IVHS — Can It Deliver on Safety?

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> [R]oughly half of all collisions between vehicles could be prevented if each driver **would** initiate his accident avoiding maneuver approximately a half to one second earlier." (Enke, 1979)

The above quote represents a core belief of many of the proponents of intelligent vehicle-highway systems (IVHS). These proponents believe that IVHS technology can reduce crashes either by providing early warning of imminent danger to drivers, so that they can take more timely and effective avoidance actions, or by automatically executing crash avoidance actions for the driver.

Enke, however, expressed doubts about the benefits of technology to help drivers in emergency situations, saying, "Possibilities for installations in the vehicle which prompt the driver to an earlier action without constantly getting on his nerves are difficult to find ..."(1979). Enke argued instead that basic changes in driver attitudes were necessary. Nevertheless, Enke's statement has served as a rallying point for IVHS proponents (see, e.g., Faber, 1988). This paper reviews Enke's analysis and shows that it depends on several implicit and explicit assumptions that raise doubts about the viability of IVHS in reducing motor vehicle crashes.

The One-Half-Second Assumption

The idea that action taken a mere one-half second to one second earlier could prevent 50 percent of vehicle-to-vehicle collisions is derived from the maximum deceleration and cornering characteristics of the vehicle fleet juxtaposed against estimates of the relative speed of vehicles in collisions. In brief, the argument begins with the observation that a vehicle-to-vehicle collision occurs at some relative velocity (closing speed). If the driver of either vehicle takes action to make their relative velocity zero, the collision would not occur. Using estimated collision speeds of rear-end, head-on, and side-impact crashes on German roads, Enke calculated that only a half to a full second of earlier initiation of braking would have been necessary to reduce the relative velocity of the vehicles to zero and prevent half of the crashes. Thus, Enke's conclusion is the result of a simple mathematical calculation applied to physical characteristics of cars and crashes.

The implication of this calculation, according to IVHS proponents, is that only minor changes in driver or vehicle response time to emergencies are needed to greatly reduce the number of motor vehicle collisions. This, in turn, suggests that rather simple vehicle improvements, such as automatic

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braking, or improvement in information available to drivers can achieve the necessary improvements in vehicle response. (Note that although this implication was doubted by Enke, it is nevertheless central to IVHS claims of safety benefits in the short term.) Although the simplicity of such analyses of physical characteristics of car crashes makes them seem convincing, they are based on questionable assumptions and data. Some of these assumptions concern the physical characteristics of crash situations and are relevant to either automatic vehicle response or human driver response. Other assumptions concern driver behavior, particularly driver behavior in emergency situations and whether it is subject to modification **by** information.

Physical Characteristics of Crashes

Enke's analysis relies on several assumptions about the physical circumstances of car crashes that affect its meaningfulness. For example, Enke specifies average deceleration due to braking as 5 m/s/s. Although this may be a reasonable value for typical road conditions, it is not a good value for downgrades or for slippery conditions caused by rain or snow. In the United States in 1992, 12 percent of fatal crashes and 18 percent of all police-reported crashes occurred on wet or snowy surfaces (National Highway Traffic Safety Administration, 1994).

Similarly, Enke's calculation assumes that the average driver in a crash has reduced the vehicle travel speed by half at the time of the crash. Enke offers no justification for this assumption other than calling it "quite a plausible mean value." This assumption does not consider that many crashes appear to show little or no preimpact braking or that some crashes actually involve acceleration. For example, rear-end crashes at expressway entrances frequently occur because a following driver, looking over his or her shoulder at approaching traffic, mistakenly assumes the driver in front will accept a gap and accelerates before looking forward. Similar crashes occur on surface streets; in one recent study of police-reported crashes in four cities, 10 percent of rear-end crashes involved a "premature" start by the following driver (Retting, Williams, and Preusser, 1994).

Enke dismisses these concerns saying that, even if there were no preimpact braking or if brake deceleration values were only half as large, braking or avoidance maneuvers would need to begin on average *"only"* l-2 seconds (rather than l/2 to **1** second) earlier. However, this small difference may be very important. At 50 km/h (slightly faster than 30 mph), a vehicle travels nearly 14 meters (about **45** feet) **in** one second; at 100 **km/h (about 63** mph), it travels 28 meters (about 90 feet). In many situations it is not possible to provide information about the need for braking or avoidance maneuvers 15-30 meters sooner. In cases with reduced sight distance, such as when a vehicle rounds a curve and comes suddenly upon stopped traffic ahead, the additional time needed for early warning will not be available. In other cases, early warning will be impossible because the emergency situation had not existed sufficiently far in advance.

The latter observation indicates another, less obvious, but critical assumption about the physical circumstances of crashes that is implicit in optimistic evaluations of the safety benefits of IVHS. That assumption is that information about the impending crash is even available to be provided sooner than l-2 seconds before the event. Such information is not available in many crash situations because the conflict situation has not yet developed. For example, head-on crashes frequently occur when one vehicle inadvertently (perhaps with an alcohol-impaired driver) crosses the center line on a two-lane road. Many of the opposing drivers in these crashes report that they had little or no chance to react. Similarly, intersection crashes in the United States often involve drivers who enter a major road from a minor road, after coming to a full stop and apparently not seeing the oncoming vehicle. The driver of the oncoming vehicle, again, frequently has had little opportunity to avoid the crash. There is no opportunity in these crash situations to provide the oncoming drivers with early information about the impending crash.

The physical circumstances of many rear-end crashes make these crashes even less amenable to early warning, such as in the previously discussed case of crashes that occur when fast-moving traffic rounds a curve and comes unexpectedly upon stopped traffic. Although IVHS technology might be used to provide advance warning of these situations through electronic signing, providing such information in a timely manner for even a small fraction of the curves where such situations may develop is a daunting and expensive task.

The rear-end collisions that occur in heavy traffic situations, where cars may be following each other with a half-second (sometimes less) headway, are an even more serious problem. Evans and Wasielewski (1982) report, for example, that in a study of one Michigan freeway, 25 percent of cars were following less than one second behind the car in front of them. In an emergency situation at such close distances, there is no extra one-half second or second of early warning to give these drivers. IVHS theoretically could be used to physically prevent drivers from following so closely, but any system that could do so would have to overcome serious operational problems. For example, in many situations, the gaps produced by this technology, which initially would be available on only a subset of the vehicle fleet, would quickly be filled by other vehicles not equipped with IVHS technology.

Although Enke’s paper deals with vehicle-to-vehicle crashes, this distinction has sometimes been lost. It is worth noting, therefore, that the possibility of early warning is even more doubtful in single-vehicle crashes, which accounted for 47 percent of occupant fatalities in the United States during 1992 (IIHS, 1993). Single-vehicle crashes frequently involve alcohol-impaired drivers whose ability to heed such warnings is doubtful. Equally important, in single-vehicle crashes there may be no indication of an impending emergency until a wheel leaves the road edge, leading to loss of control, or until the driver loses control of the vehicle due to unsuspected slippery surfaces. Thus, the physical characteristics of single-vehicle crashes appear to make them even less susceptible to prevention through IVHS technology.

Enke's conclusions also depend heavily on use of questionable statistics regarding crash speeds. An estimate of the time and speed involved in crashes was needed carry out the calculations, and Enke relied on statistics reported by Danner and Krais (1976) for crashes on German roads. The use of these data leads to two problems: one concerning the extrapolation of German statistics to road crashes around the world and the other concerning the uncertainty involved in estimating crash speeds in crashes anywhere. There is no reason to expect that the characteristic speeds of crashes in Germany are the same as those in the United States, where the population is far more rural than in Germany. Mote important, however, is the uncertainty surrounding the speeds involved in the crashes. Enke's calculation assumes that the prior travel speed of a vehicle involved in a crash is twice the estimated crash speed, which is taken to be the change in velocity (delta V) estimated by the crash investigators. Recent research indicates that when frontal crashes involve considerable offset, the usual methods of estimating delta V do not provide a good estimate of speed at the time of the crash (O'Neill, Lund, Zuby, and Preuss, 1994); rather, the calculated delta V considerably underestimates the actual collision speed. As a large proportion of frontal crashes in Germany (Scheunert, Justen, Zeidler, Schwede, 1993), as well as the United Kingdom (Hobbs, ,199l) and the United States (O'Neill et al., 1994), involve considerable offset, it is likely that Enke's calculations underestimate the additional warning time necessary to prevent crashes because they assume pre-crash travel speeds that are too slow.

Human Factors

As discussed in the preceding, the number of crashes in which the physical characteristics of the event are likely to be amenable to early waming is limited, whether the warning is given to an automatic feature of the vehicle or to the driver. But, even in those situations where early warning is possible, there is reason to question the effectiveness of IVHS systems. It is important to recognize that Enke claimed crash reductions could be achieved if drivers reacted a half to one second earlier. Setting aside the flaws in Enke's method, IVHS proponents tend to overlook this qualification and to assume that, given an early warning, drivers would always react appropriately. Even if early information could be provided to drivers, there is some question about how that information would be used. For example, drivers receive warnings about construction or other road work ahead. These construction zones clearly increase the danger of high travel speeds and frequently slower speed limits are posted. Many drivers disregard these warnings, however, and continue traveling at high speeds. Similarly, drivers may see congestion ahead and simply misjudge the likelihood that it will be a problem. Although they have had ample warning, earlier than any automatic system would provide, they fail to take appropriate action, and crashes may result.

Even if engineering ingenuity is able to devise automatic vehicle control systems that could provide safe response to such situations, it is unclear how drivers will react to it. When a safety innovation changes the driving task itself, it is quite likely to change driver behavior as well, potentially in ways that negate the benefits of the innovation (cf., Lund and O'Neill, 1986; Evans, 1991). For example, it has been shown that drivers with studded snow tires drive faster in the snow than drivers without them, although the increase in speed is not enough to completely negate the improved traction afforded by the studs (Rumar, Berggrund, Jemberg, and Ytterbom, 1976). More recently, it has been observed that the crash reduction benefits of antilock brakes on passenger cars have been quite small and perhaps nonexistent (Highway Loss Data Institute, 1994). This small effect is likely due in part to the relatively rare circumstances when antilock brakes can be expected to prevent a passenger car crash, but survey evidence suggests another factor as well: One in seven U.S. drivers surveyed with antilock brake cars said that they had driven in weather conditions in which they would not have driven a car without antilocks (Williams and Wells, 1993). Thus, if IVHS results in cars that help drivers detect or respond to emergency situations, some offsetting behavior is to be expected.

Experience with flight automation technology in aircraft operations raises further concerns about driver reaction to IVHS technology. A number of airplane crashes in recent years have involved malfunctioning or inappropriate reaction to automated flight controls (Lauber, 1992). For example, one landing overrun crash at Kennedy Airport in New York was attributed to an obviously malfunctioning autothrottle and the "crew's habitual reliance on the proper functioning of the airplane's automatic systems." In another crash, an Eastern Airlines L-1011 crew was distracted by a malfunctioning landing gear light and failed to notice when the autopilot was accidentally disengaged (National Transportation Safety Board, 1972). These and other crashes are leading aviation safety experts to reexamine the need for additional pilot training to deal with the altered cockpit environment.

an environment that changes the pilot's role from a relatively active one of flying the plane to a relatively passive one of monitoring an increasing array of automatic systems. Human factors research has shown that such passive interactions retard recognition of danger signs (Kessel and Wickens, 1978) and can also degrade manual response to the signs when such response is necessary (National Transportation Safety Board, 1984) . Significantly, Lauber notes that the older Boeing 727 aircraft without many of the recent automated features "has an accident rate during the last decade, the decade of the new-technology airplane, that is nearly indistinguishable from the accident record of the glass-cockpit [more automated] fleet as a whole." The lesson to be learned from this experience with highly trained and motivated professional pilots is that IVHS technology that automates part of the driving task is likely to place new demands on drivers, and any safety benefits of the technology may be offset by failure to use the technology correctly or because the technology does not fully account for human limitations in its use.

CONCLUSION

In the long term, IVHS may provide important reductions in crash frequencies, but these am likely to come very slowly, and they are unlikely to be of the magnitude suggested by studies based on Enke's analysis. Crashes are unique events that typically develop with little advance warning (hence the attraction of prescientific labels such as accidents). IVHS developments in driver information and vehicle control are unlikely to greatly reduce crashes because sight distances often are too short and crashes typically develop too quickly to permit vehicles to avoid the crashes. In addition, driver behavior in response to information available earlier relative to a potential crash situation is likely to be less favorable than projected by IVHS proponents.

By way of contrast, it is useful to examine other possible strategies for preventing crashes. For example, head-on crashes can be effectively prevented by highway dividers that keep vehicles from crossing into the lanes of opposing traffic. Similarly, intersection crashes can be reduced by replacing grade level intersections with overpasses or underpasses, thereby reducing the number of vehicle interactions with potential for crashes. These and other effective changes in road geometry have been applied sparingly in the past due to their expense, but they are no more costly than many proposed IVHS applications; and public funds spent would result in predictable crash reductions.

Similarly, further progress in curbing the problem of alcohol-impaired driving, an area in which there has been some modest success in recent years (Transportation Research Board, 1994), and controlling the rising problem of excessive speed could significantly reduce motor vehicle crashes.

Unfortunately, further progress in the area of impaired driving is likely to be difficult, and the United States has recently shown great reluctance to restrict drives to slower, safer speeds, trading more than 400 additional fatalities per year to allow traffic to travel 10 mph faster on rural interstate highways (Baum, Wells, and Lund, 1991). There may, however, be a role for IVHS technology in these areas; for example, in-vehicle technology may be able to physically prevent operation by impaired drivers and relatively simple devices could automatically limit maximum speeds. Such technology could produce important reductions in crash frequencies. It is likely that any safety benefits received from IVHS will come from in-vehicle technology that requires no government expenditures and no tie-ins with "intelligent" highways. This further raises questions about the validity of safety claims that have been used to justify expensive federal programs for highway-based technology.

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