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SOME HUMAN FACTORS DESIGN ISSUES AND RECOMMENDATIONS FOR AUTOMOBILE NAVIGATION INFORMATION SYSTEMS

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Abstract—This paper addresses some of the major human factors issues associated with automobile navigation information systems. Human factors objectives of navigation efficiency, ease, safety, and roadway use efficiency are specified. Major decision trade-offs for the display of navigation-related information and the operator control of navigation functions are addressed. When appropriate, design recommendations are made based on the current state of human factors knowledge. For every case, major underlying human factors concerns associated with various design alternatives are discussed.

INTRODUCTION

Significant advances in electronics and micro-computing during the past decade have led to the feasibility of functionally powerful, computer-based automotive navigation information systems. Stephens (1986) estimates that more than 40 such systems are currently under development world-wide. Although these systems range in functionality, they all have the goal of serving as a navigation aid for the driver. While these systems promise to serve a valuable function, they represent a new frontier in the automotive industry—one that could be fraught with hazards if not treated appropriately. The driving task cannot be significantly interfered with or hazardous circumstances can result. This non-interference requirement, in conjunction with requirements imposed by the environment (e.g. glare, night driving, high ambient noise), the user population (e.g. elderly drivers, various education levels), limited training opportunities, and system constraints (e.g. cost) make these systems one of the greatest consumer product human factors challenges to date.

This paper provides some design considerations and recommendations for such systems. Significant human factors progress has been made in the development of these automotive systems; and much of this progress can be generally applied to navigation systems. However, there is still a significant human factors research effort that must be accomplished in this area. Therefore, this paper should not be considered a complete and comprehensive treatment of all human factors issues.

Likely features of future navigation information systems

In-vehicle navigation and information systems vary greatly with respect to functionality, driver information, and design. However, current technology is such that functionally powerful systems can be incorporated into the automobile in a cost-effective manner. Although no determination has been made regarding available functions on most systems under development (Lunenfeld, 1990), a number of features will likely be deemed useful and therefore integrated as part of future systems. These features include (a) route planning functions based on multiple criteria for route selection (e.g. fastest or fewest turns); (b) real-time display of traffic information and route replanning; (c) "Yellow Pages" functions allowing selection of specific destinations based on several features (e.g. moderately priced Chinese restaurants within a given travel time); and (d) emergency services functions (e.g. police, ambulance, towing).

The value of navigation and information systems

Navigation to an unknown destination, particularly in instances where one is driving without passengers, is a difficult task for which the majority of cases are inefficient or unsuccessful. Outram and Thompson (1977) and Jeffery (1981) estimate that between 6% to 15% of all highway mileage is wasted due to inadequate navigation techniques. This results in a monetary loss of at least 45 billion dollars per year (King, 1986).

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An additional cost that can potentially be reduced by widespread use of navigation systems includes traffic delay. Several systems under development are designed to interface with advanced traffic management centers that will eventually be based in metropolitan areas. Once such systems are in place, real-time traffic delays can be broadcast to in-vehicle systems. These systems can then be utilized to calculate continuously the fastest route to a destination during travel. Such a capability, if widely used, has the potential for increasing efficiency for an entire infrastructure network.

Given the level of development effort and the benefits of navigation systems, apparently the trend of widespread development will continue. Thus, it will become increasingly critical that systems are designed with human factors objectives as primary requirements to ensure system safety, efficiency, and usability.

Despite the number of navigation and information systems that have been developed to date, very few empirical evaluations of the safety and usability of various designs exist in the open literature. Of those research studies, none has tested a device with the functionality that will likely be available in the not-so-distant future. Therefore, when considering the design of such systems, one should begin by addressing fundamental human factors design objectives, and subsequently, design considerations driven by those objectives.

HUMAN FACTORS OBJECTIVES FOR NAVIGATION INFORMATION SYSTEMS

The human factors objectives of navigation assistance are to allow the driver to navigate more effectively, more easily, more safely, and in such a way as to optimize roadway efficiency. To develop a system that meets these objectives, it is necessary to incorporate, test, and verify human factors design principles relevant to in-vehicle navigation systems.

Objective I: Navigate more effectively

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

Objective II: Navigate more easily

Researchers have found that memorizing a route either through lists or from maps is difficult and not well done. In addition, remembering spatial map configurations or mentally reorienting a map is difficult for people and conflicts with the spatial task of driving (Wetherell, 1979). Finally, some navigation tasks are difficult because the information is not always available or is obscured (e.g. street signs). Therefore, allowing drivers to perform the task of navigation more easily via easy-to-use systems is a worthwhile design objective.

Objective III: Navigate and drive safely

Drivers should be able to navigate without jeopardizing driving performance. Systems should be designed such that the demands imposed by the system are minimized and leave sufficient driver attention, information processing, and response resources for driving in all situations.

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

Objective IV: Optimize roadway use efficiency

Since traffic congestion is a problem encountered by many drivers and is expected to get worse, some systems try to distribute traffic more evenly throughout a system utilizing navigation assistance. If drivers are advised of congestion while they are planning their route, it is expected they will avoid congested roadways. Thus, they would be able to spare themselves the

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inconvenience of traffic congestion as well as avoid contributing to the congestion problem any further. Also, if drivers are informed of obstacles or congestion that occur while they are en route, then they may be willing and able to detour and avoid the congestion. The feasibility of this objective depends in part on the amount and detail of information provided to the driver while driving.

HUMAN FACTORS DESIGN ISSUES

To meet objectives outlined above successfully, several issues must be carefully addressed. The following sections outline these issues and recommendations based on research or human factors design principles.

Allocation of functions: "Pre-drive" vs. "in-transit"

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

Therefore, the in-transit functions should be limited to necessity and convenience. Essentially, the only functions required while the vehicle is in motion are those associated with navigation from a current location to a destination. Proper selection and design of in-transit functions will allow successful navigation to destinations without substantial driving task interference.

What are valuable functions? As discussed previously, systems will have the capability for a wide variety of convenience features. For functions allocated to the pre-drive situation, the constraints imposed on the functionality of the system are not driven by attention, information processing, or response resources. Because the vehicle is not moving and the driver's attention may be focused on the navigation information system, any feature that is useful and can be easily integrated given user capability and training constraints is a candidate function. More often, system, cost, or database constraints will limit the functionality in the pre-drive case.

With respect to valuable functions present while the vehicle is in motion, all efforts must be made to limit the functionality of the in-transit mode to those tasks that (a) do not significantly interfere with the driving task, (b) have convenience benefits that outweigh the cost (in terms of required driver resources) of including the function, and (c) will be used relatively frequently. Some functions that meet these criteria include providing navigation necessary information (distance to next turn street, direction of next turn, and name of next turn street) and providing information regarding proximal traffic congestion or obstacles. All other functions should be allocated to the pre-drive case or carefully considered (and tested) based on the above criteria.

The case for a "zero speed" category. An option available to increase in-transit functionality without compromising driving safety is the allocation of functions to a "zero speed" category (Carpenter, Fleischman, Dingus, Szczublewski, Krage, and Means, 1991). Zero speed refers to a driver who is stopped and in park. The navigation system will allow a certain subset of functions (e.g. orientation information) to be accessed from the system. However, once the vehicle starts in motion again, the display and control configuration would return to its previous in-transit state.

Pre-drive considerations

A major limiting factor associated with the pre-drive functions are imposed by usability constraints of a computer system. The solution to this usability problem is particularly challenging for navigation information systems for training and computer illiteracy reasons. It would neither be feasible nor acceptable to the user public to provide time-consuming or expensive training in an automotive purchase or rental situation. The pre-drive interface must be developed to accommodate the ill-trained, least capable segment of the population.

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Dingus, Hulse, Krage, Szczublewski, and Berry (1991) tested a number of different pre-drive functions to determine if likely users could operate a complex navigation information system effectively with little or no training. A number of simulated functions were tested, including select destination functions utilizing several criteria, destination storage and retrieval, manual route selection, automatic route criterion selection, local information/current events (yellow pages) functions, emergency services requests, system configuration set-up, and traffic information retrieval. Testing of these functions revealed that the incidence of error requiring significant recovery was relatively low, and that many of the functions tested would likely be usable by a wide variety of representative subjects. However, the manual route selection and traffic information retrieval tasks were somewhat difficult to use for the configurations tested. It was the opinion of the investigators that automated versions of these functions would increase system usability. Pre-drive function testing also revealed that the majority of the errors encountered were caused by confusion in system labeling and nomenclature.

In large part, the task of developing an interface for pre-drive functions involves human-computer interaction for the computer illiterate. Several good standards are in existence for the design of human computer interfaces. These standards describe approaches for control and display of information suitable for novice users. Three critical aspects (in addition to the careful selection of nomenclature and labeling as found by Dingus *et al.*, 1991) apply in general to the automobile: (a) the number and complexity of functions should be minimized such that all available functions are "transparent" from a top level or "main" menu; (b) control devices must be carefully considered for use in the automobile; and (c) the screen size must be carefully considered in conjunction with desired functions. For example, pre-trip route planning may require looking at minor streets (close together) over a large distance. Such circumstances require significant "panning" and "zooming" on a small screen, requiring an unacceptable level of effort for the driver.

In-transit considerations

Unlike the pre-drive case, in-transit navigation information system design must be heavily driven by safety considerations. Great care must be taken to minimize interference with the driving task. Some design issues that will potentially affect the safety of the driving task and the usability of a system while driving are described below.

Required driver attention and sensory modality selection. Concerning attention demand, two types should be considered: visual attention and cognitive attention. An easily understood analogy for visual attention is a spotlight. A beam of light can be moved serially from one object to another; likewise, visual attention can be switched from one object to another.

Visual attention is particularly important to assess in driving, since most of the information gathered by the driver is through the visual channel (Rockwell, 1972). Despite the almost sole reliance of driving on the visual modality, between 30% and 50% of visual attention time may be devoted to tasks other than driving under most circumstances (Hughes and Cole, 1986). It is the availability of this spare resource that makes the inclusion of in-transit visual navigation information feasible. However, this spare attention resource must be utilized cautiously, since depletion results in degraded driving performance. In addition, the visual attention required by the driving task can change drastically and often with changing circumstances (including a curve, the presence of traffic, or a change in type of roadway). Therefore, displayed information must be usable under the most demanding circumstances. Furthermore, research contends that age, gender, and previous driving experience must be considered. Specifically regarding driver age, research has shown that older drivers spend significantly more time looking at navigation displays than younger drivers (Pauzie, Martin-Lamellet, and Trauchessec, 1989; Dingus, Antin, Hulse and Wierwille, 1989). Consequently, when navigation systems are involved, this group devotes less time directed toward the roadway. This dictates that special consideration must be given to this segment of the population, and that minimization of glance time in design of a navigation information display is critically important.

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

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Given the requirement of minimizing visual attention demand to achieve the safe navigation objective, it seems apparent that the auditory presentation of navigation information is a superior approach to visual presentation of information. A major advantage of auditory information presentation in the driving environment is efficient allocation of information processing resources. Allocating supplemental tasks to the auditory modality (particularly in situations of high visual attentional demand) has the potential for making the composite task of driving easier and safer (Weatherell, 1981).

Cognitive attention is another classification of attentional demand. The driver may be concentrating on a train of thought while the eyes are directed toward something totally unrelated (Cohen, 1971). For example, the driver could be day dreaming, listening to the radio, or attending to an auditory display and not the road. Therefore, if navigation information is presented to the driver aurally, it will require cognitive attention even though the eyes are on the road.

The cognitive attention required to process auditory messages increases as the intelligibility of those messages decreases. Low-cost systems will be required for automotive navigation systems because of marketing considerations. This cost constraint requires selection of digitized speech that does not provide any street name information to the driver (because of database constraints) or synthesized speech that is less intelligible than digitized speech. Although the quality of low-cost synthesized speech is constantly improving, factors such as tonal quality and inflection limit its relative effectiveness (Sanders and McCormick, 1987).

Even though numerous research studies have been conducted testing various forms of synthesized speech, the state-of-the-art knowledge is not yet to the point where intelligibility/comprehensibility can be predicted in all situations or environments. However, it is known that a number of factors influence intelligibility, including speech rate, message length, message content, message complexity, background noise, pitch, and loudness (Van Cott and Kincade, 1972; Marics and Williges, 1988).

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

In addressing some of the intelligibility concerns discussed above, Labiale (1990) recommends that when considering aurally presented messages, one should restrict the amount of information presented (7 to 9 bits), or use the aural cue as a prompt to a very simple visual guidance presentation. Also recommended is the ability to repeat the aural message, especially if information is complex, to aid in intelligibility and recall.

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

Although voice presentation can alleviate visual attentional demand problems associated with navigation information, it is not a solution without problems of its own. It is therefore recommended that the auditory modality be utilized to (a) provide an auditory prompt to look at a visual display for changing or upcoming information (thus lessening the need for the driver to scan the visual display constantly in preparation for an upcoming event), or (b) have some type of simple visual information presentation to supplement to the auditory message (so that a message that is not fully understood or remembered can be checked, or later referred to, via the visual display). Use of the auditory modality in these ways can serve potentially to reduce visual

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attention demand required of navigation systems without sole reliance on voice messaging and its associated problems.

It should be emphasized that the driving task itself does not require a constant level of attentional demand, since some driving conditions require more attention than others (Mourant and Rockwell, 1970). For example, two-lane streets require more attention than interstates; curved roads require more than straight roads; and heavy traffic requires more attention than light traffic (Hulse, Dingus, Fischer, and Wierwille, 1989). When the difficulty of the composite driving task exceeds the attention capabilities of the driver, no amount of expended effort will keep performance constant. At this point of overload, performance in the navigation and/or driving tasks will begin to decline. Thus, it is important to keep the attention required of the driver below the point of overload. It would then follow that navigation information systems need to be designed to require the least amount of attention possible to ensure that safety is maintained under all foreseeable driving circumstances.

Visual information display: Some basic issues. A major concern with the design of a visual display in the automobile is legibility of information, whether that information is text or graphic. A delineation of all appropriate display parameter options (e.g. resolution, luminance, contrast, color, glare protection) is a complex topic beyond the scope of this paper. A number of legibility standards are in existence for visual displays, including those developed for aircraft applications (Boff and Lincoln, 1988). Since the automobile is fraught with many of the same difficulties as the aircraft environment (e.g. glare), these standards apply well. However, note that the selection of a display in the automotive domain will be much more highly constrained by cost and perhaps have limitations well below the state-of-the-art. Obviously, these parameters have minimum acceptable parameters below which the display is unusable. It is therefore critical to ensure that these minimum standards have been met in spite of the constraints for a given application. In addition, the problem of selecting display parameters is compounded, since viewing distance is limited in the automobile due to the configuration constraints present for an instrument panel. Adding to the difficulties found in the automobile are those introduced by the user population. Older drivers with poorer visual acuity and/or bifocal lenses must be carefully considered during the specification of the display parameters. To overcome this combination of limitations, the display parameters must be optimized within practical control. For example, Carpenter *et al.* (1991) used a "special high-legibility font" in a color CRT application to ensure that drivers could glance at the display and grasp the required information as quickly as possible. Other design aspects that aid in legibility include always presenting text information in an upright orientation (even in map applications), maximizing luminance and/or color contrast under all circumstances, avoiding selected color combinations (Boff and Lincoln, 1988) (e.g. blue lines on a white background, since for this combination the line appears to "swim"), using color coding of information sparingly (since too many colors creates more information density and search time), maximizing line widths (particularly on map displays) to increase luminance, and minimizing the amount of displayed information in general to reduce search time.

Another basic visual display concern stems from the presence of color deficiency and color blindness in the population. Approximately 8% of the male population have some degree of color deficiency or color blindness. It is therefore important in consumer product applications (including navigation systems) to avoid reliance on color coding of critical information.

The format of visual information. When directions are communicated from one person to another, the message generally consists of one of two presentation formats. Either a map representation is drawn or a textual list of instructions is given. So the question then becomes, which option is better for a navigation information system? The answer appears to be task specific.

Bartram (1980) tested subjects on planning a bus route using a list or a map. The results found subjects using a map had faster decision times than those using a list.

Another study conducted by Wetherell (1979) found that after subjects studied a driving route either using a map or a linear list of turns, those using a map made more errors when actually driving the route. Wetherell concluded that these findings could have been caused by two factors: (a) The spatial processing demands of driving, seeing, and orienting interfere with maintaining a mental map in working memory. (b) Subjects had a harder time maintaining a

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mental model of a map learned in a north-up orientation when approaching an intersection going east, west, or south.

In a study conducted by Streeter, Vitello, and Wonsiesicz (1985), subjects who drove a route through neighborhoods using a route list (series of verbal directions) were faster and more accurate than those who drove using a customized map with the route highlighted.

The above studies indicate that a textual list is easier to use than maps while navigating to unknown destinations. Note, however, that maps provide additional information (e.g. orientation information, such as cross-streets) that textual lists do not. Therefore, whether a map or list is selected should necessarily depend on the desired task and required information. Depending on the requirements of the system under design, the inclusion of both display formats, displayed in different situations, may provide the most usable overall system.

The value of route selection. Several research studies (e.g. Dingus, Antin, Hulse and Wierwille, 1989) have tested systems that do not provide a route to a destination. Such systems provide a current location, area streets, and a pre-selected destination. Such systems have several technological advantages, including less complex database requirements and no route-algorithm requirement. However, such systems require the driver to perform trip planning tasks in-transit instead of pre-drive (Antin, Dingus, Hulse, and Wierwille, 1990). Almost invariably, the information displays for navigation information systems are (and probably will continue to be) quite small. Thus, a requirement for non-route systems is to provide "zoom-in," "zoom-out," and pan features, in conjunction with prioritized streets, to avoid unreasonably high screen information densities. One can "zoom-in" to a small-scale area (e.g. ¼ mile) and see a detailed view of all area streets, and move around the map. However, if one "zooms out" (e.g. to a 20-mile scale), many of the secondary streets must disappear to maintain a reasonable information density. Therefore, it is often difficult to see all of the secondary streets along a route, particularly if it is long. One must zoom in/out and pan to various locations to plan a route prior to starting the drive. However, particularly for complex or long routes, it is difficult and time consuming to plan a route in this manner. What generally happens is that drivers, after inputting a desired destination, drive immediately and plan the route in large part as they travel. This strategy increases the attention demand of the composite driving task, since pre-drive planning has now been allocated as an in-transit task (Antin *et al.*, 1990). Dingus *et al.* (1989) therefore recommend that a provision for route selection be provided as part of navigation and information systems.

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

In terms of attention required by a visual display, clearly less will generally be required in a well designed turn-by-turn format than a full-route format. Very little information is required for a graphic turn-by-turn screen, including only direction of turn, distance to turn, and turn street name. Such information can be easily displayed in a legible, low attention-demanding format. McGranaghan, Mark, and Gould (1987) have characterized route following as a series of "view-action" pairs. A view-action pair refers to the sequential set of requirements where information is required for an upcoming event (i.e. turn), the event is executed, the information for the next event is displayed, etc. McGranaghan and his associates believe that only the information for the next view-action pair should be displayed for route following. In their view, any additional information is "extraneous" and "potentially disruptive" to the route-following task.

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

A second advantage to providing route information arises during circumstances of driver

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disorientation or required error recovery (Fleischman, Carpenter, Dingus, Szczublewski, Krage, and Means, 1991). Wrong turns induced by system or human error occur relatively frequently while using navigation systems. Particularly in the case of system errors, map information is required to allow the driver to correct the error and return to the correct route.

Selection of either a turn-by-turn or route visual display format requires careful consideration to ensure that the information is displayed in a usable and safer manner. If a turn-by-turn configuration is used, one must consider preview in general; and if a full route map is used, it is absolutely necessary to minimize the information present so that driver attentional resources are not overloaded. Even with minimization of full route map information, it is not clear from the literature that driver resources will not become overloaded in circumstances of high required driving attention. Additional issues inherent in route map presentation also need consideration prior to the selection of a route map option. These issues are described in the next section.

Route map effectiveness and distraction: Heading-up or north-up? A trade-off that must be considered with the selection of a route-map display format is whether or not the map should be presented "heading-up" (the direction that the vehicle is traveling is always up on the display) or north-up. Probably the most significant issue regarding heading versus north-up is the speed and accuracy with which the information on the display can be interpreted by the driver. With a north-up orientation, the driver must often mentally rotate the map image (e.g. if the heading is southeast) to determine whether to turn right or left. This additional operation requires additional attention and processing time, and results in more errors for the population as a whole.

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

In weighing the heading-up vs. north-up trade-off, it is the authors' opinion that heading-up is a better option. It should be emphasized, however, that either method has disadvantages. Therefore, based on these disadvantages and those discussed in the previous section, an appropriately designed verbal direction list or turn-by-turn spatial option is more desirable in comparison to a route-map utilizing either presentation rule.

Display location: To HUD or not to HUD? A major component of the driving task is scanning the environment and responding appropriately to unexpected events. Fortunately, humans are very sensitive to peripheral movement. An object moving in the periphery often instantly gets attention (which is why the potential distraction of "moving maps" is a problem). In fact, some human factors professionals believe that peripheral vision is as important as foveal vision for the driving task.

Given the above, the placement of a navigation and information display becomes critical. The information contained on even a well-designed display system will require a relatively large amount of visual attention. Therefore, if the display is placed far from the normal driving forward field of view, none of the driver's peripheral vision can effectively be utilized to detect unexpected movement forward of the vehicle. Another disadvantage of placing a display far away from the forward field of view is increased switching time. Typical driver visual monitoring behavior involves switching back and forth between the roadway and the display in question. Dingus, Antin, Hulse, and Wierwille (1989) found that during the conduct of most

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automotive tasks, switching occurs every 1.0 to 1.5 seconds. The farther the display is away from the roadway, the longer the switching takes, and the less time can be devoted to the roadway or the display (Weintraub, Haines, and Randle, 1985).

From the above discussion, the display should clearly be placed as close as practical to the forward field of view. High on the instrument panel and near the area directly in front of the driver are desirable display location features. There is, however, another automotive option that is currently just beginning to be explored: head-up displays (HUDs).

Given the above arguments, a HUD providing navigation information on the windshield could be a good choice since it is *in* the forward field of view. Besides the arguments described above, another advantage of a head-up display (at least most head-up displays) is that they are focused at (or near) infinity, thus eliminating (or reducing) the time required for the driver's eyes to accommodate between the display and the roadway. (Accommodation is the process whereby the lens of the eye is changed in thickness.) However, a number of concerns must be addressed empirically before HUDs can be widely used to display navigation information:

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

These issues (along with others) must be carefully addressed before a navigation head-up display is incorporated in the automobile for this application. (See Stokes, Wickens, and Kyte, 1990, for a complete discussion of the use of head-up displays.)

Changing driver scanning behavior: The more in-car information, the less outside information. The problem of "out of the loop" loss of familiarity needs to be considered with the development of navigation and information systems. Presently, the driver is required to obtain most information from the driving environment itself (i.e. street signs, stop lights, etc.). As more information is presented within the car in a readily accessible manner, the less likely the driver will be to obtain that information from the driving environment. Thus, any problem, deficiency, or inconsistency that requires the driver to shift attention to the driving environment will potentially result in a delay and increased effort, since the driver will have become accustomed to having the information provided within the car. Thus, there is a tradeoff: The more powerful and informative the system, the more the driver will rely on it to provide information rather than searching the driving environment for it.

It is therefore extremely important that all information provided in-vehicle be accurate and reliable. All critical information should be screened for accuracy. If the accuracy of critical information cannot be reasonably guaranteed, then that information should not be provided.

What information is really necessary and when is it necessary? As previously discussed, the navigation display information should be limited to what is absolutely necessary. But how does one determine what information is really necessary? The information required by the driver is task- and situation-dependent. All the tasks performed by the driver should be identified, and the information that is necessary to perform each task determined. When following a prespecified route, Streeter (1985) recommends that the necessary information consists of the next turn, how far away the turn is, what street to turn on, and which direction to turn. Streeter found that people familiar with an area prefer to be given the cross street of the next turn, whereas people unfamiliar with an area prefer to be given distance information.

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

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The driver should not be presented with unwanted or unneeded information. This requires the driver to filter through a set of information and decide whether each piece is important and should be attended to or not (Wickens, 1984). Also, if only relevant information is presented, then the driver is more likely to attend to it. Conversely, if much of the information is unnecessary, the driver may ignore most of what is presented, including that which is relevant and important.

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

Persuading drivers to move away from congested routes. As previously described, one of the human factors objectives for navigation and information systems is to alleviate traffic congestion. Drivers have been shown to be resistant to diverting from their present route to avoid congestion (Dudeck, 1980). Dudeck showed that 50% of drivers were willing to avoid a 20 minute delay but only 8% were willing to avoid a five-minute delay. Thus, congestion would have to be moderately severe before people would make the effort to divert. This unwillingness to detour may be dependent in large part on detour knowledge by the driver. Certainly one of the keys to persuading drivers to use an alternate route is appropriate and timely information. For example, given that there will be some time savings on an alternate route but the driver does not know how much, he or she may be more reluctant to change routes. In addition, drivers are often not willing to take the shortest or fastest route if it is less pleasant. Cross and McGrath (1977) found that drivers select routes based on the following factors: efficiency (fastest route 54%, shortest route 53%), problem avoidance (safest route 43%, more familiar with route 36%), more miles of multiple lanes 31%, roads in better condition 30%, less chance of getting lost 24%, less traffic 18%), and pleasure and personal convenience (most scenic route 25%). Factors such as road quality, number of junctions, and average speed will also be important in route selection. Streeter and Vitello (1986) had 33 women rate what was most important to them in terms of navigational preferences. For short trips they wanted to avoid road construction/bad roads and traffic. For long trips they also wanted to avoid road construction/bad roads. Other areas that were important to the drivers for long trips were use of major roads, good scenery, few stop lights, and travel time. Additional research is needed in this area to determine what alternate route features are important to convince drivers to take the most efficient route.

In-transit control issues. A navigation system that requires many driver resources may not leave sufficient resources to drive safely in all circumstances. The driver's resource demands can be divided into three processes; these are attentional demands, processing demands, and response demands (Casali and Wierwille, 1984). It is important to minimize each of these types of resource demands in order to avoid interfering with driving performance. This means that not only should navigation displays be designed to minimize driver attention and processing resource requirements, but so should response resources required by navigation system controls.

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

Several other specific control issues are present with respect to navigation information systems. First, control location has been shown to be important. The farther a control is located from the driver, the greater the resources needed to activate the control. This has been demonstrated by Bhise, Forbes, and Farber (1986) and Mourant, Herman, and Moussa-Hamouda (1980), who found that the probability of looking at a control increased with increased distance.

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Therefore, controls present on the steering wheel, or otherwise in close proximity to the driver, are easier to use.

A second important control factor to consider is complexity. Research (Dingus, 1987) has shown that continuous controls or controls requiring multiple activations are significantly more difficult to operate. Therefore, limiting controls to single, discrete activations will provide fewer resource requirements.

A third control factor is the trade-off between "hard" and "soft" push buttons. With the use of CRTs and flat panel displays in the automobile, there has been a strong temptation to use touch screen overlays for control activation. Although this can be a very good method of control in the automobile for pre-drive or zero-speed cases, research has shown that this is not true for in-transit circumstances. Monty (1984) found that the use of touch screen keys while driving required greater visual glance time and resulted in greater driving and system task errors than conventional "hard" buttons. The reasons for this performance decrement are twofold: (a) the controls are non-dedicated (i.e. change depending on the screen), and (b) soft keys do not provide tactual feedback. For a "hard" button, the driver must (depending on the control and its proximity) glance briefly at the control and then find the control using tactile information to accomplish location "fine tuning." For the soft keys, the driver must glance once to determine the location; and glance again to perform the location "fine tuning." Therefore, although soft keys are often convenient, they require greater driver resources and are not recommended for navigation information system in-transit application.

CONCLUDING THOUGHTS

The previous sections have outlined the current state of knowledge for many of the major human factors issues regarding navigation and information systems. Hopefully some of the design recommendations and trade-offs will be useful for future system development. However, it should be emphasized that many human factors issues remain, and many design details were not addressed as part of this paper. It is therefore important to (a) have a human factors professional (or professionals) involved in the development of such systems, and (b) perform system verification testing to ensure that the human factors objectives have been met prior to public release of such a product.

The most critical and desirable portion of system verification involves the in-transit functions. The most critical aspect of this verification is the determination that the newly developed system does not substantially interfere with the primary task of driving. Even if a good faith effort has been put forth to minimize demand on driver resources as described in this paper, verification testing is still absolutely necessary. Some of this verification can take place on the road under controlled circumstances. However, in order to determine driving task effects comprehensively, verification utilizing a relatively high fidelity simulation is often required. Simulator testing allows determination of behavioral changes, such as responses to unanticipated emergency situations that are extremely difficult to measure in road testing. The simulator also allows control of conditions such as traffic encounters and visibility (weather, night driving), so that variations in driving attentional demand can be accurately assessed.

Some systems will provide additional modes of operation other than the route-following scenarios primarily addressed in the previous sections. For example, some systems will be designed to provide traffic information to commuters familiar with an area. For many such options, the information and trade-offs described in this paper can be appropriately applied.

It is only through prudent application of knowledge and principles, continued research, and verification testing that this complex human factors design challenge can be adequately met. Given the importance of the human factors design objectives to the success of navigation information systems and public safety, it is hoped that all parties involved adopt such an approach.

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