Human Factor Considerations of Motorist Navigation and Information Systems

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Abstract

In-vehicle systems have the potential for ameliorating problems associated with navigation and operations including delay, excess fuel consumption, congestion, and increased safety risk. A proliferation of vehicle-based systems, however, has resulted in a lack of standardization, and a diversity of functions. User interfaces are crucial to system effectiveness. Therefore, while display and control configurations will ultimately be determined by the marketplace, it is important that human factors be addressed, and guidelines developed. This will assure standardization and display and control optimization. Human factors have been considered in terms of seven questions: "Why?", "What?", "When?", "Where?", "How?", "Who?", and "Can?".

Introduction

The highway system is designed to provide for the safe and efficient movement of people and goods. Although considerable attention has been directed toward enhancing safety (1), until recently, less emphasis has been placed on the importance of motorist navigation and its impact on system efficiency. It is now recognized that improper navigation contributes to delay, excess fuel consumption, congestion, and increased accident risk (2). Studies (3)(4) have found that from 6 to 15 percent of all highway mileage is "waisted" due to navigational deficiencies. Given annual travel in America approaching 2 trillion miles (5), the monetary loss caused by suboptimal navigation is immense. The annual cost of navigational error in the United States, not counting air pollution, is in excess of \$45 billion (6).

Efforts are underway in America and world-wide to develop systems to aid the motorist's navigational task and to provide other types of information. These systems have the potential to ameliorate most navigation problems and to aid in other aspects of the driving task as well (7). To date, the main emphasis in the development of vehicle-based systems has been to refine and improve the technology of the various systems since most are still under development. However, emphasis is now shifting to a consideration of applicable human factors, as the ultimate success of these systems rests in their acceptance and use by the motoring public.

This paper identifies a number of important human factors considerations and presents information on how the Federal Highway Administration (FHWA) is addressing them. Seven basic human factors-related questions are used as a conceptual framework for identifying these considerations, and for describing how they have been or might be addressed by the public and private sectors.

Human Factors Questions

1. Why do drivers need navigation information? 2. What information do they need? 3. When do they need it? 4. Where should the information be located? 5. How should the information be displayed and accessed? 6. Who are the users and what are their characteristics?, and 7. Can they use the systems effectively?

Why? What? and When?

The first three questions have been answered by assessing the driving task in terms of its navigational component.

The Driving Task

Driving is a sensory-motor task that is dependent on the error-free reception and use of information (8). The driving task is characterized as an **information-decision-action (IDA)** activity, where information received **in-transit** is used with information and knowledge **in-storage** to make decisions and perform actions in a continuous **feedback** process. Driving consists of a number of **descrete, interrelated subtasks**. When grouped by IDA components, these subtasks can be arranged into three **Levels of Performance** that assume the **hierarchial** structure shown in **Figure 1 of Control, Guidance, and Navigation (9)**.

Figure 1. Driving Task Model.

At the **Control Level** are the overlearned vehicle control subtasks such as steering and speed control drivers perform continuously. At the **Guidance Level** are the road following and safe path maintenance subtasks, with their reliance on judgement, estimation, and prediction. At the **Navigational Level**, two phases occur, a **pre-trip** phase where a trip plan is formulated, and an **in-transit** phase, where the plan is followed (10). Successful task performance at all levels requires an appropriate complement of information. At the navigation level trip planning, route following, and direction finding are essentially **cognitive** activities.

Navigational Information

Error free performance of navigational subtasks requires an appropriate store of pre-information with which to formulate a trip plan, and an appropriate display of information in-transit to follow the plan. This information is forthcoming using available **aids-to-navigation**. Familiarity and trip purpose are important elements to consider.

Trip Purpose and Driver Familiarity: Trip purposes range from **commuting** through **family/personal** to **social/recreational** (11). Drivers can be classified as **Locals** who are completely familiar with a location's **geography** and **road system**; **Strangers** who are unfamiliar with all aspects of an area; and **Local-Strangers** who are somewhere in between. Most local and commuting trips and trips of short duration tend to be on familiar routes, whereas recreational and other trips of long duration tend to be on unfamiliar routes. When purely local travel is factored out, a high percentage of the motoring public has some degree of directional uncertainty (12).

Pre-Trip Navigational Aids: Regardless of trip purpose, virtually no locals, virtually all strangers, and about **one-half** of all local strangers prepare a formal, codified trip plan. Aids used to develop the plan range from preparation by professionals through self-preparation using maps and brochures to verbal instructions from individuals. The plan's form varies from marked-up road maps and strip maps to step-by-step encoding of links and nodes to memory (13).

In-Trip Navigation Aids: In transit, primary formal navigational aids are **traffic control devices** such as **guide signs** and **pavement markings**. These devices are **standardized** on America's highway system on the basis of road class and navigational need (14). Devices range from **route markers** and **street name signs** on conventional roads and streets to **overhead guide signs** and **interchange sequence signs** on expressways and freeways. In some instances, special treatments such as **changeable message signs** and **diagrammatic guide signs** are used. In addition, navigation information is obtained from informal sources such as billboards and landmarks.

Information Gathering and Processing

Drivers gather information from sources inside and outside the vehicle and process it to formulate decisions. In some instances, task demands may be so simple that drivers become bored and fatigued and experience decreased **vigilance**. On the other hand, there are situations where the task is complex and demanding. Many sources of information may compete for a driver's attention, and many subtasks may have to be performed simultaneously. In these instances, which often occur at high speeds and

extreme time pressures, the key to successful performance is smooth and efficient information gathering, processing, attention sharing, and decisionmaking. In both low and high demand situations, drivers must possess a suitable store of information, including a trip plan, and must be provided with an appropriate array of needed information, **when they need it, where they require it, and in a form best suited to their characteristics** (15). This is necessary to avoid the major cause of highway system failure, **driver error** (16).

Navigational Error

Control and Guidance errors associated with improper speed and path or failure to avoid a hazard are most often manifest as **near misses**, **traffic conflicts**, and **accidents**. Errors associated with Navigation such as improper trip planning and poor direction-finding are most often manifest as **slow driving**, **erratic maneuvers**, **delay**, and **lost or confused drivers**. Secondary consequences include **incidents**, **congestion**, and **increased exposure to accident risk**.

When competent drivers with appropriate trip plans are provided with suitable navigational information in-transit, with sufficient time to gather, process, and respond, they are likely to navigate safely and efficiently (17). However, problems often occur due to pre-trip and/or in-transit deficiencies that result in navigational errors.

Pre-Trip Errors: Pre-trip errors are due to trip plan deficiencies, ranging from failure to develop a plan to development of a deficient or suboptimum one. A number of factors could result in an improper trip plan. The person preparing the plan may not possess map reading and trip planning skills. The preparer may not be able to obtain the needed aids-to-navigation or may fail to take important routing factors such as construction, recurring congestion, and new routes into account. Finally, the preparer may not be able to anticipate factors such as major incidents, adverse weather, etc. and plan accordingly.

In-Trip Errors: In-transit, navigational errors are caused by the lack of a trip plan, by an erroneous plan, deficient information display, unforeseen events in-transit necessitating a route change, and/or task demands that lead to **overload**, **missed choice points**, and **confusion** (18)(19). Drivers without plans expect to find their destinations on guide signs. However, it is not feasible or possible to display all routes and destinations, and some drivers may miss choice points. It was found (20) that many unfamiliar drivers with no trip plan used guide signs to get to the general vicinity of where they wanted to go, and stopped to ask for directions to their ultimate destination. An improper trip plan could put a motorist on a suboptimum route or fail to include a needed choice point. Deficiencies in navigational display due to **missing information carriers**, **illegible carriers**, **obscured signs**, **signs blocked by trucks or foliage**, and information that is **ambiguous**, **confusing**, or with **too high an information challenge** can all result in errors. Unforeseen events in transit can negate a plan and require a driver to make mid-course corrections, generally with insufficient information to accomplish such corrections. In any of these instances, which may occur singularly or in combination, drivers experiencing problem may **slow** or **stop**. Other

manifestations of directional uncertainty include last minute lane changes, hazardous gore weaver, stopping and backing on exit ramps, illegal U turns, etc. (21). Thus, navigation problems not only result in inefficient traffic operations, but may contribute to accidents by placing the lost or confused motorist and the rest of the traffic stream in jeopardy.

Recovery from Navigational Errors: When drivers become uncertain, confused, lost, or off their planned route, they generally find it very difficult to recover (22). They may be required to make difficult or hazardous course changes at high speeds, often with insufficient time to react. They may have to consult with hard to read maps or stop and ask for directions. One study (23) found the navigation task to be so demanding in unfamiliar urban areas that it could not be performed by the driver without the help of a second "crew" member to act as a navigator.

Answers to "Why?", "What?", "When?"

Why?: Drivers need navigation information because of the nature of the driving task and its navigational component, because of the inability of the conventional aids-to-navigation to fulfill all pre-trip and in-transit information needs, because of the possibility of error inherent in the current situation, and because of the need for a navigator to assist the driver.

What?: Drivers need navigation information to formulate an appropriate trip plan. They need information on the most optimum route commensurate with their trip purpose and desires. They need to know how to follow their plan in-transit. They need to know where they are and where they are going. Finally, they need to know what to do if circumstances force them to go off their desired path and how to recover and/or change plans.

When?: Drivers need information in the pre-trip phase to enable them to formulate trip plans and change plans if circumstances require it. Drivers need information in-transit to get to their destination in the most efficient manner. This information must be displayed in a timely manner to enable motorists to navigate safely and efficiently.

Where?

The question, "Where should the information be located?" has been tacitly answered, given the intense developmental effort to produce vehicle-based navigation and information systems. However, full implementation of in-vehicle systems in the majority of the vehicle fleet will not be realized for many years. Therefore, for the foreseeable future, navigation will remain as it is, with drivers relying on maps to plan their trips, commercial radio to inform them of major incidents, and guide signs to find their way. The display of navigational information in-vehicle will be an evolutionary process, and will coexist with the external display of information for years to come.

Vehicle-Based Navigation and Information Systems

There are a number of ways that in-vehicle navigation and information systems can aid the driver's task. Depending on the form such systems ultimately take, they could develop a trip plan, optimize a route in real-time, assure error free route following, aid in recovery if errors occur, and provide a host of information pertaining to services, attractions, weather, sources of delay, congestion,

road conditions, and road hazards. In addition, vehicle-based information systems might provide collision avoidance information, vehicle status information, inter-vehicle communications, and communications with a central authority. Depending on the type of communications link, such systems could also aid in congestion relief by enabling motorists to report incidents and road/traffic conditions, and by automatically inputting delay and traveltime data to a central traffic management authority (24)(25)(26).

Many vehicle-based systems are under development or operational throughout the world. Stephens (27) identified more than 40 of these systems in 1986. Since then, a number of new or improved systems have come under development. Vehicle-based systems range in capability from simple navigational aids to complex multi-functional driver information systems. Using communications to classify these systems, the following scheme has been developed: **No Communications**, essentially a self-contained "smart map"; **Area Broadcasting** and/or **Local Roadside Transmission**, providing one-way communications to the user; and **Mobile Radio Systems** and/or **Local Roadside Transponders**, providing two-way communications between the purveyor and the user.

Since most navigation and information systems are developmental, a determination has not been made as to what features will ultimately be incorporated, what communications capabilities will be available, what information will be provided, displayed, and accessed, and whether and what infrastructure will be established. The exact time-frame for implementation is also unclear, although efforts are underway in America to begin equipping vehicles and establishing a support structure. Advancements in technology and the marketplace will ultimately determine the features of vehicle-based systems. In the interim, emphasis should be placed on **human factors** as well as technology to assure that whatever systems are adopted will be useable, accepted by motorists, and effective in ameliorating navigational and other problems.

Answers to "Where?"

The question of where information is to be located has two responses. For now, and for the foreseeable future, navigational information will continue to be provided **external** to the vehicle. As vehicle-based systems begin to come on line, there will be more and more reliance on information being provided **in-vehicle**, with coexistence between the conventional aids-to-navigation and advanced systems. In the future, when the vehicle fleets are fully equipped, more reliance will be placed on in-vehicle information presentation, although there will probably always be some external information display.

HOW?

How navigation and other vehicle-based information should be displayed and accessed involves a consideration of **user/system interfaces**. The fact that there are so many systems under development, and that each developer is designing displays and control as they see fit has resulted in a lack of standardization from system-to-system. This variability has the potential of reducing system effectiveness. The fact that few systems are operational allows for time to establish display and control guidelines. The Federal Highway Administration has initiated a major study to resolve basic display and control issues in order to

develop needed guidelines. This study, entitled "Assessment of Effects of In-Vehicle Display Systems on Driver Performance" will assess a range of display/control techniques for a range of potential systems in terms of their effects on driver performance. It is scheduled for completion in 1991.

Display Considerations

Most vehicle-based systems display information visually. Visual displays range from maps and symbols to verbal messages (28). The form of the display ranges from a video display terminal (VDT) mounted on the dashboard to a "Head-Up Display" (HUD) viewed through the windshield. Audio displays are generally used in conjunction with visual displays, and range from tones to speech synthesis (29).

Information Displayed: The design of a given display is predicated, in part, on the information to be displayed. Many vehicle-based systems will display more than navigation information. For example, FHWA's "Pathfinder" project, a joint Federal, State, and private industry venture will display congestion and incident information in addition to position, path, and road network information (30). Automobile instrument panels are currently displaying vehicle status information along with the traditional speedometer and odometer displays. This trend will continue and more vehicle information will be provided as vehicles become equipped with on-board computers. This will affect the allocation of functions aspects of the navigation systems' displays, depending on whether a display will be dedicated to a particular function, or whether there will be shared functions (31).

Sensory Mode: There are essentially three display modes, visual, auditory, and combined visual/auditory, with the visual mode being the most prevalent. There may be cross-modal redundancy provided if a combined visual and auditory display is used. Both the visual and auditory channels have attributes that should be considered when displaying information. For example, visual information can be continuously displayed in the vehicle and can thus be available to drivers any time they need it. Auditory information, on the other hand, must be repeated (32). Since most information used in driving is received visually from sources external to the vehicle, information displayed in-vehicle can detract from a driver's information gathering task by requiring a shift in attention from the road. Unless in-vehicle information can be received in short glances or kept on screen to be viewed when convenient, such information could detract from the more prime guidance and navigation subtasks (33). In addition, there may be competition for viewing of in-vehicle navigation and conventional displays which may be a factor in commercial vehicles with multiple displays and gauges. Emphasis should therefore be placed on integrating navigation and vehicle status displays whenever possible. While hearing is not a primary sensory input channel in driving, there are situations such as at railroad grade crossings, and when emergency vehicles are on the road, when signals from on-road sources must be received. If in-vehicle auditory displays mask emergency warnings, there could be a problem. Consideration should also be given to interference from stereos, C-B's, and cellular telephones

Display Characteristics and Techniques:

Many considerations enter into display characteristics and techniques used to convey navigational and other information. Visual displays

could be analog, digital, verbal, symbolic, and/or maps, as well as combinations. Auditory displays could range from non-verbal warning signals and tones to verbal speech synthesis. A visual display's size and location is also important, since both factors affect the user's reception of the information. Thus, visual displays must be large enough to be seen and located within the viewer's field-of-view. Analogous auditory attributes are loudness and location. However, location is not as important because of binaural hearing. Another important consideration for visual display's is their conspicuity, i.e. their ability to attract attention. Even if a HUD is used, drivers may fail to look at the information if not "flagged" using a technique such as a flashing indication, a bright color, or an audio tone or speech synthesized instructions. Other considerations involve the display's stimulus characteristics. For visual displays, factors include color, brightness, contrast, and legibility. For auditory displays, factors include tone, fidelity, repetition rate, and message understandability. Other considerations include display grouping, level of interpretation required, possible reading errors, and ambiguity (34)(35)(36). Figure 2 shows a map display from the Pathfinder project, and Figure 3 shows a symbolic HUD display from the ARISE system.

Figure 2. Sample Travelplot Map Display (Pathfinder).

Figure 3. Heads-Up Symbolic Display (ARISE).

Control Considerations

A range of control techniques are being used by the various systems developers. Among the techniques used are **push buttons** to activate a display, **computer keyboards** to read-in a trip plan, and **touch-screens**. There is also work underway to develop **voice actuation**.

Control Design: Virtually all controls are **hand operated**. Hand operated control functions can be **discrete** or **continuous**. Actuation of controls is accomplished by **pushing, pulling, or turning**. Touch-screen control operates by touching a display on the **VDI (37)**. Controls can be **shape** and/or **color coded**, and may be used **verbal** or **symbolic legends**. A control's **feel** and the **amount of effort** required for actuation are often important considerations. Control **allocation** should be considered, depending on whether functions are **dedicated** or **shared**. If **voice-actuation** is used, issues related to **verbal commands** such as **language, words used, and voice level** must be addressed. Interference caused by in-vehicle equipment, conversation, and background noise could also be a problem.

Control Panel Layout: Control panel layout considerations include **compatibility** of existing vehicle and navigation system controls, **control location, control-display grouping, and control/display compatibility**. User reach and **control sequencing** may also be important.

Answers to "How?"

Displays and controls vary from system-to-system. This lack of standardization could be a problem when the vehicle fleet is equipped. Guidelines are being developed by the **FHWA** to reduce some of the variability, although user interface issues will not be fully resolved until the form and functions of these systems are finalized.

Who?

Since there is no consensus on a **"design driver"**, the question, "Who are the users of the systems, and what are their characteristics?" must be addressed. Unlike military systems whose operators are readily defined within a narrow range, for consumer oriented **vehicle-based systems**, it must be assumed that the target user population is the **overall driving population**.

User Characteristics

It is probable that systems will be designed for the **85th percentile** driver with regard to **anthropometrics** such as **seated eye height and reach**. Similarly, user **demographics** will match the overall driving population's with regard to parameters such as **age**: from a low of 14 to drivers 80+; **sex**: with an almost equal split of males and females; **socio-economic status**: from wealth to poverty; **education**: generally at least a high school education; and **training**: from none to trained, professional drivers.

In considering user characteristics, it should be understood that vehicle-based systems will not be fully operational and in widespread use until the 21st Century. Thus, **future**, rather than current characteristics should be accounted for in design and operation. This is particularly important with regard to **age**, where there is a trend toward an increasingly older driver population. Estimates are that drivers

65+ will constitute 20 percent of the traffic stream by the year 2023 (38).

Characteristics Affecting Perception: One of the most important user characteristic affecting system design and operation is perception. It is critical to system operational effectiveness that displayed information is **received and handled**.

There are many **visual sensory input** characteristics that should be considered, the most basic being that the individual receiving the information must have **adequate vision** to see the display. **Fovial vision** should be used to receive the information, requiring proper placement of the display in the driver's **field of view**. The **visual acuity** of the user is also important, since visual displays will be verbal/symbolic. Visual acuity affects **legibility** requirements and emphasizes the importance of **letter/symbol size, style, and contrast**. Given that vehicle-base systems display information in-vehicle, **visual accommodation** will be critical, as users will be constantly shifting from displays in and out of the vehicle. Another attribute to consider is **color vision, and color weakness**.

In a similar manner, there are a number of **auditory sensory input** characteristics to be considered if auditory displays are used, the most basic being that the user must have **adequate hearing** to receive the information. Signals and or speech must possess the requisite **frequency range, intensity, and fidelity** to be heard in-vehicle.

Characteristics Affecting Information

Handling: In handling information, drivers must be able to **shift attention** from one source of information to another, and properly **time share** the various **decisionmaking** components associated with the numerous subtasks they must perform in-transit. The **number of information carriers** and their **information challenge** affect a user's **reaction time**, and may lead to **overload or error** if too great (39).

Drivers use **task sharing** and **memory** to handle several sources of information, pointing to the importance of **short-term and long-term memory**. Reinforcement of **prevalant driver expectancy** aids in information handling by reducing reaction time. When information sources **compete** for a driver's attention, drivers **load shed** less important sources to attend to and process more important ones. The **number of sources** (in and out of the vehicle) and their **pacing** affect the driver's information handling. **Too much information, displayed too fast**, could lead to **overload**, while **too little information** could lead to **decreased vigilance**. Finally, the **information lead distance** is important, as information must be received in sufficient time for decisionmaking and performing a required maneuver.

Decrements

There are a number of decrements that can lead to suboptimum system operation. Some are associated with **transitory states** induced by **alcohol or drug abuse, extreme fatigue, emotional distress, attitudinal problems, and lawbreaking**. It may not be possible to account for these in design. Other decrements such as **illiteracy, inexperience, and a lack of knowledge** could be overcome by **experience, training, and making the system user-friendly**. There are also a number of decrements associated with the user population which should be taken into account in system design. These include **color weakness**: which

affects 8 percent of the male population; **deficient visual acuity**: which may not be fully correctable or factored out by driver licensing; **poor visual accommodation**: between information inside and outside the vehicle, which may be partially offset by bifocals; **hearing loss**: which is generally not tested for, but which affects a sizeable portion of the population; and **inattention**: which is a risk factor in accidents.

Effects of Age: Perhaps the most significant decrements are those associated with aging. As the driving population becomes increasingly older, more and more elderly motorists will be using vehicle-based systems. Information on all aspects of the aging process is still incomplete, and no exact age criterion for "elderly" is agreed upon. However, it is probable that older system users would experience difficulty due to **poor visual acuity, tunnel vision, presbiopia, slower reaction-time, poor hearing**, and other age-related problems. Age could also be a factor in control design as elderly individuals experience decreases in **strength and flexibility** (40)(41). Consideration may have to be given to designing in-vehicle systems for the older user.

Answers to the "Who?" Question

In response to the question of who the users of the navigation and information systems are, the answer is ultimately **everybody**. How user characteristics might affect system operations is a harder question to answer, as there is no consensus for a design user. However, as in the case of all person/machine interfaces, displays and controls must match the characteristics of operators. The fact that the user population is aging, and therefore possesses diminished capabilities, should also be taken into account.

Can?

The last question "Can drivers use the systems effectively?" assesses two issues: 1. Can drivers use the information effectively? and 2. Do these systems affect the efficiency and safety of the highway system? The best way to resolve these issues is through **operational experience**. However, given the long time-frame for implementation, it will not be possible to fully answer the "can" question in the short-term. In the interim, it is possible to provide preliminary answers through testing experience as systems come on-line in America and world-wide.

Governmental Efforts

The FHWA has developed a **High Priority National Program Area (HPNPA)** to systematically assess the effectiveness and impacts on the highway system of a number of vehicle-based systems (42). The HPNPA includes the following projects:

- o **Assessment of Alternative Technologies for Relieving Urban Congestion.**
- o **National Cooperative R&D Program for Utilizing Advanced Technology.**
- o **Cooperative Field Evaluation of an Experimental In-Vehicle Navigation and Information systems.**
- o **A Second-Phase Cooperative Experiment of a Vehicle-Based Navigation and Information System.**

- o **Assessment of the Effects of In-Vehicle Display Systems on Driver Performance.**
- o **In-Vehicle Hazard Warning Systems.**
- o **Development of Optimal Routing Techniques.**
- o **Field Evaluation of an Advisory Optimal Routing System.**
- o **Synthesis and Preliminary Assessment of Integrated In-Vehicle Navigation and Information System.**

Future Efforts: As results become available, FHWA will disseminate them to State and local jurisdictions involved in systems implementation and support. The results of the HPNPA and other FHWA-sponsored and/or implemented efforts will be used to **establish guidelines**, and to determine **economic benefits and practical significance**. FHWA will also provide **promotion, demonstration, and training**.

Answers to "Can?"

While full answers to the question concerning whether vehicle-based systems can be used effectively by the motoring public await implementation and operational experience, it is expected that the answer will be **"yes"**. It is further expected that when human factors guidelines are applied to interface design and operation, these systems **will not** adversely affect highway safety. Preliminary results from on-going studies support these expectations.

Conclusion

In conclusion, there are numerous human factors considerations that should be accounted for in the design and operation of vehicle-based navigation and information systems. Many issues still remain to be resolved. Some may be resolved analytically, others empirically, and still others await full scale implementation and operational experience. As in the case of similar technological advances, an **evolutionary** process will occur as the technology is refined and **marketplace** forces come to bear. At this stage in the development of navigation and information systems, it is important that government and private industry, electronics engineers and human factors specialists, work together to produce optimum systems configurations for the motoring public.

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