INTELLIGENT VEHICLE HIGHWAY SYSTEMS: A CALL FOR USER-CENTERED DESIGN

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16. Abstract

This essay views the prospects of Intelligent Vehicle Highway Systems (IVHS) technology from the perspective of human factors psychology. This viewpoint stresses the need for *user-centered* design in order to optimize the potential benefits and to avoid unintended difficulties with new technology. Three examples of the user-centered approach to IVHS are presented to illustrate the advantage of considering drivers' abilities and informational requirements at an early stage in design.

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WHAT SHOULD HUMAN FACTORS CONTRIBUTE TO IVHS?

One hears a great deal these days about the promise of emerging technologies for improving traffic safety (Mobility-2000, 1990; Green & Brand, 1992). Soon there will be more intelligent vehicles and more intelligent highways, although there is little hope for more intelligent drivers. Among the many possibilities are advanced communications and entertainment systems to make travel time more productive and enjoyable; real-time road information to optimize the speed and efficiency of increasing traffic flow; and smart sensors and control systems to help drivers avoid collisions. We find the prospects for these technologies, known collectively as Intelligent Vehicle Highway Systems (IVHS), to be exciting. Yet we share growing concerns that the expected benefits, particularly with regard to traffic safety, cannot be realized without careful consideration of the abilities and requirements of the human vehicle operator (Hancock et al., 1991; Hancock & Parasuraman, 1992).

The impetus for developing IVHS arises in part from widely held concerns about the high cost of traffic accidents and the likelihood that traffic density will continue to increase. To a large extent, this effort is also driven by the advent of new technology and by the expectation that such technology will yield new solutions to old problems. There is little doubt that advancing technology can bring real benefits, but there are good reasons to doubt that the technology *on its own* can effectively address the difficult challenges of traffic safety and efficiency.

It may be useful to distinguish two general approaches to research on IVHS. One approach, which has dominated efforts so far, is characterized by innovative engineering and is driven primarily by the available technology. The advent of new electronic and computational systems behooves knowledgeable engineers to ask, "What is the best way to use this technology?" The engineer is at the front line of technological innovation and, therefore, is ideally positioned to anticipate fruitful applications. Another approach, referred to as *user-centered,* begins with the user rather than the technology. This perspective emphasizes the operators' capabilities and the system's intended functions. The goal is to anticipate and avoid operational difficulties that often are not examined until after a design fails to meet expected levels of efficiency or safety (Norman, 1988). The user-centered approach seems especially useful in development of IVHS because, unless one envisions elimination of human operators, the benefits of IVHS will hinge on the systems' success in optimizing drivers' behavior. IVHS systems must utilize the users' capabilities to the fullest, and to do so, they must be fully compatible with perceptual, cognitive, and behavioral characteristics of the operator.

The Theoretical Challenge

From the user-centered perspective, design of effective IVHS technologies must be grounded on a strong theory of driving. Conventional wisdom among safety specialists, behavioral scientists, and engineers, as well as the general public, tells us that humans are seriously limited in their ability to operate motor vehicles, that they are slow to respond and prone to make errors, and that they would surely benefit from the assistance of electronic eyes and brains. This view draws support from laboratory research on narrowly defined components of the driving task and an abundant literature on traffic accidents. It does not derive much support, however, from research on driving behavior as it actually occurs, nor is it fully consistent with the facts about traffic accidents.

Based on well known statistics, one can argue that, contrary to popular wisdom, ordinary drivers are surprisingly proficient. From the standpoint of an individual, traffic accidents are rare events. Assuming 20,000 km (12,422 mi) driven per year, a U.S. driver can expect to travel for 102 years before experiencing a disabling-injury accident, and one is not likely to fall victim to a fatal accident for 3738 years (National Safety Council, 1991). Accidents are usually complicated events that result from an anomalous set of circumstances. The driver is just one part of this complex picture and often a passive victim at that. Safe driving, too, is highly complex, but it is also commonplace, and the driver is invariably an active and *central* part of this picture.

The question of how drivers achieve current levels of safety is unexplained and merits greater research attention. Meanwhile, it appears that the current standard of safety may be difficult to improve. In order to design safe and effective IVHS systems, we must clarify what conditions/situations are most troublesome to the operators, and what information or assistance will be most useful in meeting these difficult conditions. The central challenge for IVHS is to develop technology that is well coordinated with the organic control system, which is already highly successful. Failure to do this could ultimately diminish current levels of safety.

APPLYING THE USER-CENTERED APPROACH TO IVHS

From the user-centered viewpoint, early consideration of perceptual, behavioral, and cognitive aspects of skilled driving are necessary to design effective IVHS systems. Rather than let technology dictate what information a driver will have to deal with, the technology can be shaped to provide, in an effective format, the kind of information a driver needs. This section presents three examples illustrating the user-centered approach to IVHS. In each case, the operator's functional needs are taken as the primary consideration, and the technology is evaluated according to its suitability to enhance performance.

Rear Proximity Warning Systems

The purpose of these systems would be to prevent risky entrance into the path of another vehicle. From the user-centered perspective, the motorist's primary need here is for fuller information about the traffic environment. Most vehicles currently provide little or no visual contact with the environment in the directions of the rear quarters. Often the B and C pillars obstruct direct view, and most mirror systems fail to cover large "blind" sectors in both of these areas.

Perhaps a laser-radar system could be devised to sound an audible warning whenever the motorist initiates a risky lane-change. This conspicuous signal would alert the driver to stop or correct the erroneous maneuver before collision. From the user-centered perspective, however, a laser-radar warning system has several troublesome features. First, setting the threshold of warning is problematic. If the threshold is too low, false alarms will erode driver confidence; if it is too high, failures to signal a hazardous event may result in a collision. Second, interpretation of the signal will require learning and memory, and it is not likely to provide a clear perception of the nature of the impending hazard. Is it a faster car overtaking from the rear? Or is a motorcycle already nearby? Third, even if the system provides a timely warning, it cannot specify the appropriate action to avoid collision. Should the driver brake, accelerate, swerve? Fourth, and perhaps most troublesome, the laser-radar system is a "bandaid," conceived largely to compensate for an existing design flaw, the lack of adequate rearward visibility. Is there a simpler, more effective solution than expensive electro-optical technology?

Vehicle design must place high priority on providing the driver with direct perceptual access to the traffic environment. In the present example, direct perception of the potential hazards can be provided through multiradius exterior mirrors of the type used in Europe by Volvo and Saab, which in combination with a standard interior mirror eliminate blind zones in rear vision (Pilhall, 1981). A recent study (Helmers et al., 1992) showed that multiradius mirrors greatly facilitate a driver's ability to acquire information from the rear, which is critical for safe lane-change maneuvers. An electronic system could be useful as a secondary warning when a motorist fails to check the mirrors, but this secondary function is not a desirable substitute for direct visual contact with the environment.

The problem of rear proximity warning devices is instructive because it illustrates the importance of specifying the most useful information at the outset of the design process. In general, electronic warnings are not preferable to direct perception of a potential hazard. Such warnings can fail to command a driver's attention and, unlike direct perception, they do not specify the best course of action. Furthermore, we must strive to avoid developing expensive bandaids for avoidable design flaws, especially when simpler technology may offer a better solution.

Nighttime Pedestrian Accidents

Statistics show that pedestrian accidents are far more prevalent in low illumination than in daylight. A recent analysis of U.S. fatal accident data from 1980-1990 showed that, during the evening and morning hours in which there are equal periods of light and dark over the course of a year, only 20% of fatal pedestrian accidents occurred in daylight while 80% occurred in twilight or darkness (Owens & Sivak, in preparation). In bad weather, the portion of fatal pedestrian accidents in twilight or darkness increased to 93%. These findings were unchanged when accidents that involved drinking drivers were excluded, which implies that even sober drivers are generally unable to see pedestrians in time to avoid collision.

A possible countermeasure to this problem is suggested by infrared (IR) video systems that can provide clear view of a dark environment. Similar to the night vision systems of the military, IR video could be installed to display invisible surroundings on an ordinary video monitor. From a user-centered perspective, this technology offers an unprecedented possibility to enhance visual access to the traffic environment at night, but this advantage would come at a cost. Most implementations under consideration utilize a dash-mounted video monitor. Watching for pedestrians on the monitor would require vigilant observation of an interior display and corresponding neglect of the road ahead. Alternatively, it is possible to image the screen externally through a head-up display (HUD). This approach is more promising, but it raises challenging questions with regard to the driver's ability to utilize simultaneously two views of the road ahead: a direct view of real space and an indirect two-dimensional image. Military applications have already shown that it is extraordinarily difficult to guide locomotion with such displays (Weintraub & Ensing, 1992). Perhaps the ultimate system would create a life-size IR projection of the environment, a "virtual reality," but this exceeds the practical limits of current technology.

Meanwhile, the problem of pedestrian visibility can be addressed through more effective design of retroreflective markings. Recent research has shown that small retroreflective markings at the hips, shoulders, and major joints of the limbs greatly enhance pedestrian visibility at night by virtue of the phenomenon of *biological motion* (Johansson, 1975). Preliminary studies indicate that, if the pedestrian is moving, she/he is recognized as a person immediately upon detection (Owens, Antonoff, & Francis, 1992). This type of marking may reduce or eliminate an important difficulty with conventional retroreflective devices, which are *detected* at long distances *but not recognized* until shorter distances. Of course, the problem of compliance remains: Pedestrians must be induced to *use* such safety devices. Revising the rules of liability for nighttime pedestrian accidents may be worth considering (Leibowitz, Owens, & Tyrrell, in preparation).

For the present purposes, the important points are (1) nighttime pedestrian accidents can be minimized by improving visual information for the driver, (2) it is possible to do this through new video technology, although such displays involve non-trivial difficulties, and (3) better understanding of the information for perception (biological motion) has yielded a simpler, less costly alternative.

Information About Speed and Energy

Many accidents involve a law of physics that humans cannot perceive directly. The kinetic energy of a moving object, which is dissipated through braking or collision, is proportional to the square of velocity. Few drivers are aware of this basic mechanical fact. Even an engineer, who is well acquainted with the laws of motion, is unlikely to perceive that the consequences of a 20% increase in speed (e.g., 100 to 120 km/h) brings a 44% increase in kinetic energy, and it is kinetic energy, not speed, that determines the associated increase in risk. Here we have a new kind of problem: a variable of fundamental importance to safety is not perceptible to the motorist. This perceptual limitation may be related, for example, to the tendency of many drivers to drive too fast for conditions. Conventional speedometers are of little benefit because momentary speed information fails to represent the risk associated with kinetic energy. Moreover, it may foster the mistaken impression that a brief burst of speed can significantly shorten travel time.

From the perspective of user-centered design, the challenge is to devise a way to provide the driver with important information that is presently inaccessible. Helmers (in preparation) proposes to replace the conventional speedometer with an Energy Meter (E-Meter), which would be scaled in units that represent the level of kinetic energy and its consequences. For example, a basic Risk Unit (RU) could be defined relative to the energy dissipation of a survivable crash. Current standards for automotive crashworthiness assure that a properly restrained occupant can survive a frontal collision at 48 km/h (30 mph) (FMVSS, 1991). The energy dissipated in this standard crash test could serve as a simple index criterion for the RU. Thus, an E-Meter would display 1.0 RU in place of 48 km/h. Given that risk is proportional to kinetic energy, the E-Meter would display 0.5 RU at 34 km/h (21 mph) when kinetic energy is half as great as that at 48 km/h, and it would display 2.0 RU at 68 km/h (42 mph) when kinetic energy is doubled; it would display 3.0 instead of 83 km/h (52 mph), 4.0 instead of 96 km/h (60 mph), and so on up to 10 RUs instead of 152 km/h (95 mph). Unlike the familiar speedometer, the E-Meter would clearly inform a driver traveling at 5.0 RUs (107 km/h or 67 mph) that he/she is controlling energy five times greater than the standard for a survivable frontal collision. With the help of an onboard computer, one can imagine carrying derivation of the Risk Unit a step further, perhaps by incorporating the particular vehicle's crashworthiness and the prevailing road conditions in computing the effect of speed on momentary risk. Speed information, which is of value for planning or assessing progress of a trip, could also be provided through a trip computer, but then only as an *average* integrated over a certain minimum distance. Thus, while informing the driver about momentary variations in energy-related risk, the E-Meter would eliminate access to information about momentary velocity, a step that may help to avoid the potentially dangerous misperception that a transient increase of speed will substantially reduce travel time.

While the E-Meter concept remains to be tested, it provides a heuristic example of the user-centered approach to IVHS. Beginning with a general problem of safety, critical information that is not presently available to drivers was identified. Recognizing that this information is not accessible through natural modes of perception, Helmers proposed a new technological device to assist drivers by presenting otherwise imperceptible information. This proposal raises the interesting question of how one might display the kinetic energy information most effectively. Weintraub (personal communication, 1992) has suggested that variations of size or color might be used to enhance the effectiveness of an E-meter display.

IVHS AS A TOOL FOR SAFE DRIVING

In designing IVHS technology, we should avoid treating the driver as an incompetent or error-prone component of a technical system. Such a view is distorted and backwards. The evidence indicates that most driving is remarkably safe, and proficient operators deserve much of the credit for traffic safety. Based on daylight driving in the U. S. (National Safety Council, 1991), there is approximately one fatality in 124,806,202 km (77,519,380 mi) of driving. It is difficult to reconcile this fact with the proposition that drivers are generally incompetent or error-prone. From the user-centered perspective, driving is primarily a behavioral phenomenon *aided by* electro-mechanical systems, not the reverse.

Many years ago, driving was described as "locomotion by means of a tool" (Gibson & Crooks, 1938), a description that seems particularly appropriate in the present context. The "tool," however enhanced by new technologies, both creates and limits the possibilities of a driver's actions. It can be designed in ways that invite misbehavior, or it can be designed to facilitate efficient, skillful behavior (Norman, 1988). Whatever the design, so long as vehicles remain under the control of human operators, vehicle control must conform to the characteristics of human systems that evolved to guide locomotion. In the context of natural history, our vehicle-highway systems comprise a new environment as well as a new tool for locomotion. The user-centered approach requires a better understanding of how the organic control of locomotion has adapted to this new environment. What do humans *need* to control their movement at relatively high speed through a somewhat unpredictable traffic environment?

The task of driving depends upon natural capabilities of the human, capabilities that have already achieved a remarkable record of safety. But accidents do happen, and these must be due in part to limitations of the human's ability to act properly in the vehicle-highway system. Emerging technologies can assist the human operator in accomplishing the task more efficiently, skillfully, and safely. To realize this goal, the IVHS designer needs a clear view of what Nature has equipped drivers to do. This perspective is the foundation of a user-centered approach toward creating systems to assist in the natural guidance of locomotion.

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