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# IN-VEHICLE HUMAN FACTORS FOR INTEGRATED MULTI-FUNCTION SYSTEMS: MAKING ITS USER-FRIENDLY*

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## DISCLAIMER

# In-Vehicle Human Factors for Integrated Multi-Function Systems: Making ITS User-Friendly

**Philip F. Spelt & Susan Scott**

## INTRODUCTION

As more and more Intelligent Transportation System in-vehicle equipment enters the general consumer market, we are about to find out how different design engineers are from ordinary drivers. Driver information systems are being developed and installed in vehicles at an ever-increasing rate. These systems provide information on diverse topics of concern and convenience to the driver, such as routing and navigation, emergency and collision warnings, and a variety of motorists services, or "yellow pages" functions. Most of these systems are being developed and installed in isolation from each other, with separate means of gathering the information and of displaying it to the driver. The current lack of coordination among on-board systems threatens to create a situation in which different messages on separate displays will be competing with each other for the driver's attention. Urgent messages may go unnoticed, and the number of messages may distract the driver from the most critical task of controlling the vehicle. Thus, without good human factors design and engineering for integrating multiple systems in the vehicle, consumers may find ITS systems confusing and frustrating to use.

The current *state of the art* in human factors research and design for in-vehicle systems has a number of fundamental gaps. Some of these gaps were identified during the Intelligent Vehicle Initiative Human Factors Technology Workshop, sponsored by the U.S. Department of Transportation, in Troy, Michigan, December 10-11, 1997. One task for workshop participants was to identify needed research areas or topics relating to in-vehicle human factors. The top ten unmet research needs from this workshop are presented in Table 1. Many of these gaps in human factors research knowledge (marked with a # symbol in Table 1) indicate the need for standardization in the functioning of interfaces for safety-related devices such as collision avoidance systems (CAS) and adaptive cruise controls (ACC). Such standards and guidelines will serve to make the safety-critical aspects of these systems consistent across different manufacturers, thereby reducing the likelihood of driver surprise. A second area to emerge from the Workshop concerns research into techniques for integrating multiple devices in vehicles, items marked with + in Table 1. This type of research is needed to support the development and validation of standards and guidelines, and is discussed in the second section. The majority of the top ten research types identified in the Workshop (marked with *) fall under the need for a "Science of Driving," which is discussed in the last section of this paper.

| Rank | Research Type | Mean Rating |
|---|---|---|
| 1# | Guidelines of CAS warning type, location and priority | 1.50 |
| 2* | Baseline driver behavior & performance data collection | 1.51 |
| 3* | Acquisition of driver behavior/driving environment data | 1.67 |
| 4* | Describing normative driver behavior using quantitative models | 1.67 |
| 5* | Integration & development of HF driver models for IVI | 1.70 |
| 6# | CAS warning/alert standardization (signals, modalities) | 1.72 |
| 7+ | IVI integration & multi-task performance: effects on driver behavior | 1.75 |
| 8# | Standardization if CAS warning criteria | 1.78 |
| 9* | Model driver cognitive processes (behavior, loss of skill) | 1.95 |
| 10+ | IVI information display prioritization | 2.00 |

Table 1. Top ten research project titles from the IVI Human Factors Workshop, December 10-11, 1997. The right column presents the mean rating, on a five-point scale (1 is most important, 5 is least). CAS is a Collision Avoidance System, one of the specific systems considered.

## MULTIPLE DEVICE INTEGRATION AND INFORMATION MANAGEMENT

The need for research on how to integrate multiple devices and manage the information from them is indicated by items seven and ten in Table 1. This is also the primary topic of the In-Vehicle Information Systems (IVIS) Project under way at Oak Ridge National Laboratory, sponsored by the Federal Highway Administration (Spelt, et al., 1997, Tufano et al., 1997). The installation and, more importantly, the integration of multiple information sources in vehicles presents a number of challenges. The installation of multiple devices, each with its own driver interface, increases the risk of driver distraction from the primary task -- driving -- and thus increases the risk of an accident. Individually, each device has the potential to present its message to the driver at the same time as any other. To the extent that several devices "sound off" simultaneously, there is the potential for either distraction of the driver's attention away from the most important elements of the driving situation, or for driver information overload. Since either or both of these results can lead to an accident, it is clear that mitigation of this potential has important safety implications.

**Physical and Logical issues** -- It should be noted that human factors aspects of physical issues, such as installation real estate and location, must be addressed by both device and vehicle manufacturers. Logical issues surrounding the installation of multiple devices in vehicles are much more complex than the physical ones. A safe and efficient driver interface requires that devices function without interfering with each other, and also communicate among themselves without interfering with other devices (e.g., message passing between a pager and a cell phone, or between a "yellow pages" system and a navigation system).

**Information Management** -- The information management function must be a logical manipulation of the information received from the variety of subsystems installed in the vehicle. This function assumes that the devices are interconnected, and requires a system which accounts for driver preferences and needs, as well as taking into account the source of the information and its relative importance. Three kinds of information management must be performed: integrating, filtering, and prioritizing (Tufano, et al., 1997). The integrating function requires rules which can select from among the incoming information, those messages which contain related information, and combine the information into a single meaningful message. Filtering simply eliminates irrelevant or redundant information. Message prioritizing is currently an important topic for standards development both in the United States and around the world. This function assures that the most important messages are discernibly presented to the driver at a time when they are most relevant. Prioritizing must take place across different types of devices in the vehicle, a task which is difficult to achieve in situations where devices are not able to communicate with each other.

Because the user can either dismount devices or turn them off at various times, an information management system must operate with different numbers and types of devices. In addition, for each type of device, there will be different levels of capability and functionality, because there will be more than one supplier for each type of system. Finally, this type of management system should conform to the preferences and goals of more than one driver. These information management functions can be performed by an expert system, consisting of an inference engine and one or more sets of rules, to make decisions about information display. These issues are discussed more fully in Spelt and Tufano (1998) -- the final paper in this session.

**Other Interface Issues** -- In addition to the information management issues just discussed, there are issues associated with information display, as well as the user's input of information and requests to the IVIS. While there are many safety-related issues associated with in-vehicle display of information, a system which can be adjusted to suit various aspects of a driver's idiosyncratic desires and ways of using it is arguably safer than one which forces the driver to adjust to the system's functioning. Such a user-friendly system permits the user (the driver, in this case) to adjust system performance to suit his or her particular needs and ways of functioning. Within the limits imposed by safety considerations, an integrated and user-friendly in-vehicle system should permit the driver inputs to tailor the system functioning and information display to suit the driver's personal preferences and trip goals. Thus, while safety-related information should be presented in standard ways, other information, such as a yellow pages system, may be adjusted to the driver's needs. For example, the volume of acoustic signals to attract attention to new visual message displays may be adjusted, or the type of acoustic signal may be selactable, as are such signals in the operating systems of many of the personal computer interfaces. Obviously, also, such acoustic signals may also be turned off. Similarly, where permissible in light of safety considerations, the driver may select which sensory mode is used to display certain types of messages in a multimodal display.

## DEVICE PERFORMANCE STANDARDS AND GUIDELINES

In addition to results of research and development into multiple device integration, Standards and Guidelines represent an important safety contribution. Standards and guidelines assure consistency among devices of the same type, thereby increasing driver adaptation to devices from different manufacturers. Evidence for the importance of such standardization is shown in items one, six and eight in Table 1, which all relate to standardization of warnings and displays in CASs. The fact that this call for standardization is for CASs, is partly a reflection of the structure of the Workshop, in which two breakout sessions were devoted specifically to CASs. More importantly, it clearly is needed for all types of devices which are installed in vehicles, although CASs and ACCs have a most urgent need, as these devices are already entering the market.

**Guidelines** -- A good example of voluntary guidelines is the Human Factors Design Guidelines for Advanced Traveler Information Systems (ATIS) and Commercial Vehicle Operations (CVO) developed for the Department of Transportation. This work included "five years of analytical and empirical investigation into human factors design issues, research needs, and driver requirements..." (Campbell, et al., 1997). While these guidelines represent a very important contribution to the need for driver-oriented guidelines, they do not address the problems associated with <u>multiple</u> devices in vehicles, the topic for this paper. Generally, human factors work on ITS systems has approached in-vehicle devices as separately-functioning components. For example, a study of attention demand for adaptive cruise control does not consider whether the car will also have a navigation system. While this research is important, additional research is needed to provide the empirical basis for integrating multiple devices into a safely functioning system. It can generally be said that human factors research in integrated multi-function ITS <u>systems</u> is at an early stage. One such current effort is described in the final paper of this session by Spelt and Tufano.

**Formal Standards** -- A number of standards development efforts are under way, both in the United States and around the world. Because it is not possible to cover them all, only a few illustrative examples will be described; a more complete discussion can be found in Spelt (1997). The Society of Automotive Engineers (SAE) is developing several standards within the committees of the ITS Division. The ITS Data Bus Committee is developing a family of recommended practices to permit safe "plug and play" of a variety of information sources in road vehicles (Spelt, et al., 1998). These devices include both ITS-related components such as navigation systems, as well as other information devices such as cell phones and pagers. An ITS Data Bus (IDB) will permit easy and safe installation and removal of these devices, and will make the creation of standards and guidelines for multiple devices even more important. A working group of this Committee is designing a demonstration vehicle, with anticipated completion in late 1998. Implementation of an IDB will provide both the impetus and the mechanism for integrated information management.

Several standards efforts are currently under way under the auspices of the SAE Safety and Human Factors Committee. Most notable of these is a standard which will provide a methodology to prioritize all messages across multiple devices in a vehicle. This effort matches well with item ten in Table 1. Parallel to this, the International Standards Organization (ISO) is working on a Committee Draft (CD) ISO/CD 15005, "Road Vehicles - Transport Information and Control Systems - Man Machine Interface - Dialogue Principles." This effort explicitly addresses multiple devices in moving vehicles. At a recent meeting of the Committee, the United States provided significant input regarding message prioritization for both multiple interconnected devices and multiple devices which are independent of each other. These concerns had not been addressed prior to the U.S. review of the Draft.

A standard to define navigation system functions which should be available to the driver while the vehicle is in motion is also being written by SAE. Navigation functions accessibility standards are particularly needed because these systems are already deployed. This standard represents an important step in examining functions allowable during vehicle motion, although it still considers only a single device rather than multiple devices. However, such work is necessary as a preliminary to dealing with multiple devices, and it is expected that this standard can provide a useful model for considering other devices. A number of the U.S. standards development efforts are partially funded by the Department of Transportation's ITS Joint Program Office.

Human factors issues associated with safety-critical systems are now beginning to receive attention among standards development bodies. New active safety systems which provide collision warning or headway maintenance will deliver maximum safety benefits only if drivers clearly and quickly understand the message being delivered. Careful and thorough research must be conducted on how best to convey the need for an emergency evasive response to drivers. Another unresolved issue for safety-critical systems human factors is the optimum mix between false alarms and reaction times. If the system has a high false alarm rate, drivers may not respond quickly, or may not trust the information from the system. An additional issue is the extent to which drivers adapt their driving to the presence of these safety systems. That is, with a safety system present, to what extent do drivers "push the envelope" of safety, assuming that the safety system will protect them?

## A SCIENCE OF DRIVING

Before the ITS community can tackle the problems discussed in this paper, a number of fundamental gaps in human factors research for in-vehicle systems must be filled. Some of these gaps are shown in the workshop results in Table 1. Many of these gaps in human factors research knowledge can be organized under the heading of a "Science of Driving" -- an effort to establish research techniques and an empirical body of knowledge about driving which is available to the ITS system developers and integrators. This area includes work on both baseline driving characteristics and on the impact of adding devices into vehicles. In order to have an impact on early ITS in-vehicle systems integration, this research must begin quickly.

**Baseline driving data** -- At present, there is not much data readily available which contains knowledge of "normal" driving behavior. The driving research community requires a large database of normative driving behavior, against which the impacts of newly-installed devices in road vehicles can be assessed. It is impossible to determine the impact of a new device on driver attention demand, for example, if we don't know "baseline" driver attention demand. This is illustrated by the fact that five of the top ten research needs in Table 1 relate to normative driving (those marked with an * symbol). In pursuit of this goal, Oak Ridge National Laboratory completed the prototype Data Acquisition System for Crash Avoidance Research (DASCAR) for the National Highway Traffic Safety Administration (NHTSA). The purpose of the DASCAR project (Spelt, 1993; Carter, et al., 1997a, 1997b) was to create a portable data acquisition system which could be installed in vehicles to gather data both about baseline driving behavior, and about the effects of research manipulations on the driving task. These manipulations include the installation of various ITS-related sources of information, such as a navigation and route guidance system or a real-time traffic information device, as well as various devices not specifically related to ITS such as cell phones, pagers, and laptop computers. To date, not much publicly available data has been generated using DASCARs.

The lack of such a normative database has not prevented component designers and system integrators from drawing preliminary conclusions about how such devices ought to be designed and to function, however. Some research results do exist, although much of the current human factors research focuses in detail on one aspect of human behavior, such as glance frequency or the effects of age on reaction times, to the exclusion of any consideration of an overview of larger human factors issues such as attention demand, cognitive capture, or "user-friendliness." In many cases, however, it is likely that human factors decisions about device functioning are made on the basis of personal experience, or on the basis of casual conversations among friends and/or colleagues. This approach risks designing systems which are tailored to idiosyncrasies of the few people sampled. Anecdotes and "common sense" are not good substitutes for solid data, especially where safety is an issue.

**Sampling abnormal driving** -- At present, we don't have much data on near accidents or "close calls" caused by use of ITS-related devices. Most of the information the driving research community has about the impacts of these devices on roadway driving comes from accident data. One exemplary report was recently published by NHTSA (November, 1997), on the impact of cell phones and other wireless communication devices in vehicles. While this type of report is extremely useful, it does not provide any information about the impact of these devices on non-accident related driving, in other words, on "normal" driving. This problem has been confronted in other research fields, such a biology and psychology: we cannot gain a thorough understanding of the functioning of normal systems by studying only abnormal systems -- e.g., diseased organs in medicine and biology, and mentally disturbed people in clinical and personality psychology. Therefore, these data must be gathered from the installation of systems like the DASCAR in vehicles being driven for daily commuting and other routine chores. Such an undertaking is enormously expensive, more so in the data gathering, reduction and analysis than in the installation of the data acquisition systems.

**Simulator data** -- Other sources of data, of course, are the numerous driving simulators which exist. However, there is serious question in the minds of many researchers about the validity of simulator data for application to actual roadway driving situations. There is anecdotal evidence that simulator subjects take more risks, knowing that they will not really crash. Also, there is evidence that simulator drivers are more alert than normal drivers. Thus, data gathered in simulators must be validated against the same kinds of data gathered from on-road vehicles. A proposed human factors driving research strategy which integrates benchtop equipment, simulators of various types, and on-road vehicles is presented in Figure 1. In this strategy, the impacts of new components or interface techniques on driving behavior are first evaluated off-road, using either desktop equipment or various types of simulators. Once the impact of the device or interface has been determined, the research can safely move to road vehicles, either research vehicles on test tracks, or vehicles moving on public roads and highways. It is probably unnecessary

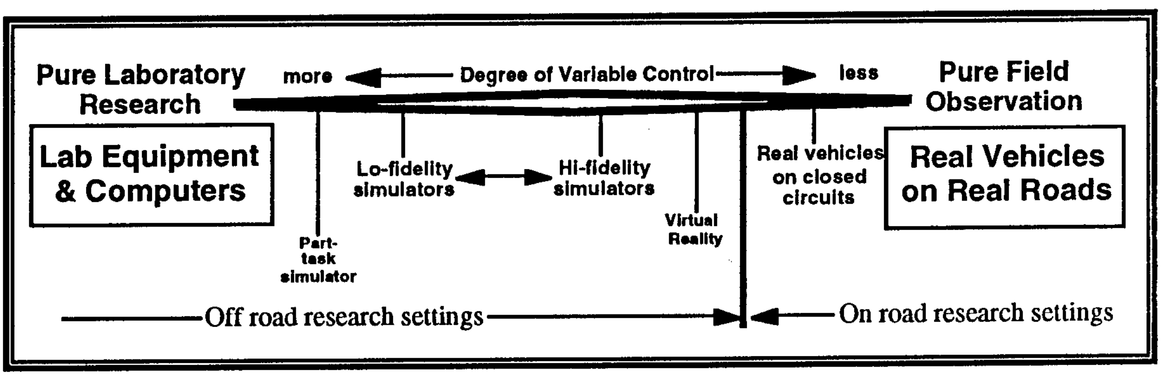


Figure 1. Proposed strategy for driving research, in which there is a progression of from desktop laboratory research to the use of real vehicles on real roads.

for any component or interface to be tested in all of the research settings depicted in Figure 1.

**Empirical models of driver behavior** -- Items five and nine in Table 1 call for the creation of models of driver behavior. These models must be created from the normative data collected as part of the Science of Driving proposed here, as well as from human factors research on the design and functioning of specific in-vehicle devices. An important model suggested by Workshop participants is Driver Expectations for how information is to be displayed, and how input controls function. In the general human factors literature, these expectations are often referred to as population stereotypes. However, in driving arenas, driver expectations may not exist in the absence of driver experience with the particular component or device being examined. For example, it is not likely that drivers will have a common expectation for how a collision warning system will signal the presence of a vehicle in the left blind spot, prior to having experience with such a device. Never-the-less, such expectations will emerge as drivers gain experience with new ITS-related devices, and a body of knowledge of these expectations is needed. Moreover, to the extent that devices from different manufacturers behave differently, driver expectations developed through the use of one manufacturer's device will not match the performance of another device, and confusion and/or accidents can be expected to result. This emphasizes the need for a certain amount of standardization of device functioning, especially for devices which have a direct impact on safety, such as adaptive cruise controls, collision warning and avoidance systems, etc. A second type of model concerns Driver Cognitive Functioning, as related specifically to driving. This class of models includes the impact on driving of such things as Cognitive Workload, Cognitive Capture (especially for head-up displays), and factors which influence Driver Attention. While these aspects of human behavior have been examined in conjunction with other tasks, not much is known about their functioning with ITS-related devices while driving. While workload and attention results and techniques from other area of research my be applicable to driving, they must be validated in driving research.

## CONCLUSIONS

Given the issues and knowledge gaps discussed, it is hard to predict with any level of confidence how system integrators will integrate multiple ITS systems. The problem of having multiple devices installed in vehicles has gained worldwide recognition, and work is in progress on the development of standards and guidelines which address the problems described in this paper. Research in under way to develop principles for managing information emanating from multiple devices, and at least one demonstration platform exists which can be used to show both the effectiveness of and the benefits from such management. The development of a body of publicly-available research results will aid this effort, but such an effort is both expensive and time-consuming. The safe and effective integration of multiple devices must be addressed soon, through appropriate research and standards development.

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