INTL. JOURNAL OF HUMAN–COMPUTER INTERACTION, *27*(6), 505–522, 2011

ISSN: 1044-7318 print / 1532-7590 online
DOI: 10.1080/10447318.2011.555296

In-Vehicle Information Systems to Meet the Needs of Drivers

Catherine Harvey[1], Neville A. Stanton[1], Carl A. Pickering[2], Mike McDonald[1], and Pengjun Zheng[1]
[1]Transportation Research Group, School of Civil Engineering and the Environment, University of Southampton, UK
[2]Jaguar and Land Rover Technical Research, Jaguar Cars, Engineering Centre, Whitley, Coventry, UK

In-Vehicle Information Systems (IVISs) integrate most of the secondary functions available within vehicles. These secondary functions are aimed at enhancing the driving experience. To successfully design and evaluate the performance of these systems, a thorough understanding of the task, user, and system is required. This article presents a review of these three variables in the context of IVISs, which aims to enhance understanding of this specific task–user–system interaction. A framework for modeling system performance for the task–user–system interaction is also proposed. This will allow designers and evaluators of IVISs to make predictions about system performance and to design systems that meet a set of criteria for usable IVISs.

1. INTRODUCTION

Driving is an example of human–machine interaction in which the human (i.e., the driver) interacts with a machine (i.e., the vehicle). As well as interacting with the primary driving functions, such as steering, accelerating, braking, and changing gear, the driver also performs secondary tasks within the vehicle, and this often involves interacting with an In-Vehicle Information System (IVIS). To design and evaluate any system, we must be able to predict how that system will perform under real conditions of use. Card, Moran, and Newell (1983, p. 404) proposed a formula to describe this system performance:

$$\text{Task} + \text{User} + \text{Computer} \rightarrow \text{System Performance}$$

This research is sponsored by Jaguar Cars and the Engineering and Physical Sciences Research Council.
Correspondence should be addressed to Catherine Harvey, Transportation Research Group, School of Civil Engineering and the Environment, University of Southampton, Highfield Campus, Southampton, United Kingdom SO17 1BJ. E-mail: c.harvey@soton.ac.uk

They went on to state that modeling the interaction between the task, user, and computer (or any interactive system) would enable designers to predict system performance (p. 405):

Model (Task, User, Computer) $\rightarrow$ Performance Prediction

Card et al. (1983) proposed a number of different methods for predicting system performance using various modeling techniques, and these are discussed later in the article. Before system performance can be predicted, however, the three variables that determine this performance (task, user, and system) must be specified and understood. In this case we are interested in the interaction between the driver (user) and the IVIS (system) when performing in-vehicle secondary tasks. These three variables are described and discussed in the following sections.

2. THE TASK

Driving is a complex, multitask activity (Regan, Lee, & Young, 2009), consisting of interactions between the driver, the car, and the environment (Rakotonirainy & Tay, 2004) and requiring the successful integration and coordination of the driver's cognitive, physical, sensory, and psychomotor skills (Young, Regan, & Hammer, 2003). This article is concerned primarily with the interaction of the driver with secondary in-vehicle tasks via an IVIS; however, the driver's performance on primary driving tasks is also important, as it is directly affected by the driver–IVIS interaction.

2.1. Primary Driving Tasks

During driving, the driver must perform a large number of different tasks while continuously monitoring the driving scene (Wierwille, 1993). Primary driving tasks involve maintaining the safe control of the vehicle (Lansdown, 2000) by guiding its position, detecting and responding to hazards, and navigating a route (Seppelt & Wickens, 2003). Hedlund, Simpson, and Mayhew (2006) listed steering, accelerating, braking, speed choice, lane choice, maneuvering in traffic, navigation to destination, and scanning for hazards as the primary driving tasks. All primary tasks will be performed by the driver during a single car journey, so it is essential that in carrying out these tasks the driver's performance is not negatively affected.

2.2. Secondary (In-Vehicle) Tasks

Hedlund et al. (2006) defined secondary tasks as all other tasks performed by the driver that are not directly related to driving. Secondary functions are not essential to successful driving; instead, their purpose is to enhance the driving experience while addressing the driver's needs (Engström et al., 2004; Matthews, Bryant, Webb, & Harbluk, 2001). Secondary functions provide information about the journey and the vehicle in the form of navigation instructions, traffic information, and vehicle data, which enables the driver to make better informed decisions about that journey and therefore to "improve the efficiency of roadway use" (Seppelt & Wickens, 2003). They can enhance comfort by enabling the driver to control the climate within the vehicle. Secondary functions provide entertainment, including audio features such as radio, CD, and MP3, and even visual media including TV and DVD. They also provide the driver with a means of communication via telephone. Traditionally, secondary functions have been controlled via hard tactile switches located on the dashboard and center console. In recent years the number and variety of secondary functions available within vehicles has increased dramatically, from simple radio and climate controls to the vast array of features just described (Gu Ji & Jin, 2010). This has been fueled by consumer demand for access to more information and enhanced comfort and connectivity while on the move. Today, some lower end automobile models still use hard switches to control all secondary functions because this is relatively inexpensive. In the premium sector however, and increasingly with volume brands, designers have attempted to integrate many secondary controls into a single menu-based interactive system (Pickering, Burnham, & Richardson, 2007), with only the most high-frequency and high-importance controls left as hard switches. Technologies such as voice recognition and steering wheel-mounted switches are also used as supplementary controls for a number of secondary tasks (Pickering et al., 2007).

3. THE SYSTEM

IVISs are menu-based systems that enable many secondary functions to be integrated into one system and accessed via a single screen-based interface. This reduces the cluttered appearance of the dashboard. Aesthetically, this approach is superior to the traditional dashboard layout and is ultimately a major selling point for these vehicles: In many cases the IVIS has become a "brand identifier" (Fleischmann, 2007). IVISs are designed to enhance the driving experience by allowing users to accomplish secondary tasks while driving (Lee, Young, & Regan, 2009). The usability of an IVIS is affected by the Human–Machine Interface, which determines how well a driver can input information, receive and understand outputs, and monitor the state of the systems (Cellario, 2001; Daimon & Kawashima, 1996; Stanton & Salmon, 2009). Although the screen-based interface has improved the visual appeal of the vehicle interior, there are a number of usability issues associated with integrating so many functions into a single system. For example, some functions that could be operated simply via the dashboard are now "buried" within a complex, multilevel menu structure and require a number of discrete steps to operate (Burnett & Porter, 2001). IVISs present a unique challenge because it is not only the usability of the system that needs to be carefully considered; both (a) the interaction between the IVIS and the primary task of driving, and (b) the potential consequences of this interaction to driving performance and safety are also of vital importance (Dewar et al., 2000). The challenge for designers is to maximize the benefits offered by secondary functions without sacrificing usability and the needs of the driver (Broström, Engström, Agnvall, & Markkula, 2006; Lee et al., 2009; Walker, Stanton, & Young, 2001).

3.1. Touch Screens and Rotary Controllers

Two main solutions have emerged in an attempt by automotive manufacturers to combine secondary driving controls into a single interactive, screen-based IVIS: touch screen and rotary controller. The latter combines a screen, usually placed at the driver's eye level, with a hard control, normally a variation on a traditional rotary dial located on the center console within reach of the driver. The rotary controller is used to navigate through the menus on screen and to select and operate the required functions. Currently, brands using the rotary controller include Audi, BMW, and Mercedes-Benz. The touch screen, on the other hand, allows direct user input to the display screen (Taveira & Choi, 2009) and therefore does not require a separate hard control. Automotive manufacturers currently using the touch screen include Jaguar, Volkswagen, and Ford.

There are a number of features that differentiate the two technologies and perhaps explain why neither has emerged as the dominant system. Rogers, Fisk, McLaughlin, and Pak (2005) distinguished between direct and indirect control devices. Direct devices, of which the touch screen is an example, do not require any translation between the input from the user and the action of the device; in other words there is "a direct relationship between what the eyes see and what the hands do" (Dul & Weerdmeester, 2001). Direct devices tend to offer increased levels of user satisfaction and acceptance (Rogers et al., 2005). Indirect devices, on the other hand, do require this translation because the control is remote from the device. The rotary controller is an example of an indirect device. Rogers et al. found that indirect devices can be better for experienced users over long periods and that older users' performance was also less variable with these systems. The translation between an input control and the associated on-screen output can, however, be more difficult to learn, and the rotary controller may therefore have lower user acceptance on initial use. This may also present a problem in high workload situations in which drivers are more likely to make a mistake if what they perceive does not match what they expect (Stevens, Quimby, Board, Kersloot, & Burns, 2002). From a physical point of view, the touch screen does not require any associated hard controls and is "space efficient" (Taveira & Choi, 2009), although the screen must be large enough for each "button" to be easily distinguishable and so may need to be larger than the display screen associated with the rotary controller. The rotary controller can enable higher precision inputs than the touch screen and provides tactile feedback to the user, which can give valuable information about whether they have made the correct input. The lack of tactile feedback afforded by the touch screen is a disadvantage in comparison, although there is evidence of recent work to develop touch screens that provide the user with some form of haptic sensation in response to touch, potentially eliminating this problem from future systems (e.g., Excell, 2008; Graham-Rowe, 2010). Screens used in combination with a rotary controller can be positioned for best visual performance, usually as close as possible to the driver's line of sight. They are also often adjustable and have some level of shrouding to reduce the potential for disabling glare (Howarth, 1990). Touch screens, on the other hand, must be positioned within the zone of comfortable reach (Dul & Weerdmeester, 2001) for the driver. This means that the device is often located significantly below the driver's eye line and that any provision of shrouding to protect from glare must be traded off against screen accessibility. The position of the touch screen (i.e., so that it is easily visible) may also mean that the driver's arm must be held outstretched during operation, which could result in some level of muscle fatigue, and the position of the arm and fingers may mean that part of the screen is obscured (Taveira & Choi, 2009).

Due to the problems just discussed, the increasing use of multifunction, screen-based interfaces by vehicle manufacturers, namely, touch screen and rotary controller IVISs, has been described as a "worrying trend" (Burnett & Porter, 2001). There is also concern that technologies such as voice recognition and steering wheel-mounted controls, which are often used to supplement IVISs, have "inherent limitations without significant safety benefits" (Pickering et al., 2007). There is an obvious need to develop a system that improves usability by overcoming the current problems of the two main IVISs and the supplementary technologies just described without losing the benefits that existing systems currently offer.

4. THE USER

Today there is a vast array of technologies available to support in-vehicle interactions. In many cases the success of the technology is limited not by the capabilities of that technology but by the capabilities of the human interacting with it. The focus has now shifted from development of technology to consideration of how to integrate this technology with the human element of the interaction—in this case, the driver (Walker et al., 2001). To optimize the human–machine interaction for IVISs, it is important to take a driver-centered approach—in other words, identify and understand the needs of the driver within the context of driving (Heide & Henning, 2006; Stanton & Salmon, 2009). Walker et al. (2001) identified three main driver needs considered to be of importance by automotive manufacturers in relation to the use of information and communication technologies within vehicles: safety, efficiency and enjoyment. In this context the main aims for an IVIS should be to ensure the safety of vehicle occupants by providing relevant information without distracting the driver from the primary task of driving, to enhance the efficiency of vehicle use by providing information about the vehicle and road network, and to provide functions that are enjoyable to use (Cellario, 2001; Walker et al., 2001). The task for automotive manufacturers is to provide an IVIS that is capable of balancing all three of these driver needs (Tingvall, Eckstein, & Hammer, 2009).

4.1. Safety

Alonso-Ríos, Vázquez-García, Mosqueira-Rey, and Moret-Bonillo (2010) defined user safety as "the capacity to avoid risk and damage to the user when the system is in use" (p. 61). On its own, the use of an IVIS poses minimal risk to the user's physical safety; however, when the user–system interaction takes place at the same time as the primary driving task, a driver's safety may be compromised due to the distracting effect of this interaction. This distraction occurs either as a direct result of the functions provided by the IVIS (i.e., loud music) or from the interaction between driver and system (i.e., the driver glancing away from the road to locate functions presented in a visual display; Horrey, Alexander, & Wickens, 2003). Based on results of the 100-Car Naturalistic Driving Study, Klauer, Dingus, Neale, Sudweeks, and Ramsey (2006) estimated that distraction caused by secondary task interaction contributed to more than 22% of all crashes and near crashes. Hedlund et al. (2006) defined driver distraction as arising from "any activity that takes a driver's attention away from the task of driving" (p. 1).

This distracting activity can divert attention from the road ahead by creating a mismatch between the attention demanded by the driving environment and the attention the driver is able to devote to it (Lee et al., 2009). If the demands of both the driving environment and the concurrent task are high, then this is likely to exceed a driver's capacity and could lead to distraction (Gu Ji & Jin, 2010; Matthews et al., 2001). There is an upper limit to the level of sensory input a human user can receive and successfully respond to at any time, and automotive manufacturers must therefore balance the provision of information via the IVIS with the capabilities of the human user. This becomes more important as the number of tasks integrated into IVISs increases. The way in which a driver shares attention between competing tasks is very difficult to predict because it is dependent on the immediate situation, specifically the demands of the road environment, and the available capacity of the driver to attend to task performance (Lee et al., 2009). This is influenced by user characteristics and will vary between and within individuals due to factors such as age, experience, stress, and fatigue (Bayly, Young, & Regan, 2009).

4.2. Efficiency

The primary aims of efficient driving are to reach the intended destination in an acceptable time, expending a proportionate level of resources (Alonso-Ríos et al., 2010). Some secondary tasks are designed to support the driving task by helping the driver to drive more efficiently (Bayly et al., 2009); for example, navigation information can guide drivers to their destination using the quickest or shortest route possible (Bayly et al., 2009; Walker et al., 2001). Traffic information presented via the radio can also inform the drivers of incidents that could impact on their journey, allowing them to make more informed route decisions and avoid holdups. As well as providing information to the driver, IVISs can also take some control away from the driver by automating tasks in circumstances where technology can offer more efficient performance than the driver (Walker et al., 2001). Automation of tasks can have positive and negative effects on the efficiency of driver performance, and the decision of which tasks to automate should therefore be taken with great care. Drivers also want to be able to interact with the IVIS itself in the most efficient way. This means performing secondary tasks via the IVIS successfully, quickly, with few errors, and within the limits of information-processing capacity (International Organization for Standardization, 1998). The efficiency of the IVIS is determined by the design of the system and its interface. An IVIS with high usability will enable a more efficient interaction between driver and system by presenting clear and useful information to the driver. The driver must also be able to successfully and efficiently input information back to the IVIS and monitor the state of the system for changes.

4.3. Enjoyment

For many people driving is not only a means of getting to a destination, it is also an enjoyable experience in itself. Secondary functions can, in some circumstances, relieve the boredom of the driving task and maintain the driver's alertness (Bayly et al., 2009); for example, audio functions offer a source of entertainment to the driver and are aimed at enhancing their enjoyment of driving. Comfort is also an important factor in enjoyment; drivers will not enjoy being in a vehicle that is excessively hot or cold. Enjoyment factors also have an impact on the saleability of vehicles (Walker et al., 2001) and play an important role in brand identification (Fleischmann, 2007; Tingvall et al., 2009). In the competitive automotive market this is essential for consideration in the design and evaluation process. Satisfaction is becoming increasingly important as a factor of the usability of products, as it has a major influence over people's enjoyment of driving. In this context, satisfaction refers to the user's perception of the level of system usability. A system that is perceived to work well, in a way that the user expects, will lead to high levels of user satisfaction (Savoy, Guo, & Salvendy, 2009). Enjoyment is a wider concept, which includes satisfaction but also relates to the functionality of the IVIS and the overall driving experience. Enjoyment can be measured subjectively by evaluating users' preferences; however, Andre and Wickens (1995) argued that the most preferred systems may not always be the best in terms of performance. In designing for usability of IVISs, performance and preference should not, however, be treated as distinct concepts. High usability will enhance a user's interaction with an IVIS, for example, by making it more efficient, effective, and easier to learn. These features of usability are also associated with increasing the user's enjoyment of the interaction, and therefore their preference for the system.

5. THE TASK–USER–SYSTEM INTERACTION

The individual components in the task–user–system interaction have been defined and discussed. The next step in forming a model to predict and evaluate IVIS usability is to investigate how the task, user, and system (just described) interact.

5.1. Multimodal Interactions

For tasks to be completed successfully there must be a transfer of information between the user and the system. This usually consists of inputs made by the user to the system and outputs from the system to the user. User inputs can be made via one of two modes: physical, which in the case of most IVISs involves movements such as pushing buttons and turning dials, and verbal, involving the user speaking commands that the system is able to recognize. Secondary driving tasks are controlled primarily by the driver's hands, via the physical mode, although voice-based controls have become increasingly widely used in recent years. System outputs can be made via three different modes: visual, auditory, and physical. The visual mode is the most common mode of information presentation from system to human used while driving (Agah, 2000; Bach, Jæger, Skov, & Thomassen, 2008; Sivak, 1996; Wierwille, 1993), and most IVISs use it as the primary mode of presentation. The auditory mode is relatively underused in driving tasks, in comparison to vision. Use of the auditory mode for secondary task information presentation has received support because auditory tasks can occur simultaneously with visual tasks with minimal interference between the two information-processing channels (Fang, Xu, Brzezinski, & Chan, 2006). During primary driving, the demands on the auditory mode are also relatively low, and there is spare capacity that could be used in receiving auditory information associated with secondary in-vehicle tasks (Hulse et al., 1998). Compared with the visual mode, physical interaction plays a very small role in information gathering while driving. Haptic feedback, such as vibrations used to alert the driver to new information, is an example of where physical system outputs could be used within a driving environment; however, the range of information and level of detail presented is severely limited in this mode. As well as sending and receiving information to and from a system, the user must also process this information via the cognitive mode. This processing enables the driver to understand the information being presented by the system and make suitable decisions in response to that information. The transfer of information between user and system via these different modes of interaction and presentation are illustrated in Figure 1.

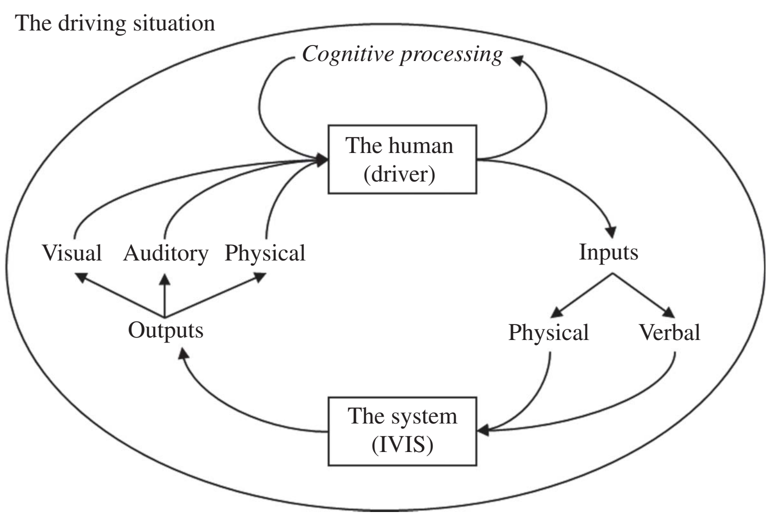

FIGURE 1 The interaction between human (driver) and system (In-Vehicle Information System [IVIS]).

5.2. Toward a Prediction of IVIS Usability

The work of Card et al. (1983) showed that it was possible to create models of the task–user–system interaction to enable predictions to be made about system performance. These predictions can then be used to inform system design improvements. Before these system performance predictions can be made, however, it is essential to specify exactly what aspects of system performance are relevant to the particular system under investigation. Defining how the system should perform gives designers and evaluators a benchmark against which to measure actual system performance and decide on the required improvements to design. In this case we are interested in the performance of IVISs, which allow drivers to interact with secondary in-vehicle tasks while driving. These systems and their specific context of use were investigated in a study by Harvey, Stanton, Pickering, McDonald, and Zheng (2010). This work involved the development of a list of criteria that are of most importance in the usability of IVISs: This is described in relation to the current work in the following section.

6. DEFINING SYSTEM PERFORMANCE FOR IVISs

Harvey et al. (2010) conducted a review of literature relating to IVISs and the context within which they are used, in order to further understand how the usability of these devices can be measured and improved. It was found that the context of use of IVISs was dependent on six factors:

Dual task environment: Fastrez and Haué (2008) suggested that one of the most important factors relating to the usability of IVISs was that the interaction with this system was not the driver's main task, that is, most of their time is also spent performing the primary task of driving (Gu Ji & Jin, 2010; Stanton & Young, 1998). This distinguishes IVISs from most other products and systems and introduces the issue of considering interactions within a "dual task environment" (Lansdown, Brook-Carter, & Kersloot, 2002).

Environmental conditions: This factor is relevant in a driving context because vehicles are driven under a wide range of environmental conditions (Fuller, 2005; International Organization for Standardization, 1996), unlike many other systems that are designed for a specific, and relatively static, environment, such as an office or factory. Environmental factors include light levels (e.g., conditions of darkness or excessive sunlight), road conditions, weather, and other road users.

Range of users: The population of potential IVIS users is very large and includes a diverse range of physical, intellectual, and perceptual characteristics that need to be considered in the design and evaluation of these systems. Two of the most important and widely studied user characteristics are age and experience, with older and novice drivers considered two of the most vulnerable groups in terms of balancing the information-processing requirements of primary and secondary tasks (Baldwin, 2002; Herriotts, 2005; Stevens et al., 2002).

Training provision: Most users of IVISs will begin as novices; however, they must start using the system well almost immediately, as it is not expected that drivers need, or want, to undergo any IVIS-related training (Marcus, 2004). This means that factors such as learnability and initial system performance must be given consideration when evaluating and designing these systems specifically (Fastrez & Haué, 2008; Landau, 2002).

Frequency of use: In the design and evaluation of IVISs it is important to consider which functions of these systems will be used most frequently by drivers. This may vary between drivers who use their vehicle for different purposes. It may be useful to model the driver–IVIS interaction in a way that gives more weight to those features of the system that are used most frequently; however, other features should not be neglected in the design process.

Uptake: For the majority of the time, interaction with an IVIS is not essential to successful driving, but it is something that the driver may choose to do to enhance his or her driving experience. The issue of uptake is strongly related to the user's subjective experience of the system, as this will determine whether the IVIS is actually used in real driving.

Harvey et al. (2010) examined which aspects of existing general definitions of usability were relevant to these six context-of-use factors in order to define a list of 13 usability criteria for IVISs, which is shown in Figure 2. These 13 criteria collectively define usability for IVISs and were developed to meet the overall needs of drivers: safety, efficiency, and enjoyment. These usability criteria must be viewed within the boundaries defined by the needs of the driver to ensure that IVISs are designed to meet these needs and contribute to the overall driving experience. The interaction between driver and IVIS must, in itself, be efficient and must also enhance the efficiency of the complete driving experience. The interaction must also increase, and not detract from, the driver's enjoyment of the driving experience. Finally, these goals of a usable IVIS must not oppose the goal of safe driving. The 13 usability criteria are all measurable, either objectively or subjectively, and can therefore be used to provide a structure for the design and evaluation of IVISs, covering all relevant aspects of usability. This provides a framework to describe what is meant by usability in relation to IVISs and means that specific methods of modeling the interaction between the task, user, and system can be targeted toward meeting each of the 13 criteria.

7. MODELING THE TASK–SYSTEM–USER INTERACTION

With regard to the formula for system performance defined by Card et al. (1983), we have so far described the system, the users and their needs, and the type of tasks being performed (sections 2–4). We have examined how these three variables interact (section 5), and defined the criteria for successful system performance in terms of IVIS usability (section 6). The next stage is to identify how the task–user–system interaction should be modeled to produce a prediction of system performance that will allow IVISs to be evaluated and improvements made to their design. A framework for this usability evaluation is shown in Figure 3. It

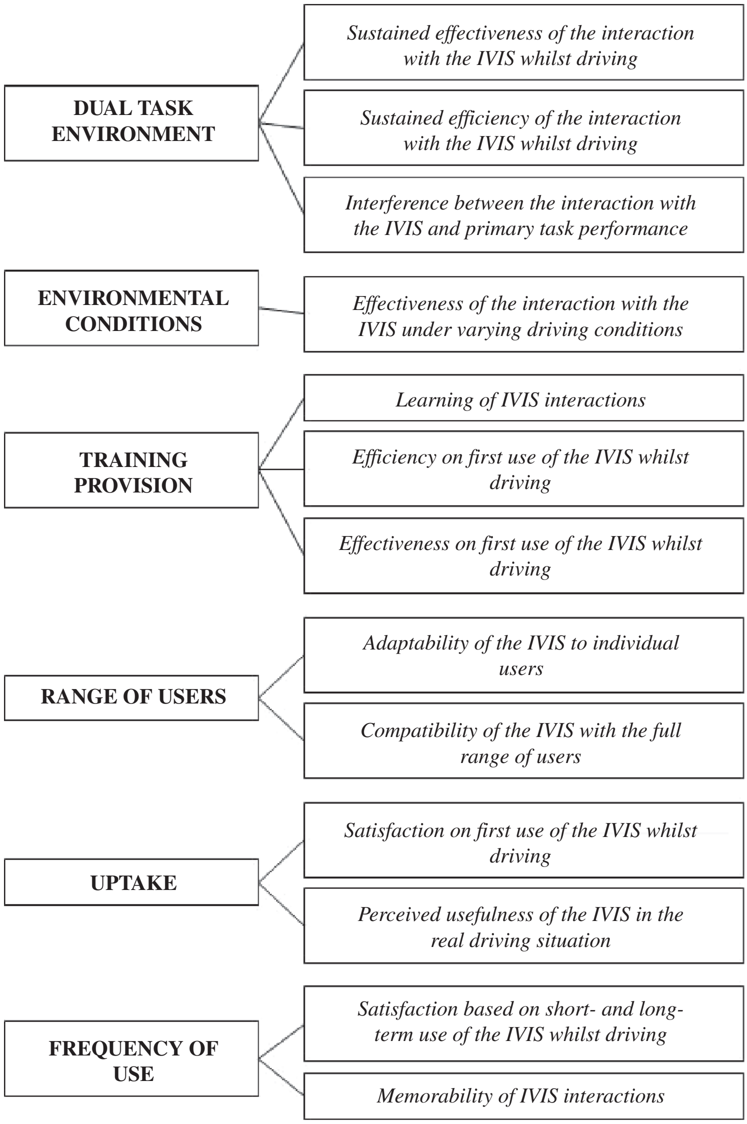

FIGURE 2 Contextual factors and usability criteria for In-Vehicle Information Systems (IVISs).
Note. From "Context of Use as a Factor in Determining the Usability of In-Vehicle Devices," by C. Harvey, N. A. Stanton, C. A. Pickering, M. McDonald, and P. Zheng, 2010, *Theoretical Issues in Ergonomics Science,* advance online publication. Copyright by Taylor & Francis. Reprinted with permission.

consists of two modeling stages, based on the work by Card et al. (1983): symbolic models and experimental models. Desktop methods are used to compute symbolic models via paper- or computer-based simulations of the interaction, which can be used to predict secondary task performance parameters such as interaction

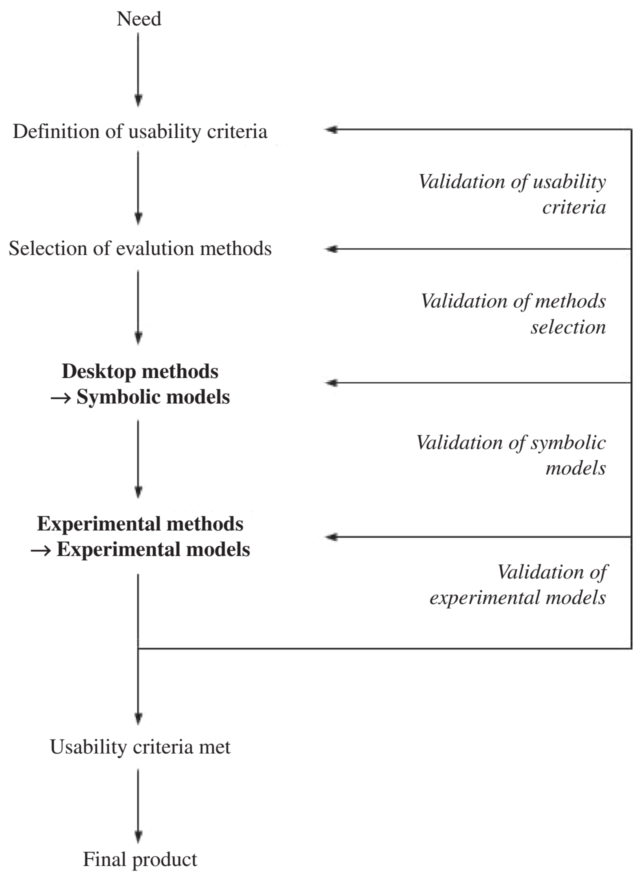

FIGURE 3 Proposed task–user–system interaction data collection and modeling process.

times and potential errors. Experimental methods measure actual performance of human users interacting with system prototypes, generating data on driving and secondary task performance. These data are used to generate models of primary and secondary task performance and of the interaction between the two. These models will be continuously refined and validated in an iterative evaluation and design process. The results obtained from applying these methods can then be used to predict how well the IVIS under investigation will meet the usability criteria. A case study is provided to illustrate the application of evaluation methods and generation of models to predict IVIS usability.

7.1. Case Study: Symbolic Models

Desktop methods were applied in the evaluation of two existing IVISs: One was a touch screen-based system, and the other comprised a remote controller with a separately located display screen. The desktop methods applied in this

Table 1: Results Summary for the Desktop Evaluation of Two Existing In-Vehicle Information Systems

Method	*Touch Screen*	*Remote Controller*	*Best Performance?*
HTA	125 total operations	113 total operations	Remote controller
CPA	63,080 msec total task time	78,430 msec total task time	Touch screen
SHERPA	6 highly rated errors	7 highly rated errors	Touch screen
Heuristic analysis	13 -ive / 7 +ive issues	11 -ive / 8 +ive issues	Remote controller
Layout analysis	11 layout changes across two menu screens	18 layout changes across two menu screens	Touch screen

Note. HTA = hierarchical task analysis; CPA = critical path analysis; SHERPA = systematic human error reduction and prediction approach.

evaluation were hierarchical task analysis (HTA), critical path analysis (CPA), systematic human error reduction and prediction approach (SHERPA), heuristic analysis, and layout analysis. The results of these methods were used to generate a model of the human–machine interaction for both systems, in terms of task structures, task interaction times, error potentials, usability issues, and physical design deficiencies. The results of this evaluation are briefly summarized in Table 1.

The results showed that the methods were able to discriminate between the two systems; for example, the CPA showed that the touch screen produced shorter task times compared with the remote controller system, and SHERPA predicted that the remote controller would produce fewer interaction errors than the touch screen. The findings also showed that HTA and CPA were most useful for generating objective data with which to make direct comparisons between the usability of the two systems. SHERPA, heuristic analysis, and layout analysis, on the other hand, proved more valuable as tools for generating possible design improvements and required a more subjective interpretation. Modeling these aspects of the Human–Machine Interface identified areas that did not meet the predefined usability criteria for IVISs. This information can be used to inform the redesign of the two systems, with the aim of fulfilling the IVIS usability criteria.

7.2. Experimental Models

Experimental evaluation methods test real users under controlled conditions to produce task performance data. A sample of users will be asked to interact with prototype IVISs while driving along a simulated route in the University of Southampton's driving simulator. Measures of primary and secondary task performance, such as the number of driving errors, lane positions, and secondary task interaction times, will be taken. Subjective ratings of usability and workload will also be collected via questionnaires and rating scales. These experimental data will be combined with the results of the desktop evaluation and used to evaluate how well IVISs can meet the usability criteria described in section 6.

8. CONCLUSIONS AND RECOMMENDATIONS

Card et al. (1983) proposed that in order to predict the performance of a particular system, the interaction between three variables—the task, the user, and the system—needs to be modeled. Before this interaction can be modeled, a thorough understanding of the task, user, and system is required, and certain criteria for a target level of system performance must be defined. A modeling approach is proposed for the evaluation of the usability of IVISs, and this article demonstrates how the information required to develop such a model can be collected and used. A discussion of the task, user, and system in the context of IVISs has been presented to provide the information necessary to understand the interaction to be modeled. Criteria for usability of IVISs, developed as part of this project and presented in a previous publication, have been used to define a benchmark level of system performance. A case study of the application of five desktop methods to the evaluation of two existing IVISs has been presented. The symbolic models developed from the results of this evaluation will be combined with experimental models to assess the overall usability of IVISs in terms of the 13 usability criteria defined previously. This modeling approach will enable the prediction and measurement of IVIS usability, and the results will be used to inform the redesign of these systems to meet the needs of drivers.

An approach to the evaluation of IVIS usability has been outlined and discussed in this article. To conclude, a set of basic recommendations that can assist designers and evaluators of IVISs when preparing to apply this evaluation process has been developed:

1. *Specify and understand the characteristics of the task, the user, and the system, and the interactions between them.* Usability is not just a function of the product; rather, it is determined by the interactions between the tasks, users, and system. To identify usability issues, evaluators and designers must have a thorough understanding of the original system under investigation. It is not only the usability of the system itself that should be considered but also the impact that this has on the primary driving task. With regard to the dual-task environment created by IVISs, the issue of interaction mode is particularly important. Including dual-task environment as a major context of use factor for IVISs directs the evaluation toward the identification of conflicts between information relating to the primary driving tasks and the secondary tasks. This can be used to minimize the potential for these conflicts, reducing the likelihood of distraction.
2. *Define a set of usability criteria for the product or system in question, taking account of the specific context of use.* Before a system can be evaluated, evaluators need to know what aspects of system performance are relevant to the usability of that particular system. Defining usability criteria, which will be specific to the context of use of the system in question, provides evaluators with a benchmark level of usability against which to evaluate. The results of evaluations and any recommendations for design improvements should also be defined in relation to these usability criteria. A set of six usability factors were defined for the context of use of IVISs: dual-task environment, environmental conditions, training provision, range of users, uptake, and

frequency of use. A list of 13 usability criteria was then derived to guide the comprehensive evaluation of these systems.

3. *Ensure that the criteria for usability do not conflict with the needs of the users.* Systems and tasks can be designed for usability; however, if little is understood about the people who will be using the systems to perform the tasks, then this interaction is unlikely to be optimal. With many of the advanced technologies available today, it is often the human user that is the limiting factor to successful performance. These limitations can be minimized if the needs and capabilities of the user are considered throughout the design and evaluation process. In the case of IVISs, designers must focus on the needs of the driver, which have been defined as safety, efficiency, and enjoyment.
4. *Maintain a successful balance between functionality and usability of in-vehicle technologies when making design recommendations.* Usability problems are likely to occur more frequently with systems that attempt to integrate high levels of functionality. Recent years have seen a large rise in the demand for and availability of technologies within vehicles. This has inevitably resulted in an increase in the complexity of IVISs, which has given rise to many of the usability issues common with these systems today. This is not to say that IVISs cannot have high levels of both functionality and usability. The evaluation framework presented here has been developed and tested using systems offering these high levels of in-vehicle functionality in an attempt to address this issue. Improving the usability of IVISs should minimize the problems caused by having many different functions, because these will be managed in an appropriate way. In cases where functionality presents a challenge to usability, new technologies, such as adaptive interfaces and task automation, should be considered in the development of design solutions to minimize usability problems.

REFERENCES

Agah, A. (2000). Human interactions with intelligent systems: Research taxonomy. *Computers & Electrical Engineering*, *27*, 71–107.

Alonso-Ríos, D., Vázquez-García, A., Mosqueira-Rey, E., & Moret-Bonillo, V. (2010). Usability: A critical analysis and a taxonomy. *International Journal of Human–Computer Interaction*, *26*, 53–74.

Andre, A. D., & Wickens, C. D. (1995, October). When users want what's not best for them. *Ergonomics in Design*, pp. 10–13.

Bach, K. M., Jæger, M. G., Skov, M. B., & Thomassen, N. G. (2008, April). *You can touch but you can't look: interacting with in-vehicle systems*. Paper presented at the Conference on Human Factors in Computing Systems, CHI '08, Florence, Italy.

Baldwin, C. L. (2002). Designing in-vehicle technologies for older drivers: application of sensory-cognitive interaction theory. *Theoretical Issues in Ergonomics Science*, *3*, 307–329.

Bayly, M., Young, K. L., & Regan, M. A. (2009). Sources of distraction inside the vehicle and their effects on driving performance. In M. A. Regan, J. D. Lee, & K. L. Young (Eds.), *Driver distraction: Theory, effects and mitigation* (pp. 191–213). Boca Raton, FL: CRC Press.

Broström, R., Engström, J., Agnvall, A., & Markkula, G. (2006). *Towards the next generation intelligent driver information system (IDIS): The Volvo car interaction manager concept*. Gothenburg, Sweden: Volvo Car Corporation.

Burnett, G. E., & Porter, J. M. (2001). Ubiquitous computing within cars: designing controls for non-visual use. *International Journal of Human–Computer Studies*, *55*, 521–531.

Card, S. K., Moran, T. P., & Newell, A. (1983). *The psychology of human–computer interaction*. London, UK: Erlbaum.

Cellario, M. (2001). Human-centered intelligent vehicles: toward multimodal interface integration. *IEEE Intelligent Transportation Systems*, *16*, 78–81.

Daimon, T., & Kawashima, H. (1996). New viewpoints for the evaluation of in-vehicle information systems: Applying methods in cognitive engineering. *JSAE Review*, *17*, 151–157.

Dewar, R. E., Fenno, D., Garvey, P. M., Kuhn, B. T., Roberts, A. W., Schieber, F., et al. (2000). *User information systems: Developments and issues for the 21st century*. Washington, DC: Transportation Research Board.

Dul, J., & Weerdmeester, B. (2001). *Ergonomics for beginners: A quick reference guide*. London, UK: Taylor & Francis.

Engström, J., Arfwidsson, J., Amditis, A., Andreone, L., Bengler, K., Cacciabue, P. C., et al. (2004, May). *Meeting the challenges of future automotive HMI design: an overview of the AIDE integrated project*. Paper presented at the ITS Congress, Budapest, Hungary.

Excell, J. (2008, July–August). Haptic technology: Magic touch. *The Engineer*, pp. 16–19.

Fang, X., Xu, S., Brzezinski, J., & Chan, S. S. (2006). A study of the feasibility and effectiveness of dual-mode information presentations. *International Journal of Human-Computer Interaction*, *20*, 3–17.

Fastrez, P., & Haué, J.-B. (2008). Editorial: Designing and evaluating driver support systems with the user in mind. *International Journal of Human–Computer Interaction*, *66*, 125–131.

Fleischmann, T. (2007). Model-based HMI specification in an automotive context. In M. J. Smith & G. Salvendy (Eds.), *Human interface and the management of information: Methods, techniques and tools in information design* (pp. 31–39). Berlin, Germany: Springer-Verlag.

Fuller, R. (2005). Towards a general theory of driver behaviour. *Accident Analysis and Prevention*, *37*, 461–472.

Graham-Rowe, D. (2010, March 3). Touch screens that touch back. *Technology Review*. Cambridge, MA: MIT. Available from http://www.technologyreview.com/computing/24679/?a=f

Gu Ji, Y., & Jin, B. S. (2010). Development of the conceptual prototype for haptic interface on the telematics system. *International Journal of Human–Computer Interaction*, *16*, 22–52.

Harvey, C., Stanton, N. A., Pickering, C. A., McDonald, M., & Zheng, P. (2010). Context of use as a factor in determining the usability of in-vehicle devices. *Theoretical Issues in Ergonomics Science*. Advance online publication. doi:10.1080/14639221003717024

Hedlund, J., Simpson, H., & Mayhew, D. (2006). International Conference on Distracted Driving: Summary of proceedings and recommendations. Canadian Automobile Association/Traffic Injury Research Foundation.

Heide, A., & Henning, K. (2006). The "cognitive car": A roadmap for research issues in the automotive sector. *Annual Reviews in Control*, *30*, 197–203.

Herriotts, P. (2005). Identification of vehicle design requirements for older drivers. *Applied Ergonomics*, *36*, 255–262.

Horrey, W. J., Alexander, A. L., & Wickens, C. D. (2003). *Does workload modulate the effects of in-vehicle display location on concurrent driving and side task performance?* Savoy: Aviation Human Factors Division, Institute of Aviation, University of Illinois.

Howarth, P. A. (1990). Assessment of the visual environment. In J. R. Wilson & E. N. Corlett (Eds.), *Evaluation of human work: a practical ergonomics methodology* (pp. 351–386). London, UK: Taylor & Francis.

Hulse, M. C., Dingus, T. A., Mollenhauer, M. A., Liu, Y., Jahns, S. K., Brown, T., & McKinney, B. (1998, October 16). *Development of human factors guidelines for advanced* *traveler information systems and commercial vehicle operations: Identification of the strengths and weaknesses of alternative information display formats* (Rep. No. FHWA-RD-96-142). Washington, DC: Federal Highway Administration.

International Organization for Standardization. (1996). *Guide to in-vehicle information systems* (DD 235). Geneva, Switzerland: Author.

International Organization for Standardization. (1998). *Ergonomic requirements for office work with visual display terminals (VDTs), Part 11: Guidance on usability* (British Standards Institute 9241-11:1998). Geneva, Switzerland: Author.

Klauer, S. G., Dingus, T. A., Neale, V. L., Sudweeks, J., & Ramsey, D. J. (2006). *The impact of driver inattention on near-crash/crash risk: An analysis using the 100-car naturalistic driving study data*. Blacksburg, VA: Virginia Tech Transportation Institute.

Landau, K. (2002). Usability criteria for intelligent driver assistance systems. *Theoretical Issues in Ergonomics Science*, *3*, 330–345.

Lansdown, T. C. (2000). Driver visual allocation and the introduction of intelligent transport systems. *Proceedings of the Institution of Mechanical Engineers, Part D: Journal of Automobile Engineering*, *214*, 645–652.

Lansdown, T. C., Brook-Carter, N., & Kersloot, T. (2002). Primary task disruption from multiple in-vehicle systems. *Intelligent Transportation Systems Journal*, *7*, 151–168.

Lee, J. D., Young, K. L., & Regan, M. A. (2009). Defining driver distraction. In M. A. Regan, J. D. Lee, & K. L. Young (Eds.), *Driver distraction: theory, effects and mitigation* (pp. 31–40). Boca Raton, FL: CRC Press.

Marcus, A. (2004, January–February). Vehicle user interfaces: The next revolution. *Interactions*, pp. 40–47.

Matthews, M. L., Bryant, D. J., Webb, R. D. G., & Harbluk, J. L. (2001). Model for situation awareness and driving: application to analysis and research for intelligent transportation systems. *Transportation Research Record*, *1779*, 26–32.

Pickering, C. A., Burnham, K. J., & Richardson, M. J. (2007, October). *A review of automotive human machine interface technologies and techniques to reduce driver distraction*. Paper presented at the second Institution of Engineering and Technology International Conference on System Safety, London.

Rakotonirainy, A., & Tay, R. (2004, October). *In-vehicle ambient intelligent transport systems (I-VAITS): Towards an integrated research*. Paper presented at the seventh International IEEE Conference on Intelligent Transportation Systems, Washington, DC.

Regan, M. A., Lee, J. D., & Young, K. L. (2009). Introduction. In M. A. Regan, J. D. Lee, & K. L. Young (Eds.), *Driver distraction: Theory, effects and mitigation* (pp. 3–7). Boca Raton, FL: CRC Press.

Rogers, W. A., Fisk, A. D., McLaughlin, A. C., & Pak, R. (2005). Touch a screen or turn a knob: Choosing the best device for the job. *Human Factors*, *47*, 271–288.

Savoy, A., Guo, Y., & Salvendy, G. (2009). Effects of importance and detectability of usability problems on sample size requirements. *International Journal of Human–Computer Interaction*, *25*, 430–440.

Seppelt, B., & Wickens, C. D. (2003). *In-vehicle tasks: Effects of modality, driving relevance, and redundancy*. Urbana: Aviation Human Factors Division, University of Illinois at Urbana-Champaign.

Sivak, M. (1996). The information that drivers use: Is it indeed 90% visual? *Perception*, *25*, 1081–1089.

Stanton, N. A., & Salmon, P. M. (2009). Human error taxonomies applied to driving: A generic driver error taxonomy and its implications for intelligent transport systems. *Safety Science*, *47*, 227–237.

Stanton, N. A., & Young, M. S. (1998). Ergonomics methods in consumer product design and evaluation. In N. A. Stanton (Ed.), *Human factors in consumer products* (pp. 21–54). London, UK: Taylor & Francis.

Stevens, A., Quimby, A., Board, A., Kersloot, T., & Burns, P. (2002). *Design guidelines for safety of in-vehicle information systems*. London, UK: Transport Research Laboratory.

Taveira, A. D., & Choi, S. D. (2009). Review study of computer input devices and older users. *International Journal of Human–Computer Interaction*, *25*, 455–474.

Tingvall, C., Eckstein, L., & Hammer, M. (2009). Government and industry perspectives on driver distraction. In M. A. Regan, J. D. Lee, & K. L. Young (Eds.), *Driver distraction: Theory, effects and mitigation* (pp. 603–618). Boca Raton, FL: CRC Press.

Walker, G. H., Stanton, N. A., & Young, M. S. (2001). Where is computing driving cars? *International Journal of Human–Computer Interaction*, *13*, 203–229.

Wierwille, W. W. (1993). Visual and manual demands of in car controls and displays. In B. Peacock & B. Karwowski (Eds.), *Automotive ergonomics* (pp. 299–313). London, UK: Taylor & Francis.

Young, K., Regan, M., & Hammer, M. (2003). *Driver distraction: a review of the literature*. Victoria, Australia: Monash University Accident Research Centre.