human factors society bulletin

volume 35, number 10 october 1992

Intelligent Vehicle Highway Systems: Problems and Promises (Part 1)

By Peter A. Hancock and Jeff K. Caird

In an HFS Safety Technical Group newsletter article, we examined some human factors and safety issues involved in the implementation of intelligent vehicle highway systems (IVHS; Hancock et al., 1991). We focused on driver workload in an operating environment that promises to significantly increase the presentation and availability of information. However, the issue of workload is only one facet of the integration of human capabilities with a more complex technical driving environment (Sheridan, 1991, 1992). Here we discuss problem areas that, when addressed, will lead to a fully functional IVHS system.

Overload and Underload

Perhaps the most prominent problem for the human factors researcher and practitioner in the IVHS area is driver overload. The proliferation of potential and actual in-car information is expected to overload the driver's processing capability and/or distract him or her from the primary task of vehicle control. The study of human factors has shown that periodic operator overload occurs in many different systems. This complicates efforts to enact human-centered automation or, more properly, to develop hybrid human-machine systems (Hancock and Chignell, 1990; Karwowski and Rahimi, 1990). In the realm of IVHS, the projected increase of in-vehicle information—combined with the wide range of individual drivers' capabilities to deal with such an influx— has elevated the workload question to its current primacy. Because our previous report (Hancock et al., 1991) dealt with questions of driver overload, we do not wish to cover the same ground in this article. However, it is important to emphasize one aspect of maladaptive loading that has not received comparable attention in the arena of hybrid systems: work underload.

It is difficult initially to conceive that underload could be an issue in IVHS, given that the general problem of workload seems to be the evaluation and simplification of available information and specification of the appropriate way to convey it. In essence these questions are centered on context-based information management and interface structure. However, many system design specifications recommend some degree of automatic vehicle control (Wiener, 1988), so what are the driver's remaining tasks? One might envisage a system in which the destination is initially specified by the driver and dynamic route changes are subject to vehicle-based computer control. In the concept of "platooning" vehicles, an advanced version of the system, the driver's role defaults to that of system monitor. Studies of intrinsic human capabilities have shown that

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Election Results

Results of the election for 1992–93 officers have been tabulated, and the winners are as follows:

President-Elect.... Deborah A. Boehm-Davis
Secretary-Treasurer-Elect... Diane L. Damos
Executive Council......... Robert A. Glass
Susan K. Meadows

The name-change ballot determined that HFS will change its name to **The Human Factors and Ergonomics Society.**

humans are poor monitors (Warm, 1984) and have problems with the sustained-attention demands of driving (Harris, 1977; Mackie and O'Hanlon, 1977). More recent research has shown that the most stressful condition is enforced vigilance in an operational environment (Becker, Warm, Dember, and Hancock, 1991; Hancock and Warm, 1989).

Many will be quick to point out that such advanced automatic vehicle control is unlikely to be among the initial developments in IVHS; however, some form of nonoperator-based steering is often used as a primary rationale in arguments supporting IVHS implementation. If some portion of a journey is to be under system control, this raises the problem of handing off control from the driver to the system and back. These oscillations in operator workload pose a continuing problem for researchers in safety and human factors.

The workload problem is not a matter of simple overload. Because the problem involves workload oscillations that accompany the change from active control to passive monitoring, the solution is to ameliorate periods of maladaptive loading. For example, for an older driver of a rental vehicle who is driving in a crowded and inconsistently traffic-regulated city, the solution may include the simplification of both information and control. However, for the professional long-haul driver during extended interstate journeys, the solution may include load augmentation and arousing stimulation.

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Given that the automated utopia (autopia) is some distance in the future, a compromise solution to the problem of transient maladaptive loads may lie in the development of intelligent interfaces (Hancock and Chignell, 1989). Briefly, the intelligent interface acts as an intermediary between human and machine, seeking dynamic task allocation strategies that maximize the human's and machine's respective capabilities while maintaining an appropriate and tolerable load on the human. How such a concept could be applied to the driver in IVHS is examined in Verwey's (1990) interesting report.

Who Is in Control of the Vehicle?

One major problem is the legal issue involved in periodic control of the vehicle. As yet there is no legal precedent in automated road vehicle control, whereas the question of pilot control in semiautomated and automated aircraft systems is of current interest. In the vastly denser and accident-replete road environment, this issue is bound to be of critical concern. Although national and international standardization may provide some form of societal regulation, the legal and judicial questions of ultimate control may represent a stumbling block for IVHS. The situation certainly reinforces the notion that IVHS implementation must rely on a strong systems-based approach if it is to be successful and accepted by the traveling public.

Evolution and Integration of IVHS Technology

A number of demonstration projects are using vehicles that are minimally equipped with on-board computer aiding (e.g., Fleischman et al., 1991; Matsuda, Fujita, and Kobayashi, 1991). The vast majority of present-day vehicles possess little or no on-board driver information aside from access to radio traffic reports. We cannot know how traffic-flow patterns will be affected when the number of vehicles with further access to IVHS information increases. Some vehicles will have the current level of driver information (e.g., radio and external variable message boards), whereas more sophisticated vehicles will have access to a wider range of data bases and other information sources (e.g., global positioning satellites and artificial intelligence vehicle diagnostics). It is perhaps an advertising ploy to intimate that the future top-of-the-line vehicle will sweep majestically and impressively down deserted back roads while those less fortunate will be stuck in nightmarish traffic jams. However, is that fantasy destined to be reality?

As developments are made in signage and roadway markings and configurations, will the level of IVHS instantiation in each vehicle influence the decision-making and response capability of its driver and, by implication, affect the drivers of surrounding vehicles? At present we do not know. However, it is clear that some conceptions of IVHS, such as platooning, strongly imply some individual control of each vehicle. (This is not to say that a system handling "dumb" vehicles could not be developed, but the problem of ingress and egress from the platoon becomes a key research issue.) A related concern is public acceptance of IVHS. We cannot pretend to know how people will react to an evolving IVHS system in which they either significantly or marginally participate with respect to their own vehicle configuration. The process must be evolutionary, but it is clearly a human factors/safety issue.

How Much Will In-Vehicle Navigation Aids Be Used?

Many of the demonstration projects in IVHS-based research concern in-car navigation assistance systems. Such projects have been initiated in the United States (e.g., Florida and California), Germany, Britain, and Japan. In these systems a data base of information about an area is available to the driver and provides route guidance to destinations and amenities (Green, Williams, Serafin, and Paelke, 1991; Ikeda, Tachita, and Shibata, 1991; Norman, Zavoli, and Heideman, 1991; Popp and Farber, 1991). On-line navigational aids guide the driver's decisions at intersections to achieve designated goals. In such systems the data structures are static. In more advanced systems, information about current traffic status is provided, and alternative routes may be used in order to minimize travel time and avoid congestion. In such systems the data structures are dynamic. The full integration and operation of these systems is expected to alleviate the traffic congestion that besets major urban areas. Such systems will probably be a boon for taxi drivers, package delivery companies, and car rental firms, but what effect will they have on the everyday driver?

To frame the question economically, how much more will a buyer pay for a vehicle that includes a static information system? To ascertain this market segment, we need to know initially what percentage of on-road vehicles are driven by private individuals and what percentage of their journeys are to unknown or uncertain destinations. It is reasonable to assume that most motorists' trips are taken in private vehicles to known destinations. Indeed, Kostynicik and Kitamura (1987) indicated that travel by private vehicles constitutes more than 80% of all personal trips. The utility of systems using static informational structures seems marginal.

However, IVHS advocates point to potential increases in transportation efficiency and the benefits of *dynamic* informational structures (principally on-road congestion avoidance). If selecting the closest three Szechwan Chinese restaurants is seen as a frivolous aim of IVHS, consider how IVHS could reduce stress-generating and productivity-wasting highway congestion; surely that is a worthy endeavor.

With respect to dynamic information, IVHS designers will need to know when, where, why, and through what medium commuters and travelers will use traffic congestion and navigational information. Everyday patterns of driving behavior will be integrally linked to city structure, work location, shopping activities, and residence. However, the assumption that all motorists behave as a single, homogeneous group of information absorbers is false (Barfield, Haselkorn, Spyridakis, and Conquest, 1989, 1991; Spyridakis, Barfield, Conquest, Haselkorn, and Isakson, 1991). Based on congestion information, some drivers will be willing to change their departure and arrival times and their routes, even during the trip, whereas others will not change their travel plans whatsoever. The motorists who are willing to adapt according to traffic information will be the target market of advanced traffic information systems. For those drivers who do not use the existing network of radio, television, and variable message signs for traffic information, future IVHS implementations will probably have relatively little impact.

Large-scale rejection of IVHS technology based on people's uncertainties (Slovic, 1990) and misunderstandings is another concern that must be addressed. As traffic-management controllers know, providing congestion information does not guarantee its use. Hence knowing the proportion of large metropolitan populations that will use advanced traffic information networks will be critical for the success of IVHS.

In-Car Display Conflicts

During a session on IVHS at a recent HFS annual meeting, an issue was raised concerning the use of voice commands or auditory displays with in-vehicle guidance systems (I. Noy, personal communication, September 1991). It appears that in certain circumstances a driver will ignore traffic control devices (e.g., a stop sign) and continue on the preset route in obedience to the in-car message. The overriding of external traffic control devices by in-car commands poses a problem: context-dependent in-car messaging assumes that the vehicle has a much more thorough knowledge of the external environment than is currently envisaged. The critical research issues concern modality of information presentation and message content that promotes safe interaction with other road users. The addition of cautionary messages such as "proceed when safe to do so" provide some clarification, yet the interaction among messaging, sensory modality, and the driver's decision making is still problematic. If local rules are always given primary consideration, there could be a decrease in IVHS effectiveness. As aviation display designers have discovered (e.g., Stokes, Wickens, and Kite, 1990), the medium of visual information display has many "satisficing" solutions. The design process for multiple display systems requires considerable testing to derive a reasonable operational fit between operator and display (e.g., Inuzuka, Osumi, and Shikai, 1991). Designing an automobile display is fundamentally different from designing an aviation display, however: instead of tailoring the display for a select group, designers must achieve a fit for the least visually capable. In addition, the incorporation of visual displays requires determining which specific information is necessary for each driver in differing conditions. For instance, how often is the speedometer or gas gauge used? This is a question of timing and context—such displays need not be omnipresent. How can auditory and visual displays be presented when the driver needs that information, and how can they be suppressed when their presence might conflict with safe vehicle operation?

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Individual Differences

How will IVHS be designed to deal with the vast range of driver skills? The population of drivers is aging, as is the general population (Transportation Research Board, 1988). The group of older drivers—particularly women—aged 75 or older is the fastest-growing segment of road users (McKelvey, Maleck, Stamatiadis, and Hardy, 1988). In gerontology the ubiquitous finding is that information processing slows with age and that this effect is magnified as the complexity of a task increases (Cann, Vercruyssen, and Hancock, 1990; Fozard, Vercruyssen, Reynolds, and Hancock, 1990). How will IVHS technology cater to such individuals while also serving the broader public? Put more positively, how can IVHS open driving to an increased percentage of handicapped and disabled drivers?

We presume that the present requirements for vehicle control and traffic control adherence in testing will be adjusted to include roadway-based IVHS developments, though vehicular configuration will remain at the discretion of the individual driver. Of course, the eventual promise of IVHS is the individualization and, potentially, the simplification of the entire driving environment, and the subsequent reduction of problems caused by individual driver differences on the highways of the future.

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IVHS: Problems and Promises (Part 2)

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In part 1 of this article (October 1992), we discussed some of the problem areas that need to be addressed in order to produce a fully functional IVHS system. Among these were overload and underload, vehicle control, IVHS technology evolution and integration, in-vehicle aids and displays, and individual differences. Additional factors are described below.

Traffic Management and Information Trust

The central tenet of congestion information is that the rational driver, upon hearing of some blockage or slowdown, will immediately begin either self-directed or computer-directed rerouting in order to minimize travel time. Given the potential control capabilities of urban traffic management systems and the plethora of roadway information that should accompany actual implementation, some complex modeling procedure would seem to be sufficient to maximize traffic flow across the system. However, we need to ask how often solutions requiring some form of optimization are successful when human operators are part of the system. There are many issues regarding congestion alleviation, not the least of which is that many current origin-destination models of flow rely on incomplete information concerning each specific vehicle; this leaves prediction of flow beyond major freeways highly uncertain. Is the goal of traffic management a top-down strategy to optimize traffic flow at a system level? If so, how much—if at all—does this impede passage of any one vehicle? What happens if and when drivers become aware of this top-down strategy? These are just a few of many questions about trust in the system and in the information it provides.

What happens when the driver mistrusts the current information? Currently such information rarely applies to the whole roadway network, given that the rate of traffic flow depends on a person's proximity to the obstruction. It is annoying to be told of a blockage, only to arrive at the scene and find essentially no slowing. How does such a violation of trust influence a driver's subsequent decisions? What if no alternative routes are readily accessible, and what are the outflow effects on arterials when a freeway's entire flow is diverted into a radically different road network? How often is congestion attributable to standing obstructions, such as inadequate roadway configuration, as opposed to the more ephemeral and unpredictable effects such as accidents, weather, and breakdowns? Although many of these questions also lie in the domain of traffic flow modeling and management, it is the human, nonlinear characteristics and goals of each driver that will dictate the actions of his or her vehicle and, thus, the specifics of flow. Neglect of the human component in this regard will lead to the failure of an intelligent vehicle-highway system (IVHS) to alleviate congestion.

How Far Will We Drive in the Future?

Congestion develops when too many vehicles attempt to occupy the same place at the same time. To alleviate congestion it is generally necessary to reduce the density of vehicles. Platooning, however, is a strategy that actually increases vehicle density. (In a platoon, vehicles follow one another closely—similar to a convoy—in a line of traffic that is controlled externally.) Ingress and egress from platoons and the suggestion that vehicles should be in spatial and temporal proximity, superseding human response capabilities in the event of emergencies, raise important human factors questions.

To compensate for the effects of congestion, motorists may leave for work after the morning congestion has passed or leave early in order to arrive at work on time. Companies in large urban areas have responded by staggering work hours in order to provide flexibility to their workers.

Another tactic to reduce congestion is decentralization. Often market forces draw persons in an organization to a centralized location, but one effect of the information age is that physical proximity to the source of the information may be diminishing in importance. Given the time frame for the implementation of IVHS, is there a scenario in which IVHS would no longer be needed by the time it is in place? This speculation is disturbing, given the prospective investment in IVHS. It implies that high-level IVHS planners must work closely with demographers. Could the relevant issues ever be adequately addressed without human factors input?

> Should the system inform the driver, or even usurp control?

Applying versus Deriving Human Factors Principles

Human factors practitioners are faced with a large range of problems with respect to IVHS. In some ways the problems resemble others that have already been dealt with in other arenas, particularly in aviation. It is important that the knowledge already gained not be neglected. However, the many context-specific constraints of IVHS mandate new and innovative models and theories. Questions of technology transfer and innovation arise at a time in our development when the traditional information-processing paradigm is undergoing reevaluation. A topic of recent discussion (Flach, 1989; Vicente, 1990) and the subject of an upcoming text (Flach, Hancock, Caird, and Vicente, in press) is the linkage between the tenets of ecological psychology and human factors, which promises to stimulate a new facet of human factors. This is an eclectic endeavor, so we are not necessarily tied to any particular view of behavior. However, as practitioners we are obliged to search for the most safe, effective, and reliable answer to the practical questions we are asked. We hope that the support for research on solutions to IVHS problems is spent not only on the application of established models of human response but

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also on somewhat doubtful ones. Some mutual benefit will accrue to those in ecological psychology and in human factors in the development of new and insightful constructs that help in complex system improvement beyond the IVHS realm.

Taking the Adaptive System Out of the Loop

The destruction of human life on our roads is an intolerable societal burden and a source of disgrace. However, the number of accidents that actually occur, compared with the opportunities for them to occur, is relatively small. Many vehicles can navigate in proximity to each other, often on intersecting courses, but actual collisions arise from only a small percentage of the total interactions because drivers can generally control their vehicles. This is a manifestation of human behavioral adaptive capability. One central issue in IVHS is the total or periodic replacement, in part or in whole, of this as-yet-unplumbed human adaptive facility. For acceptable total replacement, any surrogate controller must exceed human response capability under all operational driving conditions. If some shared control is envisaged, as in hybrid systems, IVHS implementation must ensure that the interaction between human and machine never drops below the response efficiency of the unaided human alone. In essence, we must guard against the premature transfer of control away from the current system that is preeminent at adaptive response—the human being. Possibly in no other aspect of life for the nominally "average" individual will collaboration with advancing technology play such a key role. As a main point of innovation, IVHS is doubly mandated to do it right.

What Is at Stake?

It may seem to readers that the general tone of our comments in parts 1 and 2 of this article has been somewhat critical and negative with respect to IVHS possibilities. In the remainder of this part, we wish to balance the argument by presenting an advocacy position for IVHS and the expenditures associated with its development and implementation. To begin, we need only to point to the contemporary and anticipated accident record.

Approximately 1000 people are killed every week on U.S. roads alone. For U.S. residents between the ages of 0 and 40 years, the most probable cause of death is a road traffic accident. (However, irrecoverable serious injuries caused in traffic accidents, not fatalities, generate the greater financial cost to society.) Perhaps an additional perspective on these figures may be gained by the fact that a recent edition of *60 Minutes* labeled the 2162 deaths of children from gunshot wounds as an epidemic. This number provides dismal evidence of a contemporary social problem, but road accidents continue largely unheeded in our society. Furthermore, to suggest that these trends are vastly different in any other major urbanized country—or even in developing countries—would be misleading.

As advocates we believe that the most important contribution of IVHS will be to road safety. We hope and expect that IVHS innovations will improve many facets of transportation efficiency, but the prevention and amelioration of accidents must form a central focus.

In-Car Collision Warnings

If accidents and associated fatalities and injuries are the major problems, then collision warning and avoidance systems are the putative answers. However, it is not known exactly how collision avoidance can be achieved. Again we are faced with the design question of driver versus automated control. Should the system inform the driver, or even usurp control? Will an informational system be able to detect potential conflicts and devise an avoidance strategy in the time available? What format would such a presumably multimodal message take? Here the specter of false alarms plays a critical role. Suppression of false alarms appears critical for acceptance, yet the failure to supply a warning might be even more problematic. (However, see Sorkin, Kantowitz, and Kantowitz, 1988.)

Currently we have limited answers to these questions. Should we focus on collision detection systems in order to detect conflict situations, or should we employ some form of general protective envelope approach? Can we individualize alarm systems so that they respond to likely accident conditions in a manner appropriate for the pertinent driver age group? However, the structure and function of a collision avoidance warning system implies some complex, multiarray detection system representing a considerable engineering challenge. Having derived a veridical warning signal, however, its customization for consumption by various strata of drivers is uniquely a human factors question. It is this arena that promises enhanced safety, though it also represents the most complex portion of IVHS development.

Intelligent Transportation Systems

IVHS is designed to control and manage future roadways into the twenty-first century, but is this enough? The design and conception of an intelligent system dictates that it not only accomplish its own specified goals but also supply points of contact and interchange with numerous other interactive systems. For IVHS the obvious interaction is with companion transportation systems, such as rail and air, as well as with service and customer business systems to facilitate the movement of people and goods. In this way parallel and even advanced developments in aviation should not be seen merely as a guide to implementation but as a companion system with which to develop strongly integrative implementational links.

An integrative perspective views IVHS not as a singular answer to addressing clogged freeways but as an integral part of a greater transportation solution. For example, the underlying assumption of advanced traffic information systems is that they are theoretically cheaper to design and implement than a major rebuilding of the highway system would be. A balanced global analysis also considers the expansion and development of highways and other transportation modalities as complementary to IVHS. Unless IVHS becomes a reality, this collective, intelligent transportation infrastructure will not be possible because technology integration requires resonance throughout the whole system. The future economic survival of an advanced manufacturing society will probably be predicated on such an integrated system, which alone mandates IVHS development.

In 1991 General Motors estimated that traffic congestion costs the United States up to $93 billion in lost productivity each year. That some form of national IVHS system will be implemented in the near future seems almost a certainty. Comparable efforts in Europe and Japan attest to the need for an advanced, integrated transportation system. The twin goals of facilitating efficiency through congestion alleviation and improving safety through technical advance has strong economic and political appeal. The success of this enterprise is critically dependent on the timely solution to human problems. The failure to resolve such questions may lead to catastrophes against which the events in Bhopal and Chernobyl may seem to pale in comparison.

Calls for Human Factors Participation

This article was begun more than a year ago. Since that time numerous important developments have occurred in the area of IVHS. For example, at the 1992 HFS Annual Meeting, a session devoted to IVHS revealed that the Federal Highway Administration has offered major human factors research contracts in four major areas (see Mast and Peters, 1992, for detailed information). In addition, the National Highway Traffic Safety Administration is exploring numerous issues concerned with collision warning and avoidance as they pertain to IVHS innovations (Horowitz and Dingus, 1992).

It is clear from these collective efforts that human factors is considered an important facet of IVHS. Similar prominence has been given to human factors issues in Minnesota, where the GUIDESTAR program has also sought to integrate human aspects of IVHS development into each innovative project (e.g., TRAVLINK, TRILOGY, GENESIS).

One current development illustrating this central position of human factors is the announcement concerning research on an integrative IVHS architecture (U.S. Department of Transportation, 1992). This call for information makes clear the importance of considering user needs and makes evident that multiple approaches will be examined, at least in the early stages of development. A strong architectural engineering effort is needed to link each aspect of IVHS into a unified system. Human factors input to this project is vital because the integration of human abilities is as important as the integration of technical capabilities.

Recent developments worldwide have turned the societal focus on improvement of the domestic infrastructure. Success in this area promises great return. The human role in IVHS is vital, as in most large-scale systems, and user acceptance is a critical concern. How human abilities are integrated into a technically more complex travel environment is the domain of the human factors profession. We have much to offer here, particularly in transferring our technical skills from allied realms of research. In the past many have lamented the absence of human factors input early in the system design, and now IVHS appears to provide such an opportunity. We must not fail to grasp it.

Acknowledgments

Many individuals have aired these issues, and it would be misleading to represent them solely as our own. Several of these problems were raised in a session at the 1991 HFS Annual Meeting, and each of the presenters at that session are referenced here. The policy observations of Mast (1991) are given prominence. Tom Sheridan's 1991 article, together with discussions with many colleagues such as Ian Noy, Paul Green, Mike Sobeleski, Gene Ofstead, Dick Braun, Bob Johns, Mike Robinson, Dick Stehr, and Jim Wright, have been most relevant.

We would like to thank Sterling Stackhouse, Ian Noy, and Gus Mast for comments and amendments to the present article. Although responsibility for the statements is our own, we would also like to thank the Minnesota Department of Transportation; American Honda Motorvehicles; the Center for Research in Learning, Cognition, and Perception; and the University of Minnesota Center for Transport Studies for support. Finally, we would like to thank the National Aeronautics and Space Administration, which also supports our research program. Although our work in that respect concerns aviation and pilot activities, the convergence with common problems is apparent.

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