include higher voice pitch, alerting speech or non–speech prefixes, or other features that make the warning message distinctive and can be shown to increase detectability without increasing human–system response time (Simpson et al., 1987). Boff and Lincoln (1988) suggested that warning messages be prefaced with the operator's name.

Sound Location – When speech signal and masking speech are presented from different loudspeakers, signal intelligibility increases as the distance between signal and masking speech increases (Boff and Lincoln, 1988). Therefore, in an ATIS system, auditory information ideally should come from a unique location in the vehicle, far away from the possible locations of other passengers. This could be accomplished either by installing a special speaker or by having the sound come from a virtual location by using the present sound entertainment system in the vehicle.

Message Design

Length – For warning messages, use a minimum of four syllables to provide sufficient linguistic context for warning comprehension after first enunciation of the message (Simpson et al., 1987). For increased intelligibility, sentences should be used instead of isolated words (Sorkin, 1987).

Content – Make message content appropriate for the task, and use terminology that is familiar to the users (Simpson et al., 1987).

System Design

Unreliable Information – Do not present unreliable information in the voice mode (Simpson et al., 1987).

Competing Voice Messages – Consider conflicts between multiple voice messages and between listening to voice messages and speaking (Simpson et al., 1987).

Priority of Messages – When delivering time–critical information by voice, as in warnings, incorporate a priority system to order concurrently triggered voice messages so that the most critical is presented first (Simpson et al., 1987).

Repeating of Messages – For warning messages, repeat the message after an appropriate time interval (see next guideline) only if the condition that triggered the warning message is still true (Simpson et al., 1987).

Duration Between Repeated Messages – The length of time before a warning message should be repeated depends on the severity of the consequences if the user does not correct the problem (Simpson, et al., 1987).

Spoken Menus – For spoken menus without concurrent visual display, limit the number of menu items to three (Simpson et al., 1987).

Peak Clipping – By clipping the positive and negative peaks of the speech wave, and then re–amplifying the remaining waves to the original amplitude, speech intelligibility can be increased in certain types of noise (Sorkin et al., 1987). Up to 20–dB peak clipping has no effect on intelligibility in the presence of "white" noise (Boff and Lincoln, 1988).

Filtering – Perfectly satisfactory speech communication is obtainable by filtering out all sounds below 800 Hz and all sounds above 2500 Hz (Sorkin et al., 1987). Filtering may be crucial when real–time information must be sent to vehicles, and where data transmission rates are often limited.

Tactile displays

The tactile channel is rarely used as the primary channel to transmit information, but instead, is used as a redundant form of information. The most common use of the tactile channel is in the design of manual controls to provide feedback. On a computer keyboard, the "F" and "J" keys often have a raised surface to indicate the position of the index fingers on the home row. Many aircraft have a "stick shaker" tactile display connected to the control column. Whenever the plane is in danger of stalling, the control column will vibrate to alert the pilot to take corrective measures (Kantowitz et al., 1983). Tactile displays are also used on highways. Reflective strips placed on the white line of the emergency lane or on the yellow dividing lines not only enhance the road contours, but makes the car vibrate if the strip is crossed.

Unfortunately, no specific guidelines for tactile displays can be given. It can only be stated that an effort should be made to encode manual controls on an ATIS/CVO system with tactile information to enhance feedback and to allow drivers to manipulate controls without taking their eyes off the road.

Manual controls

ATIS/CVO systems do not require high volumes of data input by drivers. Drivers primarily select a menu or data item rather than input data. The philosophy of an ATIS system is that the machine (i.e., in–vehicle system and infrastructure) provides all of the information: route directions, maps, information on services and facilities, traffic warnings, and weather advisories. The primary control tasks of the user are to choose the information desired and to control its presentation.

Commercial vehicle systems might have higher volumes of data to input, due to the functions of an electronic credentials system and an electronic log book. Once again, however, the purpose of these systems is to eliminate the need for manually entering information such as mileage and location, since these data can be automatically recorded by the CVO system interfacing with the vehicle and with the infrastructure (i.e., fleet command).

The following guidelines are given for manual controls by the authors cited.

Task Selection – Use a keyboard if data entry volume is high (Greenstein and Arnaut, 1987).

Keyboard Layout – Use a standard layout. Even for untrained users, the QWERTY keyboard is no better or worse than an alphabetic layout (Greenstein and Arnaut, 1987).

Cursor Positioning Devices – Trackballs are the most accurate cursor positioning devices, although touchscreens and lightpens have led to faster response times (Greenstein and Arnaut, 1987).

Touchscreens – Touchscreens have many advantages:

- Direct hand–eye coordination.
- No command memorization is needed.
- The operator may be led through a correct command sequence.
- Minimal training is needed.
- High user acceptance.

Their disadvantages include:

- Arm fatigue with prolonged use.
- Limited resolution.
- Difficulty in selecting small items.
- Slow data entry.
- The finger or arm may obscure the screen.
- Inadvertent activation (Greenstein and Arnaut, 1987).

One obvious disadvantage ignored by Greenstein and Arnaut is that touchscreens have no inherent feedback. It is crucial that supplementary feedback be given with touchscreen responses. Given these advantages and disadvantages, it seems that touchscreens can be recommended for an ATIS/CVO system, provided one need not enter high volumes of information, use this type of control for an extended period of time, or edit text on the screen. Note, however, that the lack of touchscreen feedback and tactile feel can be a problem in dual–task environments (as previously discussed). Therefore, touchscreens are only recommended for pre–drive circumstances.

Touchscreen Size – The screen should be large enough to accommodate enough sensors to allow for a one–key–per–letter keyboard. Therefore, a 5x6 or 6x7 matrix is recommended. If a smaller matrix is used, such as the 5x5 matrix currently used in the TravTek system, then a less efficient data entry form must be used, which leads to more errors and slower data entry (Dingus and Hulse, 1993).

Touchscreen Sensor Size – The sensors should not be smaller than 19 mm square according to the Mil Std 1472D (1989). However, anthropometric data should be consulted to determine the range of fingertip widths before selecting a final measurement.

Steering Column Controls – These types of controls should be safer than alternative controls (such as a touchscreen), since drivers' hands do not leave the wheel.

For an extensive listing of manual control guidelines, including physical measurements, see Woodson's report (1981).

Maintenance considerations

Maintenance is often overlooked when designing systems. ATIS/CVO systems must be designed so that maintenance is easily accomplished. Mil Std 1472D (1989) provides an extensive list of design criteria for system maintenance. Listed below are some of the more applicable guidelines for ATIS systems.

Power Failure – Some indication should be provided when power failure occurs. All mission–essential electronic computer and peripheral system components should incorporate an automatic self–check software and hardware diagnostic program at power up and at the request of the operator to ensure that they are functioning properly. For example, when starting up a vehicle, the ATIS system should run a self–check on all functions, including communication functions such as external positioning systems (i.e., GPS) and cellular communications. Cellular communication is essential for roadside emergency assistance.

Out–of–Tolerance – A display should be provided to indicate when equipment has failed or is not operating within tolerance limits. An example would be a series of LED's inside an ATIS system chassis that indicate if certain elements are not working properly. Screen displays should also be used to display any malfunctioning aspects of the ATIS, such as cellular communications, CD–ROM, or hard drive. When a fault occurs, the system should provide the user with information on how to fix the system (e.g., take the vehicle to an authorized ATIS repair shop).

Printed Circuit Boards – Printed circuit boards should be designed and mounted for easy removal and replacement. Consider such factors as finger access, gripping aids, and resistance created by the mounting device. Appropriate feedback should be provided to ensure that technicians know when the board is securely connected.

RESEARCH ISSUES, HYPOTHESES, AND EXPERIMENTS NEEDED FOR GUIDELINE DEVELOPMENT

ATIS/CVO research to date has been system description–oriented, with details of organization of research that is in process or needs to be conducted. There are many human factors research issues that need to be addressed before a comprehensive set of guidelines can be developed. However, as shown in this report, a number of issues have been resolved for ATIS systems and comparable systems and need not be re–addressed. It is apparent that as the development of hardware progresses, the next few years will see a marked growth in the literature available from both U.S. demonstration projects and foreign sources. Therefore, as the research planning phase of this project progresses, it is critical to continue reviewing current studies. Currently, the largest gap in findings is within Japanese research. Apparently, there is such a drive to get products to market in Japan that little human factors–type testing is done before products are released. This is not to say that the products are poorly designed, but the danger does exist of producing a product with a high workload demand. It is also possible that the information does exist, but that the publication of research findings stays within Japanese journals or never leaves the company whose system is being tested. Unlike the European system of development, the Japanese system is very competitive, and studies that could leak product information are withheld to maintain corporate secrecy.

In general, specific ATIS research is lacking for IVSAWS and ISIS applications. Although these ATIS systems generally do not have complex user interfaces, they present unique human factors and safety issues. IVSAWS is an alarm type of display; therefore, issues of timing, modality false alarms, and potential operator reactions must be addressed. Many ISIS issues are similar to IRANS and IMSIS; however, presentation of regulatory information carries with it critical issues of message reliability, priority, understanding, and interpretation.

In many ways, CVO research is leading the way for automotive ATIS applications. However, the types of CVO applications that are feasible and desirable are significantly broader in scope than automotive applications. Greater functionality can be provided for the driver because of demographics and greater opportunities for driving. However, issues of overload and driving intrusion are just as critical, if not more so.

Documents for human factors and safety research

There are two noteworthy reports guiding human factors and safety research. The first is the ITS report by Barb and Mast (1992), Safety and Human Factors Considerations, which is the product of a conference held at UMTRI in December 1990. The four working groups for ITS–Automatic Traffic Management Systems (ATMS), ATIS, Automatic Vehicle Control Systems (AVCS), and CVO–convened and formulated research recommendations.

The second major report is by Sheridan (1991) and is titled Human Factors of Driver–Vehicle Interaction in the IVHS Environment. This report does not contain focused information on CVO. However, ITS effects are dealt with in terms of human factors theory and models, such as human error, mental workload, cognitive models, control theory and dynamics, information processing, dynamic decision theory, and signal detection theory. The report also discusses experimental program needs for understanding and evaluating ITS safety.

Besides these two reports, the Transportation Research Board (TRB) has also produced relevant publications. A comprehensive inventory of 19 safety issues are categorized into 5 areas in the 1991 TRB circular #375, Strategic Highway Plan. Their framework consists of people, vehicles, highway environment, post–crash, and safety management. In TRB record #1318, Safety and Human Performance, Highway Systems, Human Performance, and Safety 1991, articles by Hitchcock (1991);

Hungerford, Sperling, and Turrentine (1991); Khattak, Schofer, and Koppelman (1991); Taoka (1991); and Turrentine, Sperling, and Hungerford (1991) are presented. The four relevant article topics are:

- Driver warning and co–pilot devices.
- Problems of requirement specification and hazard analysis.
- Engineering design concept for ITS safety.
- Real–time responses to in–vehicle ITS in Europe.

Each of these sources should be used to develop research requirements. In addition to these findings, a number of research requirements were addressed in the other literature reviewed as part of this report. Also, the authors have identified gaps that were apparent from a lack of research activity. The above–mentioned research requirements are combined and described in the next section.

Specific research requirements

Research on in–vehicle guidance display systems is still needed to determine the effectiveness of different message lengths and wording, and icon effectiveness and salience. More research is also needed to determine the most effective voice–based guidance system. Several factors to be investigated include synthesized versus natural speech, voice in combination with text, and the style in which information is presented.

Advisory system display characteristics require further investigation. Optimal character size and screen density need to be determined for older and younger drivers. Standard icons that most effectively present information to drivers of all age groups need to be developed. Further research on vertical disparity should be performed to determine its effect on reaction time.

Zwahlen et al., (1987) suggested that the use of touch–panel controls in automobiles should be reconsidered and delayed. More research dealing with driver information acquisition, information processing, eye–hand–finger coordination and touch accuracy, control actions, and safety aspects needs to be conducted, and the designs and applications need to be improved to allow safe operation during driving.

Research is needed to determine the effectiveness of advisory systems in identifying drunk drivers and deterring them from driving. Effective warning systems are needed to advise alcohol–impaired drivers of potential hazards. Engineering adaptations, such as the use of protected left–turn signals, need to be investigated to help determine if they will prevent accidents caused by alcohol–impaired drivers.

In general, further research is needed to investigate the information needs of drivers. The needs of urban, rural, local, and visiting drivers must be determined. The amount of information available to drivers upon request and the amount provided to drivers normally must be determined. Research is also needed to determine how much information should be provided to drivers in the case of incidents and alternate route selections.

Barrow (1990) made three research recommendations:

- Driver perceptions and attention selection techniques need to be understood.
- Effects of monitors, as opposed to HUD's, need to be determined.
- Standards across manufacturers are needed to hold down the complexity of interfaces and establish user–friendly systems. NHTSA should define basic guidelines.

Barb and Mast (1992) made the following recommendations for research on six areas of "Plain Old Driving" (POD):

- Environmental complexity and information needs for basic driving.
- Driver's mental models.
- Mental workload.
- Dynamic eye and body movements.
- Driver cognitive and sensory motor response to highway incidents.
- A taxonomy of driver errors.

In order to define driver needs, research and development are needed as described below (Barb and Mast, 1992):

- Detailed specification of the information is needed by the driver to make each ITS function effective.
- Which sensory display modes and associated information format and density are most appropriate for each of the ITS functions. Visual display information should be coded to allow for aggregation from successive glances. Timing of information presentation includes speed, control activation, traffic density, headway, weather, and driver characteristics such as age and ability.
- Determination of which associated data entry and function selection encoding and formats would best support the above items (hard keys, soft keys, voice recognition, or cursor control).
- Task analysis and error taxonomy for ITS interactions.
- Development of design–oriented human factors guidelines for displays and controls for the multiple ITS functions and for their integration.

The following items are needed to improve tools for data collection (Barb and Mast, 1992):

- Rapid prototyping through computer graphics and modular systems for use in actual vehicles.
- Modification to test tracks or actual highway networks to allow ITS experiments.
- Simulators measuring drivers' responses to incidents.
- Techniques for setting up and using focus groups in experimental measurements and demonstration projects; use of clinic technology to determine user acceptance.

Various data bases need significant improvements (Barb and Mast, 1992):

- An improved means to compile data statistics on traffic congestion build–ups, lane blockages, and resultant vehicle responses.
- Improving accessibility and usability of ITS–related human factors data code for use by researchers, designers, and government agencies.
- Defining procedures for future accident reporting and debriefing on ITS–equipped vehicles. On–board recorders, like those in aircraft, may be needed to augment self–reports and police reports.
- Research to provide indicators and models that lie between detailed measures of human and vehicle behavior, and ultimate safety criteria (mortality). Researchers must determine when additional information causes overload or "pollution."
- Finally, a new generation of ITS–sensitive engineers and human factors people needs to be trained.

Sheridan (1991) proposed the following specific ATIS–related experiments:

- Simulator experiments in map interpretation and navigation while driving. Driver's ability to read and understand navigation information from maps, symbols, and text, in various combinations, is of particular interest.
- Simulator experiments in dynamic warning. Scenarios of interest include imminent collision, which requires the fastest response; intersection hazard; turn required by prespecified routing; and surrounding traffic situation. Immediate steering or braking is required in all of these scenarios.

- Measurement of vehicle/driver safety status. Trouble can be detected in incipient stages, and sensors need to be developed to do so by analyzing vibration signatures and other combined factors. Researchers also must ask if risk homeostasis will occur as people perceive they are safe and increase their level of risky driving. Definitions of "safe physiological and psychological" status need to be defined, along with methods to measure them.
- Technology forecast/assessment of communication off highway and with other vehicles. Researchers must ask if people will try to create a mobile electronic office with telephone, fax, computer, printer, pager, and answering machine, and what are the negative consequences of using such devices. Also, will commuting become a more social activity, and how will that change the commuter culture.

Gould (1989) makes the following observations.

As researchers await technological breakthroughs, there is a need to focus on the mode by which people structure or allocate space and on how they later recall and use that information. This will be key to designing optimal vehicle navigation systems. Individual cognitive differences also need to be considered. Stasz and Thorndyke (1980) found that the best predictor of their definition of map learning was the Building Memory Test from the Educational Testing Service. The test uses building position recall from a street map. Sholl and Egeth (1980) found that map reading and map learning have separate cognitive bases and that general mathematical and verbal abilities were strong predictors of map reading ability.

Sadalla and Hauser (1991) make the following research recommendations:

- Driver situations need to be classified in terms of their stress–producing potential. Currently, there is no means of calibrating the relative stress –producing potential of either roadway design variables and/or traffic congestion variables. Also, more needs to be known about the extent or duration of traffic–induced stress.
- Exploration of the relationship between aging and driving stress is necessary. A hypothesis is that "as people age, they should become more physiologically and psychologically stressed by traffic." Variables of roadway design and traffic situations that contribute to elderly drivers' stress need to be quantified.
- Investigate the long–term cumulative impact of driving stress on both younger and older drivers. Longitudinal studies have not been performed, but are necessary to measure changes in health. Both prospective and retrospective research designs should be used.
- Mechanisms that mediate the relationship between driving stress and health changes should be explored. Effects of driving stress on the immune and cardiovascular systems need to be clarified.
- A psychometric instrument needs to be developed to specifically measure resistance to driving stress. Questions should include the following topics: hardiness, locus of control, sensation seeking, Type A behavior, risk taking, and dominance, as they relate to driving.
- A validation of the driving stress instrument as it pertains to subjective distress and physiological reactivity is needed.
- Validation of the instrument as a moderator between driving stress and health is needed, as well as a longitudinal study of drivers exposed to high levels of traffic stress. According to the instrument, higher scores should indicate more health problems.
- An evaluation of the relationship between traffic stress, personality, and immune system response is needed. Neuroimmunological research identifies the associations between specific subjective psychological states, neuroendocrine processes, and the immune system. Noninvasive tests of saliva can be done using a technique of radio immunoassay. Experiments that examine variable interactions include stimulus variables, individual differences in stress susceptibility, and immune system response.

Marans (1990) made the following recommendations regarding user acceptance, in which three research areas were identified. The University of Michigan is planning the following:

- In–depth interviews with automobile and electronic industry decision–makers, as well as government planners.
- A nationwide, ongoing household survey of the driving public. The sample will be segmented across geographic region, size of community, and selected socio–economic characteristics.
- Conduct a literature review of previous research on driver acceptance of new technologies at the level of individuals, organizations, and societies.

Boyce (1988) posed the following research questions:

- What are the likely savings in travel time from user–optimal route choices as compared with existing dispersed route choices?
- What additional savings would result from the introduction of system–optimal route choices and the timing of traffic–signal systems with better historical and real–time information?
- How would improved highway travel time information change the behavior of commuters with regard to departure time, choice of mode, and choice of residential or job location? What would be the benefits or costs of these changes?

Burgett (1991) described some of the safety hypotheses associated with the TravTek system:

- Hypothesis: If it takes no more time to gather information from a display of TravTek information than it does to gather information about some other functions, such as climate control, then the TravTek display is as safe as the climate control display.
- Hypothesis: TravTek will relieve the burden of "loading tasks," such as seeking exits from a congested freeway, which will prevent attention overload.
- Hypothesis: For fixed roadway characteristics (e.g., speed limit and number of lanes), collision rates will vary directly with the level of congestion.
- Hypothesis: Collision severity will vary inversely with the level of congestion.
- Observation: Data will be indirect measures of safety–precursor events to collisions since ITS TravTek collision data do not exist. Precursor events are lane deviation and reduced headway.

Fleishman (1991) listed the research and evaluation questions for the TravTek ITS Operational Field Test:

- Does TravTek allow a statistically significant reduction in speed variance?
- Does TravTek allow a statistically significant reduction in number of stops or instances of zero speed per trip?
- What is average speed per trip?
- What is average number of miles per trip?
- What is the number of new routes offered to drivers because of congestion/traffic incident information?
- What is the number of new routes accepted?
- What is the frequency of broadcast/reception of Dynamic Link Ratios?
- What are the types of incidents, start and end times, and locations of incidents?
- How often are trips avoided?

CVO–specific research requirements

Given that the average commercial driver is likely to be quite different than the average automobile driver in terms of demographic characteristics such as size, age, sex, and health, and performance characteristics such as information processing and response abilities in a multi–channel information system, it is critical to examine driver characteristics in the context of CVO (IVHS America, 1992a).

It is important to considers human factors when developing CVO technologies. Areas that need to be studied are:

- Information requirements issues.
- Display issues.
- Driver performance issues.
- Driver behavior issues (IVHS America, 1992a).

Researchers must identify the information needed by the driver, vehicle, and control agencies (e.g., ATMS, fleet managers) and then identify the best means of presenting that information to users (Boehm–Davis and Mast, 1992).

Barb and Mast (1992) described several CVO research needs and questions that need to be addressed:

- Characterization of truck drivers, trucks, and truck operations in a representative manner so that Human Factors and Safety (HF and S) studies can adequately address the application of ITS to trucking.

  Drivers. What is the distribution of human performance–related properties over the truck driver populations and what is their state while driving?

  Vehicles. What are the truck control characteristics and other physical attributes that impact upon human factors and safety issues?

  Road network. What is the time/space characterization of truck routing?

  Motion environment. What is the time/space characterization of vehicle movement in the immediate proximity of heavy trucks, such that collision prevention technologies can be quantitatively specified?

  Information. What truck–specific information flow characterizes current operations?

  Operations. What characteristics of commercial truck transport operations influence the driver's daily workload and the safety risks?

  Regulation. What regulatory and enforcement practices influence operational safety going down the road once the driver and vehicle have been duly licensed?

  Accident studies (study of heavy vehicle accidents and their causes in light of potential ITS interactions). Issues of interest include commercial vehicle maneuvers at the time of a destabilizing event, critical driver errors, characterization of non–police–reported accidents, and congestion caused by specific types of truck accidents.

- Definition of safety needs and determination of performance targets to be achieved through the application of ITS technology to trucking. Primary areas include the following:

  System safety. What targets or potentially achievable benefits can be set for the overall safety of improvements in trucking operations derived from ITS application to CVO, considering driver, vehicle, and system–level factors?

Truck control. What specific opportunities exist for truck control and warning aids employing ITS technology? What performance requirements can be stipulated as a means of defining such opportunities?

Cockpit design. What features in the design of ITS displays within the truck cab can be stipulated or constrained as requirements?

Driver training. What opportunity is there to use ITS technologies as a training tool for truck drivers or dispatchers? What special training may be needed to attain ITS literacy or ITS operability among truck drivers?

Hazards. What are the specific requirements for materials for the ITS functions serving to improve the safety of hazardous materials transportation?

Auto inspections. What performance requirements or targets can be stipulated for ITS applications that operate in real–time to confirm the physiological, licensing, and hours of service compliance of truck drivers and the mechanical state of trucks as they pertain to safety?

Truck routing. What are the requirements for routing constraints that must be incorporated within route guidance and navigation functions to reflect access limitations applying to large trucks?

- Development of methodologies (including research protocols and tools) for studying the HF and S issue involved:

Rapid prototyping. Develop tools for rapidly prototyping ITS packages to be used in truck development and research on user cabs, so as to expedite the engineering friendliness.

Crash avoidance. Develop the protocol for evaluation of crash warning and crash intervention systems intended for CVO application.

CVO driving. Develop one or more levels of driving simulator capable of representing the CVO driving environment.

Crash recorders. Low–cost, rugged devices for research on causal elements in truck accidents with specific attention to pre–crash data indicating accident modalities and opportunities for automatic countermeasure.

Safety benefits. Develop the means to assess the accident reduction benefits of ITS as they accrue to CVO, recognizing that traditional data sources and analyses have focused upon the results of impact rather than the causal factors.

- Conduct applied research and operational testing to determine the human factors acceptability and safety–effectiveness of ITS technologies applied to trucking:

User acceptance. Study in a market prediction sense the predisposition of truck drivers, dispatchers, managers, and regulatory enforcement people to specific systems and categories of systems.

Display. Study the constraints upon display technologies within the authentic truck cab environment characterized earlier by certain vibration, noise, lighting, and geometric layout parameters.

Workload tolerance. Study driver tolerance for workload changes requiring the need to interact with in–cab information functions for advanced systems.

Route guidance. Identify the problems posed when presenting route guidance to the truck driver.

Dynamic warning. Study the application of dynamic warning systems to heavy–duty trucks and truck combinations. This includes inter–vehicular collision, run–off–road, and rollover warnings.

Driver monitoring. Study the application of driver monitoring systems to CVO drivers, with examination of both the sensory technology and the systems considerations of data interpretation and usage in an alerting approach.

Summary of Knowledge Gaps Key to the Development of Human Factors ATIS/CVO Guidelines

ATIS/CVO research to date has been system description–oriented, with details of the organization of research that is being conducted or needs to be conducted. There are many human factors research issues that still need to be addressed before a comprehensive set of guidelines can be developed. However, as shown in this report, a number of issues have been resolved for ATIS or comparable systems and need not be re–addressed. As the development of hardware progresses, the next few years will see a marked growth in the literature available from both U.S. demonstration projects and foreign sources. Therefore, as the research planning phase of this project progresses, it will be critical to continue reviewing current studies.

The ITS literature produced to date aids in the development of the initial phase of ITS. However, because there is a lack of empirical data, the development of comprehensive guidelines is that much more dependent on analysis, modeling, and empirical research.

It is anticipated that the data from initial U.S. operational tests and additional European and Japanese projects will fill some of the gaps in the human factors knowledge base. TravTek, as previously described, has a number of IRANS and IMSIS features and will provide data from numerous studies with well over 1.6 million km (1 million mi) of data collected. The University of Michigan Transportation Research Institute's (UMTRI's) project also will provide data, as well as preliminary models that may help in the establishment of guidelines. The ADVANCE and Guidestar projects promise data from even larger groups of users in the near future.

In order to develop comprehensive and general guidelines that are useful for years to come, models of driver performance while using ATIS and CVO systems must be developed. This research will likely include application and/or modification of existing models (e.g., UMTRI or model driver processing proposed by Sheridan, 1991, or Kantowitz, 1990), as well as creation of new models or model parameters associated with ATIS/CVO–specific applications.

In general, ATIS research is lacking IVSAWS and ISIS applications. Although these ATIS systems probably will not have complex user interfaces, they present unique human factors and safety issues. IVSAWS will be an alarm display; therefore, issues of timing, modality false alarms, and potential operator reactions must be addressed. Many ISIS issues are similar to IRANS and IMSIS; however, presentation of regulatory information carries with it critical issues of message reliability, priority, understanding, and interpretation.

In many ways, CVO research is leading the way for automotive ATIS applications. However, the types of CVO applications that are feasible and desirable are significantly broader in scope than automotive applications. Due to differences in driver demographics and greater opportunities for training, greater functionality can be provided for the CVO driver. However, issues of overload and driving intrusion are just as critical, if not more so, for CVO applications when compared to automotive applications. In addition, system design alternatives that would be unacceptable for automobile drivers due to cost and/or acceptability/marketing constraints may be acceptable for certain CVO applications. Therefore, a number of CVO–specific empirical projects must be undertaken to establish guidelines for the broad scope of useful CVO functions.

In general, further research needs to be performed to investigate the information needs of both automobile and CVO drivers. The information needed only by urban, rural, local, and visiting drivers must be determined. The amount of information available to the driver upon request and the amount provided to the driver normally must be determined. Researchers also need to determine how much information should be provided to the driver in the case of incidents and alternate route selections.

Driving capacity is a major research gap requiring both the application of existing guidelines and the creation of new guidelines. The human factors community is currently divided on the issue of what is safe and what is unsafe in the driving environment. The primary cause of this debate has centered around IRANS applications and will require additional research to resolve. In addition, many of the more difficult issues relating to resource capacity for trained CVO drivers and multi–function systems have not been addressed empirically or descriptively. Carefully planned and executed experiments that provide general principles instead of system–specific do's and don'ts are needed. In addition, an understanding of potential safety benefits and the costs of using ATIS/CVO are needed for guideline development. It is easy to dismiss a display that provides complex information as requiring too many driver resources. However, until (1) a comparison is made with current techniques for retrieving necessary information, and (2) an assessment is performed to determine the benefit of having the information, a proper assessment cannot be made.

Driver acceptance of ATIS and CVO technology also needs to be researched. Even a safe and efficient system design will not achieve the goals of ATIS and CVO systems if the needs and desires of the user are not met. Poor market penetration will result. Although a number of surveys have been conducted and describe desirable ATIS and CVO features, ongoing research is necessary to establish the information and control requirements for system (and product) success. Once information requirements have been established, human factors design guidelines can be established.

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LIST OF ABBREVIATIONS

AAA American Automobile Association

ACS Automatic Clearance Sensing

ADIS Advanced Driver Information Systems

ADVANCE Advanced Driver and Vehicle Advisory Navigation Concept

AMTICS Advanced Mobile Information and Communication System

ARI Army Research Institute

ASME American Society of Civil Engineers

ATIS Advanced Traveler Information Systems

ATLAS Acquisition par Télédiffusion de Logiciels Automobiles pour les Services

ATMS Automatic Traffic Management Systems

AV Advanced Vehicle

AVC Automatic Vehicle Classification

AVCS Automatic Vehicle Control Systems

AVI Automatic Vehicle Identification

AVL Automatic Vehicle Location

AVM Automatic Vehicle Monitoring

BAC Blood alcohol concentration

CAD computer-aided dispatch

CARIN Car Information and Navigation

CB Citizens band

CD Compact Disc

CD-I Compact Disc-Interactive

CD-ROM Compact Disc-Read Only Memory

CEC Commission of European Communities

CFL Cold-cathode Fluorescent Lamp

CRT Cathode Ray Tube

CVO Commercial Vehicle Operations

DOT Department of Transportation

DRIVE Dedicated Road Infrastructures for Vehicle Safety in Europe

D-STN LCD Double-Layered Super-Twisted Nematic Liquid Crystal Display

EP Electronic Placarding/Bill of Lading

ERTICO European Road Transport Telematics Implementation Coordination Organization

EUREKA European Research Coordination Agency

FCC Federal Communications Commission

FHWA Federal Highway Administration

FM frequency modulation

GM General Motors

GPS Global Positioning System

HAR Highway Assistance Readout

HELP Heavy-vehicle Electronic License Plate

HFL Hot-cathode Fluorescent Lamp

HIDO Highway Industry Development Organization

HMD Helmet/Head Mounted Display

HUD Head-up Displays

IGOR Interactive Guidance on Routes

IMSIS In-Vehicle Motorist Services Information Systems

IRANS In-Vehicle Routing and Navigation Systems

IRTE Integrated Road Transport Environment

ISIS In-Vehicle Signing Information Systems

ITE Institute of Transport Engineers

ITS Intelligent Transportation System

IVHS Intelligent Vehicle Highway System

IVNS In-Vehicle Navigation Systems

IVSAWS In-Vehicle Safety Advisory and Warning Systems

JSK Japan Traffic Management and Technology Association

LCD Liquid Crystal Display

LED Light-Emitting Diode

MADD Mothers Against Drunk Driving

MC Ministry of Construction

Minerve Media Intelligent pour l'Environnement Routier du Véhicule Européen

MIT Massachusetts Institute of Technology

MPT Ministry of Posts and Telecommunications

NASA Nation Aeronautics and Space Administration

NHTSA National Highway Traffic Safety Administration

NPA National Police Agency

NTIS National Technical Information Service

OBC On-board Computing

PAR Packet Access Radio

PROMETHEUS Program for European Traffic with Highest Efficiency and Unprecedented Safety

RACS Road/Automobile Communication System

RDS Radio Data System

RDS-TMC Radio Data System-Traffic Management Center

RF radio frequency

RH relative humidity

RTI Road Transport Informantics

SAE Society of Automotive Engineers

SST Spread Spectrum Transmission

STRS Shared-Trunked Radio Systems

TFD Thin Film Diodes

TFT Thin Film Transistors

TMC Traffic Management Center

TN Twisted Nematic

TRB Transportation Research Board

TWC Two-way Real-time Communication

UMTRI University of Michigan Transportation Research Institute

VFD Vacuum Fluorescent Display

VICS Vehicle Information and Control System

WFL Warm-cathode Fluorescent Lamp

WIM Weigh in Motion