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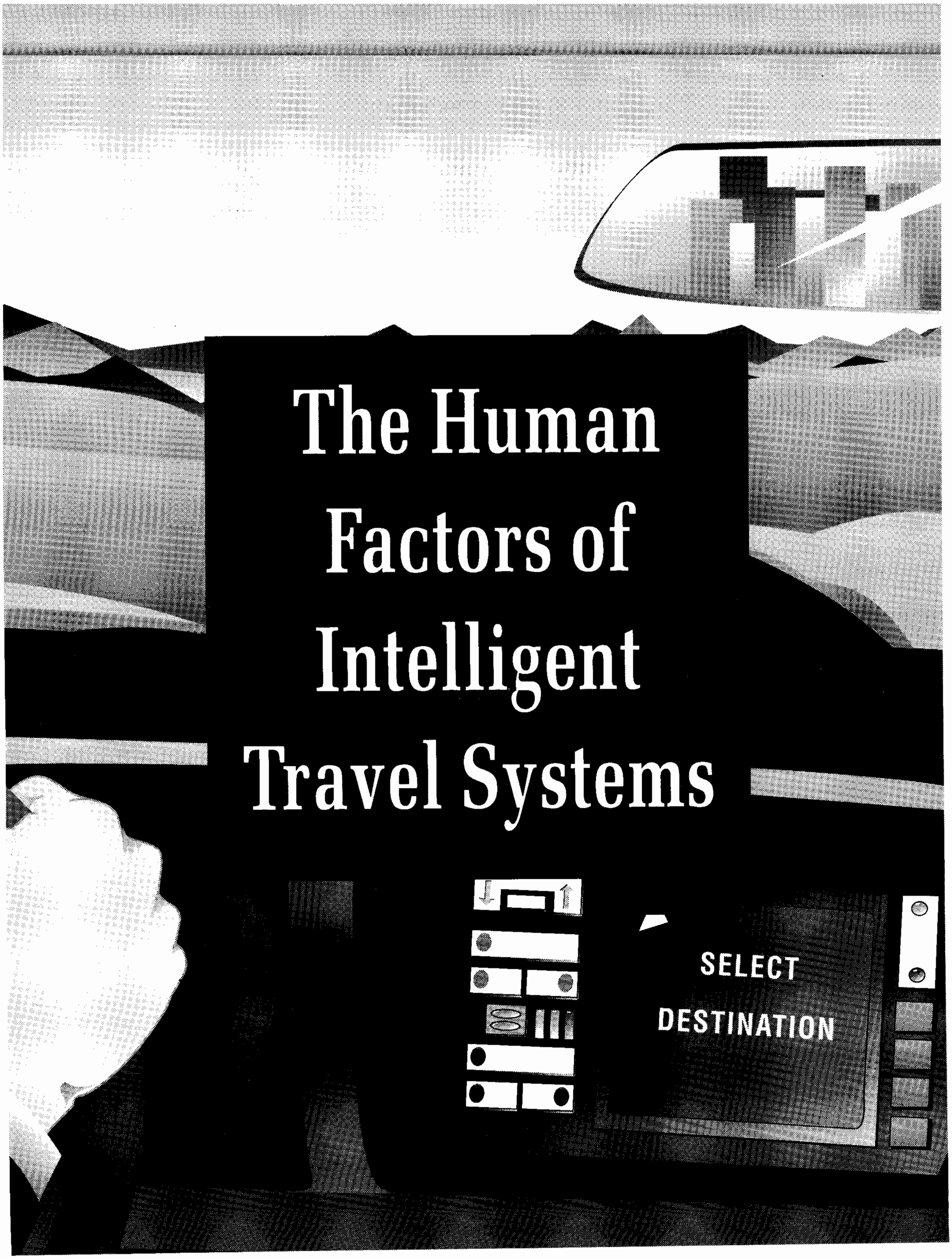
The Human Factors of Intelligent Travel Systems



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Safe and effective intelligent vehicle-highway system technologies must be driver centered.

By P. A. HANCOCK, W. L. DEWING, & RAJA PARASURAMAN

Transportation plays a vital role in the economic health and welfare of the global community. Traditionally it has been viewed as the safe and efficient movement of people, goods, and services. Safety represents delivery without mishap; efficiency is measured in terms of transit time.

Yet the system that supports such transit faces a serious crisis. Congestion has become the norm for roads and highways in virtually all large metropolitan areas. Projections of current accident rates suggest that there will be one traffic fatality per minute on the world's roads by the turn of the century, and the cost of pollution and lost time productivity will continue to spiral. Little wonder that this picture of a dangerous, clogged, and polluting roadway system has stimulated concern. One potential solution to this problem is through the application of technological innovation.

In the United States this application is represented as intelligent vehicle-highway systems (IVHS). IVHS involves the use of advanced sensor, computer, communication (radio/optical), and control technologies for regulating the flow of vehicles along roads and highways. Major efforts in IVHS are currently directed to advanced traffic management, automation of vehicle control, advanced traveler information, and commercial vehicle operation.

A critical question concerns the nature, design, evolution, integration, and evaluation of an overall IVHS architecture. In this article we are directly concerned with this system architecture for IVHS, and particularly the orientation taken in order to ensure successful implementation. Our view of this architecture features a driver- or user-centered approach, which focuses on the centrality of human factors issues at the earliest possible stage of IVHS system architecture development.

The development of a driver-centered IVHS architecture requires a systems approach to generate a plan of implementation, an evaluation of all aspects of operation, and a coherent account of methods of integration. Some earlier efforts have addressed this problem but have featured a *technology-based* approach (Varaiya and Shladover, 1991). Here we present an approach predicated on the assumption that the major goal of IVHS is to serve the road user, and therefore that the optimal systems approach is founded on a driver-centered architecture.

Visual Information Load on the Driver

In considering the driver's role in IVHS, one of the first questions concerns the sources of information on which drivers base their actions. For the foreseeable future, the major task of the driver will remain the momentary manual control of the vehicle. For that purpose the majority of information comes from viewing the external environment. Most IVHS implementations will have little direct impact on this form of information use, though variations in the form of information presentation (for example, such as that given in variable-message signs) will certainly affect the driver. The exception lies with on-board collision avoidance systems that momentarily take control of the vehicle (more about these later).

Out-of-the-window visual perception also provides information about route navigation and traffic advisories. Indeed, as currently used, traditional signs and newer variable-message freeway signs provide the driver with the most information of these kinds. The more familiar drivers are with a route, the less they make use of such signs. If the destination is unknown, however, use of signs increases, and driving is often slow or hesitant, particularly in the case of older drivers.

(We would be remiss here not to mention the projected efforts at vehicle platooning and the already existing research on automation of steering control. Such developments may be included in future IVHS innovations, but it appears unlikely that they will be implemented in the near future

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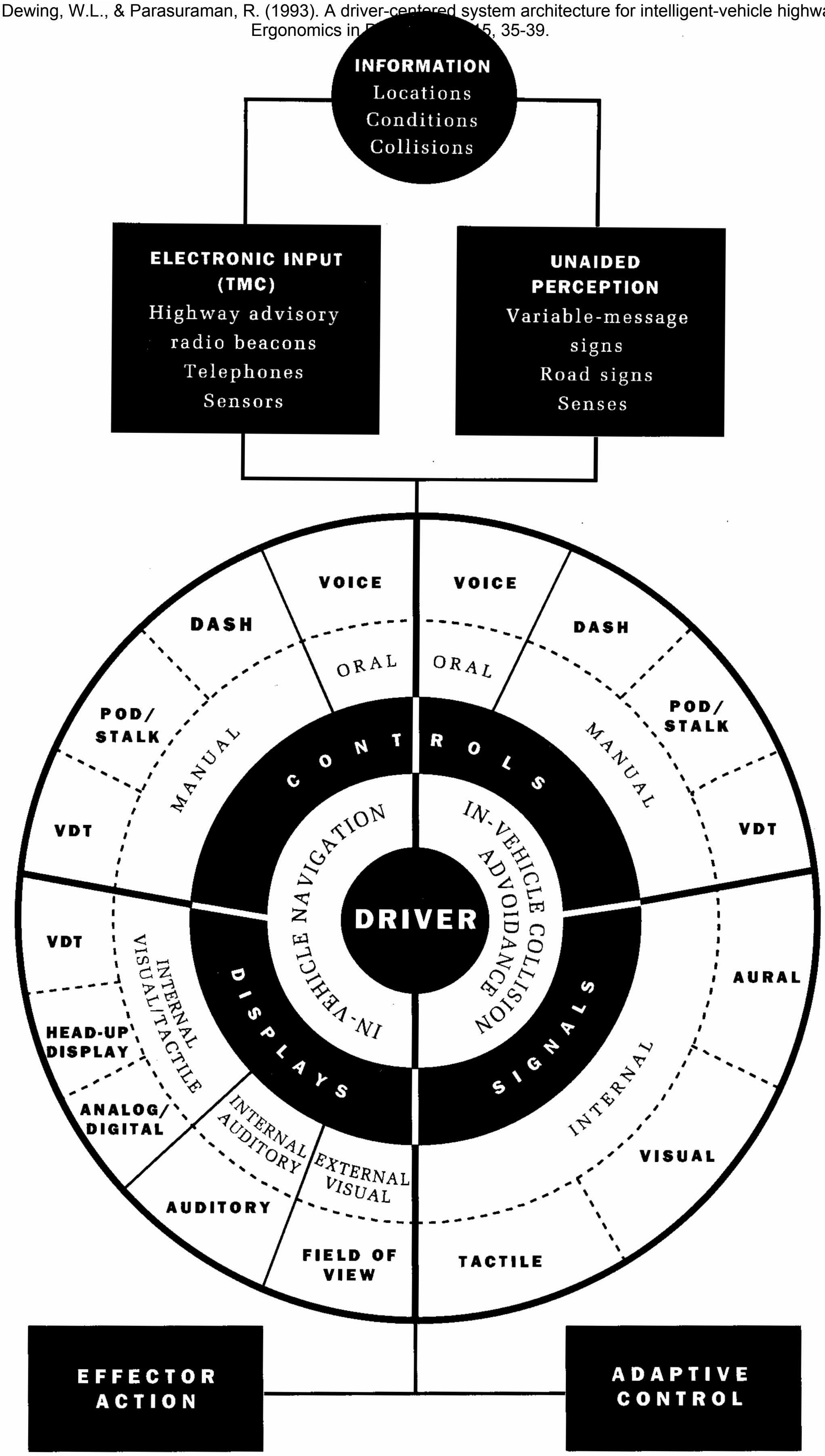

Figure 1. A driver-centered system architecture for a fully functional IVHS system.

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in IVHS programs that are already in operation – for example, GUIDESTAR, an overall IVHS project of the Minnesota Department of Transportation that includes technological elements as well as technology transfer, education, and outreach.)

The information sources mentioned earlier are transient and external to the driver, whereas in-vehicle displays provide permanent, internal sources of information. Although both internal and external sources add to the overall visual load on the driver, most in-vehicle displays provide information that is needed only periodically, such as an indication of an almost-empty gas tank. Only in infrequent, emergency circumstances do in-vehicle displays assume a critical status.

Furthermore, because the driver's attention must be devoted primarily to steering, in-vehicle displays are constrained in the nature of information they should display and the format in which it is displayed. Several IVHS proposals include a considerable increase in the level of visual information supplied to the driver. For example, current navigation systems provide information that requires drivers to divert attention away from the road and direct it to detailed head-down displays.

Automated operations are currently available in many aviation settings, but it will be a considerable time before they become feasible in the driving environment. Whether or not to apply them in IVHS differentiates various architectural approaches. Current in-vehicle IVHS displays are frequently small video display terminals (VDTs) that contain occasionally complex alphanumeric messages rendered in small letters and numbers. [Editor's note: see "Getting from There to Here with TravTek" elsewhere in this issue.] Switching attention between out-of-the-window views and such in-vehicle displays can lead to a potential conflict and sensory and cognitive overload for the driver. It is not surprising, therefore, that drivers have restricted access to some functions of currently operating in-vehicle navigation systems when the vehicle is in motion (see Hancock and Parasuraman, 1992).

The increased information supplied to the driver with IVHS technologies requires simplification of both the current and additional displays. One option lies with time-critical displays: information is displayed only when it has reached a critical level. In general, models based on driver attention load and task-related workload will be best suited for IVHS implementation.

Drivers will probably make their needs for user-friendly systems known to the designers by virtue of their wallets.

Presentation of Information to the Driver

An IVHS system will present the driver with three basic types of information: location, condition, and collision-potential information. Location information will come from both out-of-the-window perception and in-vehicle navigation systems. Included in this category would be the locations of items such as emergency facilities, businesses and services, parking areas, rest areas, and public transit vehicles. The navigation system will provide regional maps for route planning and destination location. The data for these maps, as well as other location information, will come from either an on-board computer and data base system programmed with location information or from communications with a traffic management center (TMC).

TMC information may be especially useful when the driver has left his or her "home" territory. Outside the geographical area known to the on-board data base program, the computer will communicate with the local TMC for location information. Communications between a vehicle and a TMC can be established through radio frequencies, which may be accessed from a car or home. Radio transmissions between the TMC and a vehicle can be transmitted via a radio data system through beacons along the roadway.

Condition information will be provided by a combination of all three information sources: navigation systems, collision avoidance systems, and out-of-the-window views. Dynamic information regarding weather conditions, road conditions (such as grade, curvature, surface, height clearance), traffic conditions (for example, areas of congestion, construction and emergency incidents) vehicle condition and performance, and driver condition and performance comprise this second type of information. The navigation systems will supply route guidance to the driver, allowing him or her to avoid areas of delay, where accidents, congestion, or road construction may be occurring. Similarly, collision avoidance warning systems will

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rules of conduct for how they should interact. By considering the system design from a driver-centered perspective at the outset, the design process will fulfill stated operational goals and will not violate basic assumptions and objectives of user service (DOT, 1992). The interface designer must incorporate a philosophy regarding the relationship of the driver to IVHS. This philosophy must be defined early in the design process and adhered to throughout.

A case can be made that the interface should be adaptive to a certain extent. That is, the driver should be allowed, within limits, to tailor the level and type of automated help systems in the vehicle to his or her own needs, much as an individual driver can choose to use or not use cruise control on the highway. Adaptive or intelligent interfaces may also help to prevent some of the difficulties that can arise with "static" interfaces.

Users of automation in aircraft and in processing plants have sometimes had to deal with problems such as failure to detect automation malfunction, loss of system awareness, and manual skills degradation. Systems with adaptive interfaces may be less vulnerable to such problems. Of course, an adaptive interface is not a panacea for poor interface design, and not all IVHS subsystems should be adaptive. The challenge will be to identify those subsystems that would benefit most from being implemented with an adaptive user interface.

The Role of Ergonomic Design in an Integrated System

Suggesting the need for human-centered design in an ergonomics publication may strike some as preaching to the converted. Undeniably, engineers have overall responsibility for design, and they frequently emphasize technology-centered approaches. Ergonomists have rarely been able to influence the design of large engineering systems at an early stage, so what makes us think that IVHS will be any different? We don't know the answer, yet three facts suggest reasons for optimism.

First, the record of experience with the technology-centered approach to the integration of automation in commercial airline cockpits has not been as successful as expected (Norman et al., 1988). Not only ergonomists but also engineers are among those calling for human-centered automation in aircraft.

Second, unlike the relatively small number of users of aviation automation (pilots and air traffic controllers), the users of IVHS will be hundreds of thousands of individual drivers. As consumers of personal computers have done, this group will probably make its needs for user-friendly systems known to the designers by virtue of their wallets. Market forces may thus provide the impetus for ensuring ergonomic input to IVHS.

Finally, and most encouragingly, the explicit recognition of the need to fully provide user services in the recent Federal Highway Administration's request for information (DOT, 1992) demonstrates an emphasis on user-based issues. While the current body of proposed architecture evaluation criteria continues to emphasize technical performance, this is a clear case in which human factors professionals have an opportunity to participate proactively in the design process. As this is the form of opportunity we frequently insist that we must have, it is now incumbent upon us to collectively grasp it.

The approach we take in this discussion can more generally be represented as a *traveler-centered orientation*, in which the users of the system, not the hardware and software technology, are given priority. This orientation also best serves system operators and maintenance personnel because the focus on human activity considers their contribution and needs also. Indeed, it may well be that in an intelligent integrated transportation system, individual travelers will possess transponders and portable information and control devices rather than locating such instrumentation only in vehicles. This is another area in which the transfer of information from aviation procedures will be of direct use (e.g., portable mission profile computer loading into the vehicle).

Although IVHS design can profit from previous experience with automation in aviation, the ergonomic issues in these two domains of transportation are not identical, particularly with respect to user populations of the two systems. With the exception of those who fly their own aircraft for leisure, virtually all pilots have to retire at or before the age of 60 years, whereas there are no age restrictions (to date) for users of IVHS. This distinction is relevant because older drivers can be at greater risk for motor vehicle accidents as a consequence of age-related decline in attentional and other cognitive skills required for safe driving. Pilots are rigorously selected, highly trained, motivated, and

Who's in Control?

User acceptance is critical to the success of IVHS. As marketing director for the Minnesota GUIDESTAR Program, Mike Sobolewski is responsible for communicating the innovative aspects of IVHS to the driving public. In forums conducted for this purpose, the most frequently raised concern centers on the question of AVCS (Automated Vehicle Control Systems). Many drivers express aversion to relinquishing control to a fully automated vehicle. For the purpose of acceptance alone, it may be more appropriate to refer to AVCAS (Automated Vehicle Control Assistance Systems), rather than the more sterile and obviously daunting AVCS conception. As assistance is also a preferable user-based option, such an acronym might eventually prove a more accurate representation of this IVHS component.

dynamically keep track of road conditions as affected by weather and wear via external sensors. The sensors will communicate with the vehicle's on-board computers to alert the driver to threatening driving conditions or even to initiate vehicle control, such as automated braking.

Collision-potential information would be conveyed by fast-time, multiple-array sensors, but views of the driving scene out the window will continue to determine the driver's actions. This type of information includes warnings of potential driver fatigue, vehicle rollover, off-road excursions, lane departure, loss of traction, and intersection hazards. Collision avoidance systems will rely on both internal and external sensors to detect potential hazards. These sensors will communicate with the on-board computer to issue a warning to the driver and, in extreme cases, take over primary control of the vehicle.

Adaptive control (Hancock and Chignell, 1989) may be initiated by the computer in two cases: in the event a warning to the driver is ignored or when the computer's sensors detect a threat to the vehicle or the driver to which the driver cannot respond in sufficient time according to its calculations. Adaptive control may include, but is not limited to, evasive maneuvering, automatic braking, and, in cases of a collision, activation of an emergency beacon. Activating a beacon would summon emergency personnel such as police or paramedics and guide them to the location.

As information is transmitted and/or stored, it will need to be available to the driver through an interface of signals, displays, and controls. Signals may be transmitted audibly, visually, or in tactile displays. Examples may include VDTs, head-up displays, voice commands, vibration, or more traditional analog/digital dash-mounted displays. The controls may be activated manually via VDTs, fingertip-mounted controls such as pods or stalks, and traditional dash-mounted controls, or by voice command (see Figure 1, page 14).

Data coming into the system is subject to perceptual, decision-making, and memory processing. The choice of signal/display/control format should be dictated by the type of information being transmitted to the driver and the frequency and duration with which the driver looks at the controls.

Guidelines on the distribution of task load (both physical and cognitive) in Wickens's (1980) model of multiple resources function as a useful approach to the design of a display/control configuration for the driver. Virtual reality can be useful in developing and testing other models of human response to differing display configurations in the driving environment (see Kozak, Hancock, Arthur, and Chrysler, in press).

Information Flow and the Driver-IVHS Interface

A fully functional IVHS system will generate an interrelated information flow with a number of intrinsic feedback loops at different levels of operation. Perhaps the most appropriate way to describe the architectural structure of an IVHS system and its dynamics is to analyze the information flow among the different subsystems. The point of departure is the individual driver. We can state our goals at multiple levels of abstraction, starting from macro concerns with safe and efficient transition between points of origin and destination, and dissect such goals into more micro-based concerns for the momentary operation of the vehicle.

The design of the interface between driver and in-vehicle information displays and external control centers will be a key to effective use of IVHS by individual drivers. An effective interface will explicitly identify roles for the driver and for IVHS subsystems, as well as explicit

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considered to be domain-specific experts. In contrast, users of automobiles in an IVHS context – everyday drivers – are unselected, minimally trained, possibly unmotivated, and not necessarily experts in automobile automation.

With a user-centered approach, it could be argued that these differences lead to completely different problem areas and, hence, design solutions. However, aspects of the human-centered design approach in aviation automation are generalizable – for example, the provision of adequate feedback so that the user always knows what the automation is doing with respect to achieving the overall goal. IVHS, however, will need to cope with the special requirements imposed by an unselected, untrained user population, a minority of whom will have some sensory, cognitive, or motor impairments. These additional requirements may be regarded as a burden, but we believe that they may actually strengthen IVHS systems. If the IVHS architecture is designed so that an older, untrained, possibly impaired driver can use the system, it will probably serve the so-called average user in a superior manner.

What leads us toward the adoption of IVHS? Flink (1975), in paraphrasing the observation made by Brownell in 1923, indicated:

> "The ultimate failure to significantly ease the impact of the automobile occurred even though the responses of city governments and local leaders to the automotive challenge was in the best American pragmatic tradition. As the numbers of automobiles mounted, so did the governmental response: new taxes, improved roads, expanded parking facilities, extensive surveys, and a vast system of regulations enacted to guarantee the auto's operation in the public interest and welfare." Thus, instead of attempting to discourage the use of private passenger cars in cities, politicians and city planners adopted the expensive and ultimately unworkable policy of unlimited accommodation of the motorcar.

Is IVHS merely one more effort to sustain the untenable? Certainly, alternative solutions, such as telecommuting, should be entertained because they also solve some of the problems of advanced transportation. We need to keep asking why a transportation system is needed and who that system serves. In viewing future integrated intelligent transportation in this way, numerous alternatives become apparent, including the substitution of information for physical material, and the option not to travel at all. These questions are essentially those of human motivation and therefore mandate human factors efforts at multiple levels of application.

The Primacy of the Intelligent Driver

IVHS implementation procedures that start with traffic modeling and traffic management premises are unlikely to encapsulate the subtle nuances of drivers, whose individual, nonlinear actions will dictate the overall efficacy of IVHS. The proposed and actual outputs of advanced traffic management centers should be integrated with what is known about individual response and workload management in technically more demanding driving conditions. In the absence of total automation, the near- and long-term success of IVHS will depend directly on how well the needs and capabilities of these individuals are integrated into an overall systems architecture.

The users of IVHS will possess a wide spectrum of driving capabilities and will be required to deal with ever-expanding sources of information. Our recommendations for design, in terms of presentation of information to the driver, suggest that a key concept is the systematic integration of that input. The ability to guide the vehicle to its destination (navigation) and to avoid other objects (collision avoidance) are two ends of a common continuum whose axis is time.

To reduce information load, we recommend that displays be simplified – particularly through the use of content-contingent displays. To minimize the need to switch visual attention from one information source to another, we recommend display integration; by this process, multiple aspects of system status may be assessed via unified displays. Both of these measures should serve to optimize driver workload. The effective arrangement of sensors and effectors around the driver should also enable optimal response to incoming information.

Finally, adapted interfaces provide a means by which these recommendations can be implemented. They represent only a small illustration of what human factors can contribute to an IVHS architecture, and we contend that the human factors community can add much more.

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