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Human Factors and Safety in the Design of Intelligent Vehicle-Highway Systems (IVHS)

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Intelligent Vehicle-Highway Systems (IVHS) have been proposed in the wake of rapid worldwide growth in traffic volume and density. These systems involve the application of advanced sensor, communications, computational, and control technologies to the design of highways and vehicles to improve traffic flow and safety. Similar technologies have been applied in other transportation systems such as aviation and air-traffic control, and it is suggested that the human factors insights derived from these systems can be usefully applied, proactively rather than retroactively, in IVHS design. Several safety and human factors issues relevant to the design of IVHS technologies, both near-term and long-term, are discussed, including: (a) the optimization of driver mental workload in highly-automated "hybrid" systems; (b) the design of in-vehicle navigation aids and the resolution of display conflicts; (c) individual and group differences in driver behavior and their implications for training and licensure; (d) the evolution and integration of IVHS technologies; and (e) traffic management and the regulation of driver trust in IVHS. Successful resolution of these issues and their incorporation in IVHS design will provide for fully functional systems that will serve the twin needs of reducing traffic congestion and improving highway safety.

INTRODUCTION

Motor vehicles are traversing the roads and highways of the nations of the world in increasingly larger numbers each year. Traffic volume has increased markedly, not only in highly mobile societies like the United States, but throughout the world. At the same time, road capacity is not increasing significantly. As a result, roads clogged with traffic have become the norm in virtually all large metropolitan areas. At the present rate of growth, it is estimated that there will be over one billion vehicles on the roads of the world by the year 2020. With the rise in traffic congestion has

come an increase in the number of road traffic accidents, including multi-vehicle incidents that have collisions of more than 100 vehicles. Currently in the United States, traffic accidents are the major cause of death for persons up to 38 years of age and are the leading cause of accidental death up to the age of 78 (National Safety Council, 1991). It is estimated that if these trends in traffic volume and accident rate continue there will be a global frequency of one serious accident per second, and one fatality per minute by the year 2020 (Michon, 1990, July). When injury and hospitalization resulting from accidents are added to the death toll on the road, then a grim picture emerges of a transportation system that is dangerous, inefficient, and tremendously costly to society.

Many measures introduced in recent years (e.g., mandatory use of seat belts, lowering of

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speed limits, stricter penalties for drunk driving, and improvements in road signs) have improved road safety and limited what might otherwise have been runaway costs of transportation accidents. Nevertheless, absolute accident frequency continues to grow, as do the societal costs. New solutions are therefore required for improving a transportation system that is ill-equipped to handle the anticipated rise in traffic volume. One answer receiving implicit acceptance in the U.S. and world-wide is the application of advanced sensor, computer, communications (radio/optical), and control technologies to the design and manipulation of highways and vehicles. Although this endeavor appears under several names, we refer to it here as Intelligent Vehicle Highway Systems (IVHS).

What Are Intelligent Vehicle Highway Systems (IVHS)?

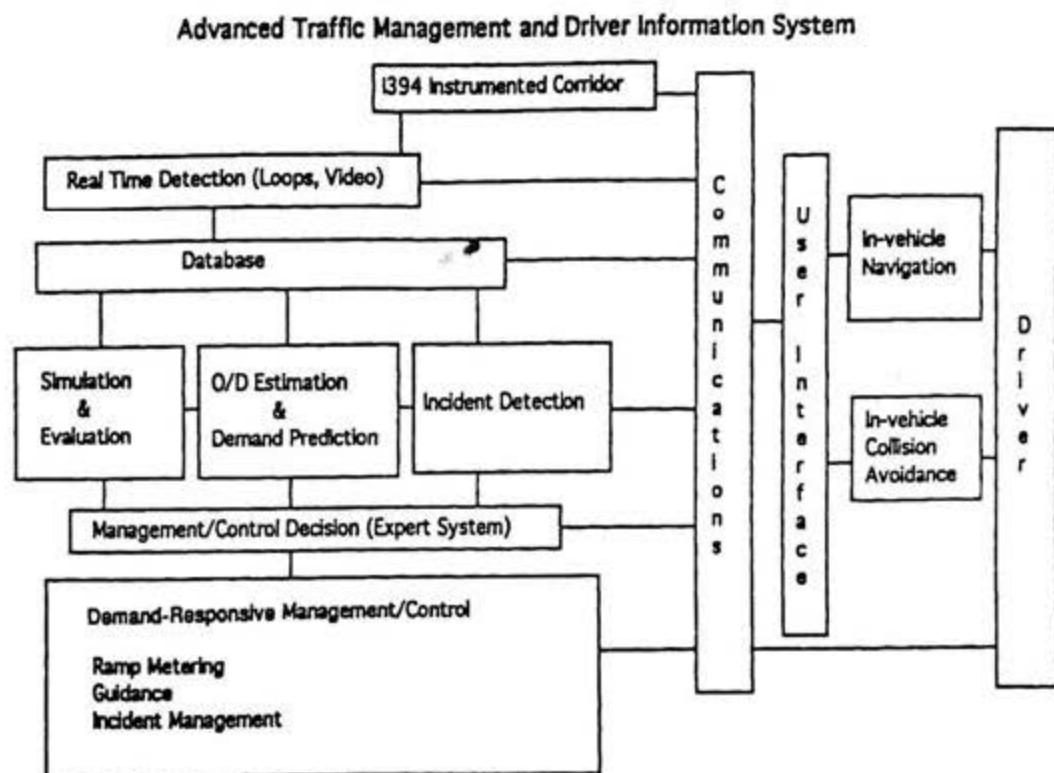
Intelligent Vehicle Highway Systems (IVHS) refer to the integrated usage of technical systems to improve the traffic flow and safety of contemporary and projected roadways (Hancock & Caird, *in press*). As such it spans broad concerns from advanced traffic management to in-car driving enhancement technologies (Hancock, Caird, Johnson, Shekhar, Yang, Coyle, & Pawlacyk, 1991, April 1-9). Driver aids range in scope from near-term systems using currently available technology, such as electronic map displays for in-car navigation, to long-term possibilities, such as "platooning" of cars and automatic steering that will require maturation of developing technologies. The general objectives of IVHS are to use advanced technologies to reduce traffic congestion, accidents, and energy costs, thereby enhancing the safety and efficiency of automobile transportation. The IVHS concept follows in the line of earlier programs in Europe and Japan such as PROMETHEUS and AMTICS (Sheridan, 1991). Figure 1 presents a summary architecture of an operational IVHS program. This is the GUIDESTAR program, which represents a collaboration between the Minnesota Department of Transportation (MN/DOT) and the University of Minnesota through its Center for Transportation Studies.

In the near term, IVHS will aid drivers by providing information about routing, navigation, collision avoidance, and monitoring vehicle and traffic status and will include such innovations as automated toll collection, which is already in the prototype stages. Individual drivers will be able to sample different information sources on demand in the expectation that such actions will theoretically simplify the driving task. IVHS is also expected to manage global traffic flow to permit better decisions by the drivers and traffic controllers to reduce traffic congestion without significantly expanding the number or capacity of the highways. The IVHS system will collect information about traffic from various remote sensing devices and will use such data to detect traffic incidents, predict potential congestion, and implement remedial actions. In addition, IVHS is expected to use control algorithms for traffic light activation and freeway entry ramps and will use these sources of control to manage traffic. Drivers will receive the information via electronic signboards on highways as well as from in-vehicle systems. The combined result of these information and management systems will be an increased traffic flow over safe routes that are relatively congestion free.

Long-term projections of the scope of IVHS are still evolving (e.g., IVHS America, 1992, January; Transportation Research Board, 1991). What is as yet uncertain is the necessity in the future for active driver control of steering the vehicle. A number of futurists (e.g., Asimov, 1990, October) project that steering will also be carried out by automated systems and that only high-level goals, such as the desired destination, will be directly dictated by the driver. This "no hands" thrust is one potential function of IVHS and represents essentially the complete automation of driving. It has the perceived benefit of increasing the capacity of freeways. One concept is "platooning" where vehicles are coupled together in rafts and packeted down the freeway. Vehicles would then be given collision-avoidance, lane-tracking, and other automated control systems to steer, accelerate, and decelerate. Compression of lanes and decreases in intervehicle distance would then yield a 40% increase in traffic flow (Wright, 1990).

As a result of enhanced IVHS development including the evolution of automated control,

FIGURE 1
OVERALL ARCHITECTURE OF THE GUIDESTAR IVHS PROGRAM, BEING A COLLABORATION BETWEEN THE MINNESOTA DEPARTMENT OF TRANSPORTATION AND THE UNIVERSITY OF MINNESOTA UNDER THE AUSPICES OF ITS CENTER FOR TRANSPORTATION STUDIES



Wright (1990) has estimated that as a percentage of a car's total value, new in-car electronics and automation will climb from the present 6% to 20% by the year 2000. Currently, much of the electronic information used by contemporary vehicles is opaque to the driver who does not need to know the moment-by-moment functioning of any number of the vehicle and traffic systems subcomponents. Much of the added computational capability will be dedicated to IVHS devices that will provide information on navigation, traffic congestion, road-side services, collision-avoidance warnings, as well as the outputs of devices that monitor the attentional state of the driver (e.g., alertness, workload, fatigue, etc.).

Human Factors in Automated Systems as a Model for IVHS

The application of advanced sensors, intelligent automation, and communication networks to driving follows a similar trend of

technological development in other areas of transportation, for example: aviation, air-traffic control, and shipping — although the difference in training and selection of operator differentiates these endeavors. Application efforts in these former areas have had a checkered history. The new automated systems in aviation and shipping have proven efficient and have significantly increased performance capabilities, via advancements such as all-weather flying in commercial aviation. Nevertheless, the new systems have raised several concerns in the area of human factors. For example, the ability of the pilot to intervene effectively when an automated subsystem fails is one of the key issues in automated cockpits (Wiener, 1988). Other difficulties that operators of automated systems may face include loss of system awareness and manual skills degradation (Norman et al., 1988). Parasuraman, Bahri, Deaton, Morrison, and Barnes (1990) have summarized some of the

benefits and costs associated with aviation automation. Wiener (1988), in characterizing the tradeoffs between automation and manual control in the cockpit, presents the case for both sides of the automation issue. The same questions that have been raised in the context of aviation appear applicable to IVHS automation. For example, concerns that the House of Representatives Committee on Science and Technology has about aviation automation for the 1980s is extendible to vehicle automation in the 1990s, but on a much larger scale.

Systems in which tasks and functions are allocated *adaptively* to the human operator or to automation, in response to changing task demands on the operator, may be less vulnerable to the problems that have been associated with "traditional" automation (Hancock, Chignell, & Loewenthal, 1985; Noah & Halpin, 1986; Parasuraman et al., 1990; Rouse, 1988). Adaptive automation has been proposed in a number of advanced cockpit concepts such as the Pilot's Associate and related systems (Parasuraman et al., 1990). Undoubtedly, similar designs will be proposed for IVHS. However, adaptive systems have not yet been fielded, and their theoretical benefits are only beginning to be verified empirically (Parasuraman, Hilburn, Molloy, & Singh, 1991).

What Are the Human Factors Issues?

Given the lessons learned from automation applications in the field of aviation, the time is ripe to consider human factors early in the development of IVHS. Poor interface design, workload regulation, skill degradation, automation-induced complacency, and so on, are some of the issues that human factors professionals have *reacted* to in aviation automation. Many of the same issues may, in principle, now be treated *proactively* in the design of IVHS. The goal of incorporating human factors into the design of IVHS will be helped considerably by the fact that in many IVHS development plans there is explicit recognition of the importance of human factors. Indeed, in several such programs questions regarding human factors are of preeminent concern. Principal among these concerns are issues of safety of the driver, particularly in

controlling, managing, and using the expected increase of in-vehicle information with IVHS implementation. Here, we examine safety issues in some depth. However, safety is only one facet of the overall picture of integrating human capabilities with a more complex technical driving environment (see Sheridan, 1991). In what follows, we have indicated a number of problem areas that need to be addressed for the smooth and successful implementation of IVHS. Should these problems be successfully resolved, then we shall reap the rewards of a fully functional IVHS system. The benefits of such a system are also briefly examined in this paper.

Under IVHS, future driving will bear distinct similarities to the management of many contemporary semi-automated systems. As a result, the human factors issues will be similar. The issues related to automation will include, at the very least, the following. First, how will driver workload be regulated under IVHS? The questions here are the same ones that have been raised in the context of increasing levels of automation in the cockpits of commercial aircraft. In particular, what is the tradeoff between high workload and high fatigue on the one hand versus boredom and complacency on the other? Second, the tradeoff between replacing intelligent human capabilities with "dumb" devices, a characteristic of current automation practices, will need to be re-examined in the context of IVHS. According to Norman (1991), automation should either be made more or less intelligent than exists in current implementations; the middle ground that current automated devices occupy is such that the operator is not sufficiently well-informed about what the automation is doing. Third, when a new technology is introduced, a problem is solved and created simultaneously; however, the latter does not manifest itself immediately. Fourth, for collision avoidance, what is the tradeoff between false positives and false negatives in identifying collision-likely targets? Fifth, will IVHS fall victim to the same type of thinking that dictates the mere addition of more automation as problems are sequentially encountered? Other questions regarding human factors will center mainly around the design of the driver interface and the design of IVHS components

to match the characteristics of drivers of widely differing capabilities, including those with physical or cognitive disabilities, elderly drivers, and very young drivers.

We recognize that here we are only dealing with a small subset of the potential range of human factors and safety issues. Indeed, in recent reports other issues have been identified in detail (IVHS America, 1992, January). For example, the human factors and safety subcommittee of IVHS America has recently issued a draft report in which four major areas of concern are established. These are: (a) advanced traffic management systems (ATMS); (b) advanced traveler information systems (ATIS); (c) advanced vehicle control systems (AVCS); and (d) commercial vehicle operations (CVO). The authors of each section identified some historical facets of each element while using the expertise of each subgroup member to establish a research agenda. We do not present these concepts in detail here, except in cross-reference issues.

DESIGN ISSUES FOR IVHS

Regulation of Driver Mental Workload

Perhaps the most prominent problem for the human factors researcher and practitioner in the IVHS area, and certainly one that has received major attention, is the question of driver overload. We expect that the proliferation of potential and actual in-car information may act to overload the processing capabilities of drivers and/or act as a source of distraction from the primary task of vehicle control. The projected dramatic increase of in-vehicle information in IVHS, combined with the large range of individual driver capabilities to deal with such an influx, has elevated the workload question to its current primacy.

The workload of driving can be examined using a number of assessment techniques. From a task/function analytic perspective, the task of driving is composed of three major interlinked categories of activity: (a) vehicle control; (b) navigation; and (c) collision avoidance. Each of these functions contribute to the overall driving workload. Driving is also a particularly good example of a real-

world *divided* attention task. Even under routine, low-traffic conditions, the driver must coordinate several tasks together and generally can do so quite efficiently. Of course, many of these task components become highly automatized with practice, so that under normal driving conditions the demands of divided attention on the driver will generally be within the limits of their attentional capacity. When traffic density increases, however, or when driving at intersections, traffic circles, etc., (see Hancock, Wulf, Thom, & Fassnacht, 1990) divided attention demands may sometimes exceed driver capabilities.

This line of reasoning led to a number of early attempts to measure the "spare attentional capacity" of drivers by imposing different secondary tasks on the main driving task (see Brown, 1978, for a review). In testing drivers in the UK, Brown combined primary performance measures with the subsidiary task technique (see Brown, 1962a, 1962b, 1965; Brown & Poulton, 1961; Brown, Simmonds, & Tickner, 1967), while Wierwille and his colleagues in the United States have used these techniques in their work on driver and pilot workload (Hicks & Wierwille, 1979; Wierwille, & Conner, 1983; Wierwille, Rahimi, & Casali, 1985; Wierwille, Casali, Conner, & Rahimi, 1986). These secondary-task techniques have proved useful in evaluating the effects of some aspects of the driving environment on performance. As an example of this type of study, consider the early investigation of Brown and Poulton (1961). They required drivers to detect the simultaneous onset of three small lights mounted on the three rear-view mirrors of an instrumented car during prolonged driving. Reaction time to light onset was found to be sensitive to driving difficulty. Another example concerns the effect on driving performance of "cellular" car telephones, which have come into widespread use recently. In a pioneering study, Brown, Tickner, and Simmonds (1969) found that a reasoning task presented over a radio telephone headset adversely affected driving tasks requiring "effortful" decision making, such as distance judgments, where as more "automatic" tasks, such as gear shifting, were not affected; McKnight and McKnight (1991) also recently found an adverse effect of cellular phone use on differ-

ent perceptual tasks during simulated driving. A third example concerns the driver's residual attentional capacity during left-hand turns, which are a major contributor to accidents involving older drivers (Brainin, 1980) and automobile-motorcycle collisions (Wulf, Hancock, & Rahimi, 1989). Using probe reaction time and eye-blink frequency as secondary task measures, Hancock et al. (1990) found that turn sequences were associated with greater demands on central attentional capacity than straight driving.

In contrast to this traditional approach to task decomposition, we can use an ecological approach (Flach, 1989; Flach, Hancock, Caird, & Vicente, in press; Vicente, 1990) to task analysis in driving, focusing on goals and intentions (e.g., Gibson & Crooks, 1938). Although this approach has yet to reach fruition, it promises a new perspective on the question of driving workload. Previous investigations of the mental workload imposed by driving have used the four major methods of workload assessment. Some of our own recent work used primary task performance, subjective response, and physiological assessment methods to examine the mental loads of simple driving maneuvers in actual on-road conditions (Hancock et al., 1990). Evidence from the above studies and our own work is convergent in suggesting that different phases of driving impose different mental workload levels. Therefore, driver workload cannot be regarded as an all-or-none single level response but should be viewed as a continuous variable that momentarily fluctuates in level. On occasion IVHS systems should act to "offload" the driver, and conversely, under certain driving conditions of boredom and monotony, IVHS should act to augment current load level to raise drivers up to an optimal level of loading.

Studies of automated systems in aviation have revealed a complex relationship between the level and amount of automation and operator workload (Parasuraman et al., 1990; Wickens, 1992). One conclusion that can be reached is that it is not inevitable that workload is reduced with automation. Anticipated automation benefits may not be realized if the pilot is faced with greater workload levels with an automated system than existed prior

to the automation, despite the fact that the automation was intended to reduce workload. Wiener (1987) collected opinions about automation from 166 pilots of the highly-automated Boeing B-757. He found that only about one third of the pilots felt that automation in this modern aircraft had led to the claimed decrease in pilot workload, while the remaining two thirds felt that workload had remained the same or had actually been increased. McDaniel (1988) described how this problem can occur in the context of fighter aircraft automation:

"If the automation of a critical function is not perfectly reliable, the pilot will need to monitor it in order to intervene quickly should a malfunction occur. If the pilot continuously monitors the automation, he or she can intervene in about one second. If the pilot is attending to another task when the malfunction occurs, the reaction time will be several seconds because he or she must also refresh his or her awareness of the situation as well as detect that a malfunction has occurred, what has malfunctioned, and what to do about it. In many situations, the malfunctioning aircraft cannot survive even those few seconds. As a result, a pilot dares not perform a second noncritical task rather than monitor the automated critical task. So, while this type of automation permits a useful task to be accomplished, it does nothing to free the pilot's attention resources for other tasks" (p. 837).

The paradox is that in some cases implementing automation in an attempt to reduce workload may actually result in increased workload because of the cognitive workload associated with monitoring the automation. Several recent studies have shown that monitoring a system for possible malfunctions for prolonged periods of time induces a high level of mental workload, despite the fact that the information-processing requirements of such a task are not complex, and few overt control actions are required (Deaton & Parasuraman, in press; Hancock & Warm, 1989; Parasuraman, 1987; Becker, Warm, Dember, & Hancock, 1991).

The general lesson that has been learned is that the goal of automation must be to optimize and regulate the level of workload, not invariably to reduce it, for underload may be

as potentially a source of difficulty as overload. It is hard, initially, to conceive that underload may even be an issue in IVHS, as the general problem of workload seems to be the *evaluation* and *simplification* of available information and specification of the appropriate way in which to convey it. In essence, these are centered on context-based information management and interface structure. However, in a system in which there is some degree of "automatic" vehicle control, we have to examine most carefully the range of tasks that remain the primary responsibility of the driver (see Wiener, 1988). It may well be envisaged that destination is initially entered by the driver, and dynamic route changes are subject to vehicle-based computer control. Given also the concept of "platooning" vehicles, the drivers' role in such an admittedly advanced version of the system defaults to that of system monitor. Understanding intrinsic human capabilities informs us that humans are poor monitors (see Warm, 1984; Parasuraman, 1986) and have problems with the practical sustained attentional demands of driving (Harris, 1977; Mackie & O'Hanlon, 1977). More recent research has shown that enforced vigilance in the operational environment is most stressful (Becker et al., 1991; Hancock & Warm, 1989). While many will be quick to point out that such advanced automatic vehicle control is unlikely to be among initial developments, the general notion of some form of nonoperator based steering is often used as a primary rationale in efficiency arguments for IVHS implementation. Given that some portion of a particular journey is under system control, there is the problem of actually handing off control from the driver to the system and back. These oscillations in operational workload pose a continuing general problem for researchers in safety and human factors.

In reality, the workload problem cannot be seen as one simply of overload. Rather, it involves the identification of workload oscillations that accompany the change from active control to passive monitoring. The problem is to ameliorate periods of maladaptive loading. Solutions obviously include the simplification of both information and control for the older driver of a rental vehicle in a crowded and inconsistently traffic-regulated conurbation.

However, a solution may equally be represented by load augmentation and arousing stimulation for the professional long-haul driver during extended interstate journeys. Given that the automated utopia (autopia) is some distance in the future, a compromise answer to this problem of transient maladaptive loads may lie in the development of adaptive systems or intelligent interfaces (see Hancock & Chignell, 1989; Parasuraman et al., 1990). Briefly, the intelligent interface acts as an intermediary between human and machine in searching for dynamic task allocation strategies that maximize the use of their respective capabilities while maintaining an appropriate and tolerable load upon the operator (Hancock & Chignell, 1990, August; Rouse, 1988). As mentioned previously, adaptive system concepts are currently being examined in the context of aviation automation, but empirical evidence for their efficacy has not yet been firmly established. The way in which such a concept could be applied to the driver in IVHS is examined in Verwey's (1990) report.

Keeping the Driver in the Loop

The regulation of driver workload under IVHS will tax the creative efforts of automobile designers if the driver is removed from the control loop completely. Such a driver — even the term "driver," which implies a degree of active control, may need to be abandoned for some modern jargon such as "automated vehicle supervisor" — would undoubtedly suffer from the problems of underload enumerated above, unless ways are found to keep him or her involved in irrelevant activities. More importantly, taking the driver out of the loop may adversely affect the ability of the driver to intervene manually if necessary, as has been found to be the case in aviation.

The destruction and carnage on our roads represents such an intolerable societal burden that any potential remediating solution should be given serious consideration, even one in which the driver is completely removed from the control loop. Yet despite the fact that the human driver appears to be the "weak link" in the automobile transportation system, removing that link may not be a good solution. In one way, the actual number of accidents that

occurs on the road, compared to the opportunities for them to occur, is relatively small. Why is it that so many vehicles can navigate in close proximity to one other, often on intersecting courses, and yet the collision rate represents only a small percentage of the total number of these interactions? In reality, this can only happen because drivers, in general, do a reasonable job of controlling their vehicles, and this is a manifest outflow 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. Clearly any surrogate controller must *exceed* human response capability under *all* operational driving conditions for acceptable total replacement, as it has been shown that human response is particularly averse to systems that purport to provide surrogate control but in reality prove to be unreliable. If some shared control is envisaged, as is the case of hybrid systems (Karwowski & Rahimi, 1990), then 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, which is preeminent at adaptive responding, namely the human being. Perhaps nowhere in the day-to-day life of the nominally "average" individual will collaboration with advancing technology play such a key role. As a main point of innovation then, IVHS is doubly mandated to do it right.

Design of In-Vehicle Navigation Aids

At present, 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 some general form, database information about an area is accessible by the driver to provide route guidance to area-wide destinations and amenities (see Green, Williams, Serafin, & Paelke, 1991; Ikeda, Tachita, & Shibata, 1991; Norman, Zavoli, & Heideman, 1991; Popp & Farber, 1991). On-line navigational aids act to guide the driver's decisions

at intersections to achieve designated goals — that is, the data structures are static. In more advanced systems, current information about traffic status is provided, and alternative routing may be sought to minimize travel time and avoid congestion — that is, the data structures are dynamic. We expect that the full integration and operation of these systems will help alleviate the considerable and growing problem of traffic congestion that besets most major world-wide conurbations. While such systems will probably represent a great boon for the taxi driver, the package delivery companies, and the car-rental firms, what will be the impact of such technologies on the everyday driver?

To frame the question economically, how much more money would the average consumer be willing to pay to purchase a vehicle with such 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 the journeys that they make are to unknown or uncertain destinations. It is probably a reasonable assumption that the majority of trips motorists take are in private vehicles to known destinations. Indeed, Kostyniuk and Kitamura (1987) indicated that travel by private vehicles constitutes over 80% of all personal trips. For systems using *static* informational structures, the marginal utility seems questionable. However, the advocate responds with the continued hope for IVHS with respect to transportation efficiency and the benefit of *dynamic* informational structures, being principally on-road congestion avoidance. If selecting the closest three Chinese restaurants that do hot and spicy can be a questionable aim of IVHS, what of the reduction of stress generating and productivity wasting highway congestion? Surely this latter aim 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 homoge-

neous group of information absorbers is clearly false (Barfield, Haselkorn, Spyridakis, & Conquest, 1989, 1991; Spyridakis, Barfield, Conquest, Haselkorn, & Isakson, 1991). At the poles of the obedience continuum, some drivers will be willing to change their departure and arrival times, as well as routes before and even during their trip, based on congestion information, while others will not change their travel plans whatsoever. The group of motorists that are willing to adapt to traffic information to varying degrees will be the target market of advanced traffic information systems. For those drivers that currently do not use the existing network of radio, television, and variable message signs for traffic information, future IVHS implementations most likely will have little relative impact. Large scale rejection of IVHS technology based on individuals' uncertainties (Slovic, 1990) and misunderstandings is a concern that must be addressed. As traffic management controllers recognize, the mere provision to the motorist of congestion information does not guarantee its use. Hence, knowing the proportions of large metropolitan populations that will be willing to receive and adapt to advanced traffic information networks will be critical for IVHS success.

In-Car Display Conflicts

An important human factors issue concerning IVHS was raised at the last Human Factors Society meeting, (Noy, 1991, July). It concerns the use of in-vehicle guidance systems using voice commands or auditory displays. It appears that under certain circumstances the driver will ignore traffic control devices, such as 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 particular problem in that context dependent in-car messaging assumes a much more thorough knowledge of the external environment on behalf of the vehicle than is currently envisaged. The critical research issue concerns modality of information presentation and message content that promotes safe interaction with other road users. The addition of cautionary messages like "proceed when safe

to do so" provides some clarification, yet the interaction between messaging, sensory modality, and drivers' decision-making is still a problematic issue. If local rules are always given primary consideration, there could be a decrease in IVHS effectiveness and potential safety also.

As aviation display designers have discovered (e.g., Stokes, Wickens, & Kite, 1990), the medium of visual information display has many satisfying 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, & Shinkai, 1991). A fundamental difference between aviation and automobile displays, however, is that instead of designing for a selected group of individuals, a fit must be achieved for the least visually capable. In addition, the incorporation of visual displays as part of vehicle and advanced traffic information evolution requires a solution to questions regarding the specific information needs of individual drivers in differing conditions. For example, how often is the speedometer or gas gauge used? This is a question of timing and context, since such displays need not necessarily be omnipresent. Additional questions are: How is it that auditory and visual displays can be presented when the driver needs the information? How can they be suppressed when their presence might conflict with safe vehicle operation?

Matching IVHS to Individual and Group Differences in Driver Behavior

The goal of an efficient, safe transportation system will be met only if the design of IVHS technology fits the needs of the "average" driver and is complemented by sufficient attention to individual and group differences among drivers. Will IVHS be sculpted to deal with the vast range of driver skills in the 21st Century? Age represents one of the more important driver variables. It is well known that older adults are growing in numbers throughout the world (Martin, 1988; National Research Council, 1988). In the United States, for example, the number of persons aged 65 years or older is expected to double over the next 40 years, from 32 million (12.7% of the total population) in

1990 to 64 million (21.1%) by 2030 (Taeuber, 1983). The population of drivers is also aging along with the general population (Transportation Research Board, 1988). In particular, drivers aged 75 years and older, especially women drivers, represent the fastest growing segment of road users (McKelvey, Maleck, Stamatidis, & Hardy, 1988).

How will IVHS technology cope with the necessity to cater to such individuals while serving a broader traveling public? In a more positive way, how can IVHS open driving to an increased percentage of handicapped and disabled drivers? Furthermore, the population of older drivers will include those with slowly debilitating degenerative diseases such as Alzheimer's disease (AD), which is the leading cause of intellectual impairment (dementia) in adults (U.S. Department of Health and Human Services, 1984; Office of Technology Assessment, 1988). Alzheimer's disease leads to severe abnormalities in memory, attention, and other cognitive functions that impact driving ability; but in the early stages of the disease, drivers with AD may be difficult to distinguish from healthy, older drivers (Parasuraman & Nestor, 1991). The number of drivers with mild or undiagnosed dementia is not known but is probably growing with the population of healthy, older drivers.

It is important to emphasize the confluence of diverse factors that make the testing and evaluation of older drivers the critical arena for IVHS development. In addition to the relative disproportional growth of this segment of the driving public, there is good reason to believe that an IVHS system that works for older drivers will work for the rest of the driving public, and, conversely, an IVHS system that fails to serve the older driver will leave a large and increasing segment of the driving population at risk (Hancock, Caird, & White, 1990). A more thorough analysis of the accident record, however, shows that despite their acknowledged self-regulation of risk, older drivers are still over-represented in accidents involving a number of common driving maneuvers (e.g., merging and overtaking). Clearly, it is this group that will benefit most from a successful in-vehicle collision avoidance system that represents a strong safety component of IVHS implementation. In addi-

tion to the noted maneuvers, older drivers are over-represented in left-turn accidents (Hancock, 1991, November). One common factor between each of these maneuvers is the necessity to synchronize one's actions with the spatio-temporal dynamics of other road users. The failure to accomplish this points to a deficit problem of older drivers, which is a sequential slowing in information processing with age (Cann, Vercruyssen & Hancock, 1990; Fozard, Vercruyssen, Reynolds, & Hancock, 1990).¹ Older drivers react more slowly and therefore have more dynamic problems in traffic, which to them is running at a progressively faster relative rate. A successful IVHS system promises to be a bridge across this progressively widening gulf.

One particularly useful way to identify particular problems and resultant analytical methods, hypotheses, and models directed to their solutions is to examine the practical problems of building an IVHS interface for the older driver. Some problems have already been identified that pertain to the timing of warnings, whether too soon or too late. These questions can be addressed within the context of older driver testing in which customization of warning interval can be adjusted with respect to the actions of each individual driver. For younger drivers, warnings that were too early would quickly come to be ignored. However, the fact that older drivers need a longer foreperiod of warning will again test the boundaries of the envelope of the technology, making the system that works for the older driver work for everyone. In general, older individuals are more reluctant to use technical innovations; hence, acceptance by older drivers is critical. Such acceptance mandates reliability and an obvious safety benefit, as trust that is lost by an IVHS system will be

¹Fozard, J. L., Vercruyssen, M., Reynolds, S., and Hancock, P. A. (in press). Age changes and sex difference in reaction time: The Baltimore longitudinal study of aging. *Journal of Gerontology*. (This paper is from the Baltimore longitudinal study on aging which has data on the same individuals over some 30 years. These data indicate the ubiquitous slowing effect but also show the interaction with complexity and the gender effect where women slow at a progressively faster rate than men. As older women are the fastest growing segment of drivers, these findings have direct relevance to the development of IVHS technology and integration.)

recovered only at great cost and after an extended period of use (Riley, 1989).

The single most important method for studies involving the development and testing of safety systems for vehicles, such as the IVHS, is simulation. In particular, a simulation environment whose results can be validated by test track and on-road testing is essential if realistic and trustworthy findings are to be obtained without undue risk to the driver. As mentioned earlier, Gibson has proposed a model that can be described as an envelope of safe progress (Gibson & Crooks, 1988). This driver-based performance model is particularly appropriate to the testing and evaluation of IVHS systems. Based on this matching between a perceptual characteristic of the driver and a physical envelope that describes the control capabilities of the vehicle, potential incursions into a future envelope of safe progress can be derived to inform the driver of potential conflict. We have developed this concept further to indicate to the driver a number of conservative strategies for avoiding problems; this procedure is called SEER, for Safe Envelope of Egression Response. It is insufficient for any warning system to merely signal the presence of potential or actual conflict. Rather, the system should also provide information on the preferred response strategy. SEER promises to achieve this goal and already uses a computer-based development for collision avoidance developed in our earlier work (Yang, Shekhar, & Hancock, 1991, August; Yang, Shekhar, Hamidzadeh, & Hancock, 1991). This safety aspect of IVHS, expected to reduce collisions and thus injury and fatality, is the strongest rationale for such developments from a societal perspective.

The general question of designing a transportation system to match individual and group differences centers around training and licensure. Presumably, the present necessity for vehicle control and traffic control adherence in testing will be extended to include roadway-based IVHS developments, although vehicular innovation will presumably remain the discretion of the individual driver. Of course, the eventual promise of IVHS is the individualization and potentially the simplification of the whole driving environment, such that the current problems associated

with particular individual drivers may be actually reduced on the technical highways of the future.

Training and Licensure

With the proliferation of in-car displays and aids, learning to drive may prove to be more challenging for novice drivers. Training issues will therefore come to the forefront as they have in the context of automation in power plants and aircraft. Automation can place conflicting demands on drivers in the future, which they may not be well-equipped to meet (e.g., passive monitoring under normal conditions versus active control in an emergency), unless they have been specifically trained to cope with these demands. Inadequate training has been shown to be related to several automation-induced problems in the cockpit. For example, the negative effect of automation on monitoring performance may be related, in part, to a lack of "automation-based" skills. This reflects inappropriate training because automation necessitates a shift from psychomotor skills to more cognitive and problem-solving skills, which may not be emphasized in the training program (Idaszak & Hulin, 1989). Most training programs are based on eliciting appropriate responses from the pilot to display messages and flight conditions. Pilots are taught how to respond to a particular signal in a specific situation, but learning information-processing skills is not typically emphasized. Driver training programs of the future may need to be similarly structured.

One vital question for regulatory bodies is the potential for graded licensure for IVHS equipped vehicles. This possibility has to be considered as many of the design concepts for advanced in-car displays significantly increase the demands placed on the driver. If, through the use of technologies such as head-up and context specific displays, driver workload can be simplified and dynamically regulated, then licensure issues might appear moot. However, if this large and complex system development follows precedent, then a serious analysis is needed concerning the degree to which individual drivers should be able to operate ever complex in-car systems. In essence, the need for selected licensure will

be a direct admission that human factors has failed to solve the information load issue for the wide spectrum of the driving public. This particular issue highlights just how much IVHS is a SYSTEM development, in which actions of the state and federal agencies cannot be considered dissociated from the plans and designs of vehicle and IVHS component manufacturers. While simulation might be used as a method for differential licensure testing, the preferred strategy for development would be for human factors interfaces that are both transparent and "direct" enough even for naive users and the older and infirm members of the driving population.

Evolution and Integration of IVHS Technology

There are at present a number of demonstration projects in which vehicles have been minimally equipped with on-board computer aiding (e.g., Fleischman, Carpenter, Dingus, Szczublewski, Krage, & Means, 1991; Matsuda, Fujita, & Kobayashi, 1991). These vehicles exist in a traffic world in which the vast number of vehicles possess little or no on-board driver information beyond perhaps access to a local traffic radio bulletin. What we cannot as yet know is: What are the effects on traffic flow patterns when a slowly increasing number of vehicles attain further access to IVHS information? What we can be sure of is that some vehicles will continue to have the present level of driver information (e.g., radio and external variable message boards), while progressively more sophisticated vehicles will have further access to a wider range of databases and other real-time information sources (e.g., global positioning satellites). It is perhaps an advertising ploy to suggest that the top-of-the-line vehicle will sweep majestically and impressively down deserted back roads, while the less fortunate and less able vehicles are stuck in nightmare traffic jams. However, is such a personal and individualized 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 the

direct interaction on the drivers of surrounding vehicles? At present, we do not know. However, what is clear is that some conceptions of IVHS such as "platooning" strongly imply individual actions on behalf of each vehicle (this is not to say that a system handling "dumb" vehicles could not be developed, but again the problem of ingress and egress from the platoon becomes a key research issue). In this context, platoons are groups of vehicles traveling at high speeds and in close proximity. Their characteristics are similar to a "train" of vehicles except that individual vehicles must be able to disengage on command. This leads to the further concern of public acceptance of IVHS from the program's very beginning. How will individuals react to an evolving IVHS system in which they either deeply or marginally participate with respect to their own vehicle configuration? While we cannot pretend to have the answer and by definition this answer itself must be an evolutionary one, it is clearly a human factors and safety issue.

Traffic Management and Information Trust

The central belief in communicating information about traffic congestion is that the rational driver, upon hearing of some blockage or slow down initiates either a self-directed or computer-directed alternative routing to minimize travel time to a required destination. Given the potential control capabilities of urban traffic management systems and the plethora of roadway information that should accompany actual implementation, it would appear that some complex modeling procedure would be sufficient to maximize traffic flow across the system. But how often is success visited on solutions requiring some form of optimization where human operators are part of the system? There are many issues in this congestion alleviation area, not the least of which is that many current origin-destination models of flow rely on incomplete information concerning each specific vehicle, leaving prediction of flow beyond major freeways highly uncertain. We might initially touch upon the objective of traffic management. Is the goal a top-down strategy to optimize traffic flow at a system level, and if so, how far

does this, if at all, sub-optimize the passage of any one single vehicle? What happens if and when drivers become aware of this top-down as opposed to bottom-up strategy? This is only one in a series of questions about trust in the system and the information it provides.

What happens when the driver mistrusts the current information? This information, at present, is rarely contemporary for the whole network, as the rate of flow decreases depending upon an individual's proximity to the obstruction. How frustrating and 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 an individual driver's subsequent decisions? What if there are no readily accessible alternatives and what are the outflow effects on arterials when a whole freeway flow is diverted into a radically different road network? How often is congestion due to standing obstructions like inadequate roadway configuration versus the more ephemeral and unpredictable effects like accidents, weather, and breakdowns? While many of these questions also lie in the domain of the traffic flow modeling and management community, it is the very human and indeed non-linear characteristics and goals of each individual driver that will dictate the actions of each component vehicle and thus the specifics of flow. Neglect of the human component here can, and indeed will, lead to the disastrous failure of the congestion alleviation aim of IVHS.

Recent research on the impact of aviation automation on trust is relevant to the use of IVHS by the driver of the future. Riley (1989) suggested that the trust that pilots have in an automated system may determine their response to either rely on or to override the automation. In addition, their level of trust will depend on their evaluation of the abilities of the automation to do what it is supposed to do. The pilots' evaluation of their own capabilities to perform what the automated system can do reflects their self-confidence. According to Riley's model, if confidence is higher than trust, then pilots will shift their preference from automation to manual control, especially in risky situations. In a study of simulated process control, Moray and Lee (1990) showed that operator trust in automation declined following an

automation malfunction failure, but then recovered and increased so long as no further malfunctions occurred. Taylor (1990) also emphasized the importance of trust in highly automated aircraft, particularly when functions and tasks are distributed among the crew. He interviewed 50 operational aircrews using 12 tactical decision making scenarios. Six of the scenarios were related to navigator decision making and six to pilot decision making. Of the six scenarios in each group, three were described as conditions engendering high trust and three as low trust conditions. Principal components analysis of the pilot responses indicated that demand for trust was related to the perception of risk, whereas supply of trust was related to the level of judgment/awareness and uncertainty/doubt.

DISCUSSION

Approximately 1,000 people are killed per week on the roads of the United States alone. In America, between the ages of 1 and 40 years, the most probable cause of death is in a road traffic accident. If fatalities are at the center of the accident world, the penumbra of irrecoverable serious injury which surrounds road deaths extracts, if anything, a greater ongoing cost to society (National Safety Council, 1991). The recent Transportation Research Board Report (TRB) provides even more staggering comparisons with our traditional conception of killers such as cancer and cardio-respiratory disease (TRB, 1990, 1991). Perhaps a further perspective is put on these figures by comparison with a recent *60 Minutes* special that labeled the 2,162 deaths of children from gunshot wounds as an epidemic. While such numbers provide dismal evidence of a contemporary social problem, the often fatal, traditional, equal opportunity road accident continues to stalk largely unmolested through our society. To suggest that these trends are vastly different for any other major urbanized country, or even the developing countries, would be misleading. This bleak picture can and must be dealt with. Currently, IVHS offers the best possibility for a long-term solution to the problem of road safety, given that it is designed with human needs in mind.

How Far Will We Drive in the Future?

In trying to point to a number of problem issues, it is not possible to deal with each one in depth. However, another topic that we cannot pass over is the question of how much drivers will drive in the future. Congestion develops as a function of too many vehicles attempting to occupy the same regions of space-time coincidentally. To alleviate such congestion, it is, in general, necessary to spread the density of vehicles out over space and time.² Two obvious motorist strategies are evident to us each morning for compensating for congestion time constraints, namely waiting to leave for work until after the congestion has passed or leaving early to compensate for increased congestion in order to arrive at work on time. In response, staggering work hours is a tactic that has been used by commercial companies in large urban areas to provide this flexibility to workers. There is, of course, the comparable tactic of decentralization in space. It is often market forces that act to draw individuals in one organization to a centralized location. However, it has been asserted that the criticalness of this physical proximity is diminishing. Given the time frame for the nationwide, and indeed worldwide implementation of IVHS, is it possible that IVHS will no longer be needed once it's in place? Such a speculation might indeed be disturbing given the prospective investment in IVHS. This observation implies that high level IVHS planners must work closely with demographers. While such a question cannot simply be answered at present, our question should be: Can these issues ever be adequately addressed without human factors input?

In-Car Collision Warnings

If accidents and associated fatalities and injuries are the major problems, then collision

²However, we should note that "platooning" is a strategy that actually advocates increasing vehicle density. The suggestion that vehicles should be in spatial and temporal proximity that supersedes human response capabilities in the event of emergencies and the ingress and egress from such "platoons" are human factors questions of some considerable importance and urgency.

warning and avoidance systems are the putative answers. However, exactly how can such collision avoidance 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 have time to detect potential conflicts and represent them with preferred avoidance strategy in the time horizon available? What format would such a presumably multi-modal message take? And here the specter of false alarms plays a most critical role. Suppression of false alarms appears critical for acceptance, yet the failure to supply warning would perhaps be even more insidious (but see Sorkin, Kantowitz, & Kantowitz, 1988). As yet, we have limited answers to these questions. Should we focus specifically on collision detection systems or should we employ some form of general protective envelope approach? Can we individualize alarm systems such that they respond to likely accident conditions for the pertinent driver age group? There is a recent government contract to address precisely these issues. However, the structure and function of a collision avoidance warning system implies first some complex, multi-array detection system of considerable engineering challenge. Yet having derived a veridical warning signal, its customization for consumption by differing strata of drivers is uniquely a human factors question. It is this arena that promises enhanced safety, yet also represents the most complex portion of IVHS development.

Intelligent Transportation Systems

IVHS is designed to control and manage the future roadways into the 21st Century, yet we may ask whether this is enough. The conception and design of an intelligent system not only accomplishes its own specified goals, but also supplies points of contact and interchange with numerous other interactive systems. For IVHS, the clear 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 only as a guide to implementation, but

as a companion system with which to develop strongly integrative implementational links. An integrative perspective also views IVHS not as a singular answer to addressing our 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 our highway system. 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 is not possible since technology integration requires resonance throughout the whole system. It is probable that the future economic survival of an advanced manufacturing society is predicated on such an integrated system, an observation which alone mandates IVHS development.

Intelligent systems implemented under the aegis of IVHS must cope with a variety of emergency scenarios and sources of failure. As Mast (1991) pointed out, system failures in the vehicle or in other IVHS components must "fail softly" or otherwise be designed to be transparent to the driver by the use of backup systems. Here again, research on the design of "error tolerant" systems in aviation (Norman et al., 1988) will have implications for IVHS design. It has been estimated that traffic congestion costs the country up to \$93 billion in lost productivity each year (General Motors, 1991, May 15). It seems almost certain that some form of National IVHS system will be implemented in the near future. 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. Failure to resolve such questions may lead to catastrophic failures against which the likes of Bhopal and Chernobyl will pale in comparison. If those in the past have lamented the absence of human factors early in the system design process,

IVHS appears to provide such an opportunity. We must now grasp it.

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