Intelligent Vehicle/Highway Systems: Definitions and Applications

BY GARY W. EULER

"Transportation engineering is the application of technology and scientific principles to the planning, functional design, operation, and management of facilities for any mode of transportation in order to provide for the safe, rapid, comfortable, convenient, economical, and environmentally compatible movement of people and goods." It is interesting that this definition, taken from the Policies of ITE, focuses on the application of technology and scientific principles to transportation problems,

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for this is also the focus of international efforts in the area of Intelligent Vehicle/ Highway Systems (IVHS).

The essence of IVHS is to make significant improvements in mobility, highway safety, and productivity by building transportation systems that draw upon advanced electronic technologies and control software. The term applies to transportation systems that involve integrated applications of advanced surveillance, communications, computer, display, and control process technologies, both in the vehicle and on the highway.

IVHS will not change the nature of transportation engineering, but it does hold vast potential for allowing transportation engineering professionals to improve the services they are providing to the public.

IVHS will also cause reassessment of how these services are provided. The communication of reliable, accurate information in real time among users, vehicles, and transportation management centers will require partnership arrangements between the private and public sectors and among local and state government agencies to plan, design, build, operate, and maintain the kinds of systems needed.

And while transportation systems planning, design, and operation will always be the basic functions that transportation engineers perform, skills will also be needed in such areas as information management, communications technology, control software algorithms, and systems engineering in order to perform these functions for tomorrow's systems.

Role of IVHS in Tomorrow's Transportation Systems

The strong interest in IVHS has been sparked in large part by the serious congestion problems facing many metropolitan areas around the world and the dramatic travel increases predicted for the future. The concept of alleviating congestion through technological means while preserving individual mobility is very appealing. Interest has also been sparked by the dramatic improvements in highway safety and commercial vehicle productivity that are possible. Some of the effects that IVHS could have in each of these areas are described in the following sections.

Operations

The essence of IVHS as it relates to transportation operations will be the improved ability to manage transportation services as a result of the availability of accurate, real-time information and to greatly enhance control of traffic flow and individual vehicles.

Decisions that individuals make as to time, mode, and route choices will be influenced by information that currently is not available, is not available when it is needed, or is incomplete, inconvenient, or inaccurate. For example, IVHS technology would enable operators to detect incidents more quickly; to provide information immediately to the public on where the incident is located, its severity, its effect on traffic flow, and its expected duration; to change traffic controls to accommodate changes in flow brought about by the incident; and to provide suggestions on better routes and information on alternative means of transportation. The information would be provided to people through computer or cable television networks at home or

For descriptions of specific IVHS projects mentioned in this article, see the article by Robert French, which begins on page 23.

work site, at transit stops and other transportation terminals, and in the vehicle itself through both visual displays and audio means. As an example, ride-matching information could be provided in real time; such reliable, timely information would make it easier for travelers to determine a high-occupancy vehicle (HOV) alternative, and it would improve operation of HOV modes.

The availability of this information would also enable the development of new transportation control strategies. For example, to obtain recommended routing information, drivers will have to specify their origins and destinations. Knowledge of origin and destination information in real time will enable the development of traffic assignment models that will be able to anticipate when and where congestion will occur. Control strategies that integrate the operation of freeway ramp metering systems, driver information systems, and arterial traffic signal control systems and that meter flow into bottleneck areas can be developed to improve traffic control.

Eventually, perhaps toward the third decade of the 21st century, totally automated facilities may be built, on which vehicles would be controlled by electronics in the highway. This would enable vehicles to move along a crowded urban facility at very high speeds and at very close headways, leading to large increases in capacity. Long-distance travel along interstate highways could also be made faster, safer, and easier. Until that point is reached, the same kinds of technologies that would enable total control will be applied to assume partial control (for example, to assist in maintaining the appropriate headway behind a lead vehicle), potentially smoothing traffic flow and also leading to capacity increases.

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Safety

Whereas many safety measures developed over the years have been aimed at lessening the consequences of accidents (such as vehicle crashworthiness and forgiving roadside features), many IVHS functions are directed toward the *prevention* of accidents. A premise of the European PROMETHEUS program, for example, is that 50 percent of all rear-end collisions and accidents at crossroads and some 30 percent of head-on collisions could be prevented if the driver is given another half-second of advance warning and reacts correctly. Over 90 percent of these accidents could be avoided if drivers take the appropriate countermeasures one second earlier. IVHS technologies that involve sensing and vehicle-to-vehicle communications will initially be designed to automatically warn the driver, providing enough lead time for him or her to take evasive actions. The technologies may also assume some of the control functions that are now totally the responsibility of drivers, compensating for some of their limitations and enabling them to operate their vehicles closer together but safer.

Even before these crash-avoidance technologies become available to the public, IVHS holds promise for improving safety by providing for smoother traffic flow. For example, driver information systems will provide warnings on incident blockages ahead, which may soften the shock wave that propagates due to sudden and abrupt decelerations caused by unanticipated slowdowns. Transportation information systems may also encourage diversion onto other routes or modes to avoid incidents, leading to shorter queues, fewer abrupt decelerations, and more rapid return to normal and safer conditions. Navigation systems should serve to reduce excess travel and erratic maneuvers made by lost drivers, perhaps reducing fatalities by as much as 7 percent.

Potential safety dangers must, however, also be acknowledged. A key issue involves driver distraction and information overload from the various warning and display devices in the vehicle. Other issues include dangers resulting from system unreliability (for example, a warning or driver-aid system that fails to operate) and the incentive for risky driving that IVHS technologies may provide. These are important research issues that must be addressed before such systems are widely implemented.

Productivity

The availability of accurate, real-time information will be especially useful to operators of vehicle fleets, including transit/HOV, emergency, fire, and police services, as well as truck fleets. Here, quick response is essential. Time lost is lost productivity and money. Operators will know where their vehicles are and how long a trip can be expected to take; thus, they will be able to advise on best routes to take and will be able to manage their fleets better.

There is great potential for productivity improvements in the area of regulation of commercial vehicles. Automating and coordinating regulatory requirements through application of IVHS technologies can, for example, reduce delays currently incurred at truck weigh stations, reduce labor costs to the regulators, and minimize the frustration and costs of red tape to long-distance commercial vehicle operators.

There is also potential to improve coordination among freight transportation modes; as an example, if the maritime and trucking industries were to use the same electronic container identifiers, freight handling efficiencies would be greatly improved.

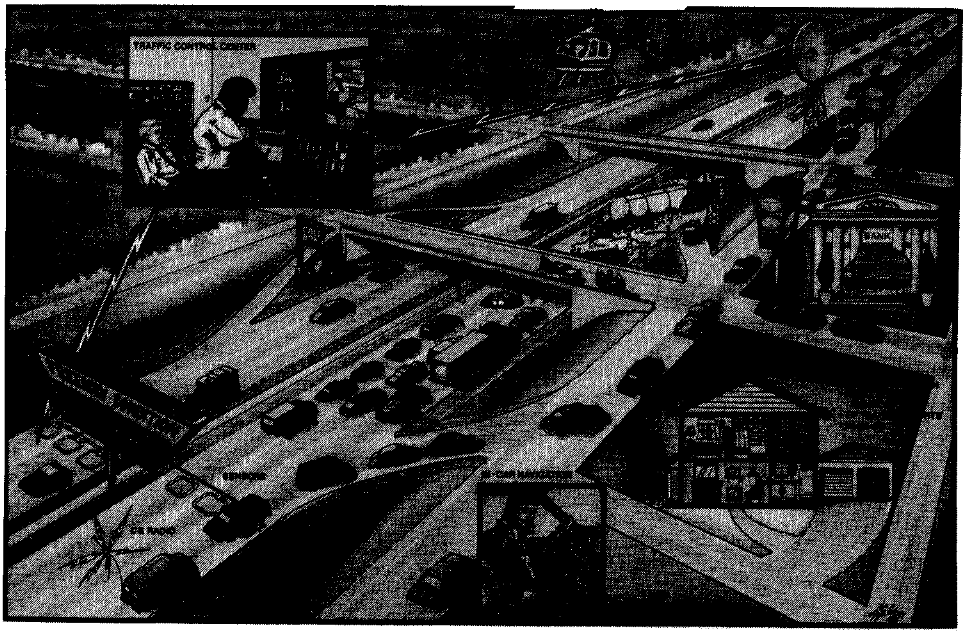
IVHS Categories

As part of the process of planning a national IVHS program in the United States, four categories have been defined and popularly accepted: Advanced Traffic Management Systems (ATMS), Advanced Traveler Information Systems (ATIS), Commercial Vehicle Operations (CVO), and Advanced Vehicle Control Systems (AVCS).

Advanced Traffic Management Systems

Advanced traffic management systems have six primary characteristics differentiating them from the typical traffic management system of today:

1. An ATMS works in real time.
2. An ATMS responds to changes in



Los Angeles's SMART Corridor project will improve traffic operations on the Santa Monica Freeway and five major arterials between downtown Los Angeles and the San Diego Freeway. (Reprinted with permission from Los Angeles County Transportation Commission.)

traffic flow. In fact, an ATMS will be one step ahead, predicting where congestion will occur based on collected origin-destination information.

3. An ATMS includes areawide surveillance and detection systems.
4. An ATMS integrates management of various functions, including transportation information, demand management, freeway ramp metering, and arterial signal control.
5. An ATMS implies collaborative action on the part of the transportation management agencies and jurisdictions involved.
6. An ATMS includes rapid response incident management strategies.

To implement these kinds of systems, real-time traffic monitoring and data management capabilities will have to be developed, including advanced detection technology, such as image-processing systems, automatic vehicle location and identification techniques, and the use of vehicles as probes. New traffic models will have to be created, including real-time dynamic traffic assignment models, real-time traffic simulation models, and corridor optimization techniques. The applicability of artificial intelligence and expert systems techniques will have to be asse ,sed, and applications, such as rapid incident detection, congestion anticipation, and control strategy selection, will have to be developed and tested. Responsive demand management strategies will have to be evaluated during periods when heavy congestion is predicted, including such strategies as HOV or transit information databases and incentives, parking restrictions, and congestion pricing implemented through automated toll collection systems.

Advanced Traveler Information Systems

Advanced Traveler Information Systems (ATIS) will provide drivers with information on congestion and alternate routes, navigation and location, and roadway conditions through audio and visual means in the vehicle. This information might include incident locations, location of fog or ice on the roadway, alternate routes, recommended speeds, and lane restrictions. ATIS will provide information that would assist in trip planning at home, at work, and by operators of vehicle fleets. ATIS will also provide information on motorist services, such as restaurants, tourist attractions, and the nearest service stations and truck and rest stops (this has been called the yellow pages function). ATIS could include on-board displays that replicate warning or navigational roadside signs when they may be obscured during inclement weather or when the message should be changed, as when speed limits should be lowered on approaches to congested freeway segments or fog areas. An automatic Mayday feature may also be incorporated, which would provide the capability to automatically summon emergency assistance and provide vehicle location.

A number of very critical human factors issues must also be investigated.

A substantial effort is required to define the communications technology, architecture, and interface standards that will enable two-way, real-time communication between vehicles and a management center. Possibilities include radio data communications, cellular systems, roadside beacons used in conjunction with infrared or microwave transmissions or low-powered radio signals, and satellite communications. Software methods to fuse the information collected at the management center and format it for effective use by various parties must also be developed. These parties include commuters, other trip makers, and commercial vehicle operators, both before they make a trip and while they are en route; operators of transportation management systems; and police, fire, and emergency response services.

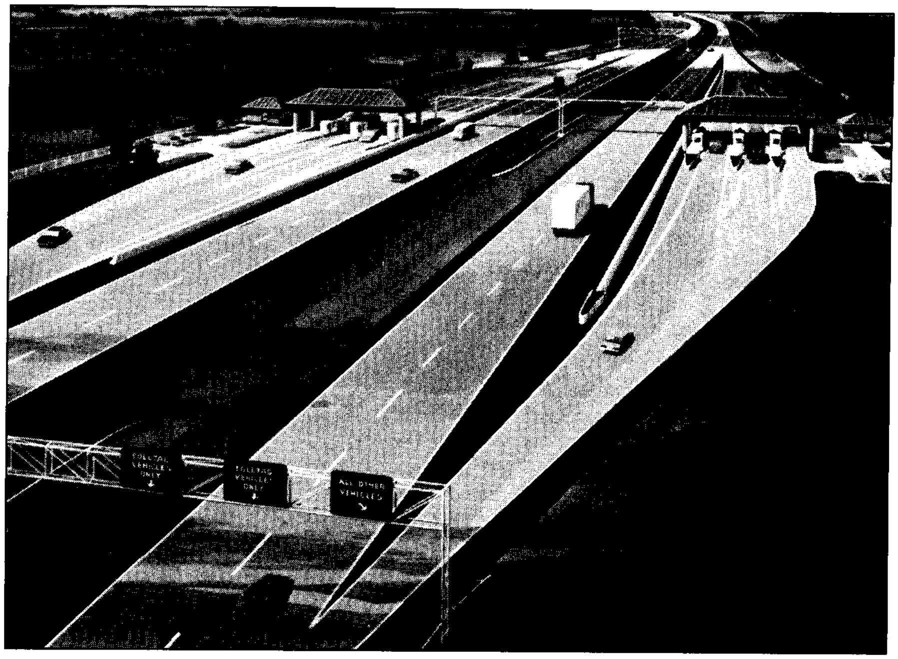
A number of very critical human factors issues must also be investigated. These include looking at how individuals make travel, mode and routing decisions; accounting for the requirements and characteristics of special groups, such as commercial vehicle operators and the elderly; and identifying the critical pieces of information and the best way of conveying them. The human factors issues also include a critical examination of in-vehicle display methods, among them: What are the roles of audio messages and in-vehicle displays? Where should visual displays be located and what technology should be used? What should be shown on visual displays? Answers to that last question could include directional arrows to guide vehicles through intersections and interchanges; text messages; electronic maps that display information on traffic conditions, perhaps using color graphics; and critical roadway signs.

Commercial Vehicle Operations

The application of IVHS technologies holds great promise for improving the productivity, safety, and regulation of all commercial vehicle operations, including large trucks, local delivery vans, buses, taxis, and emergency vehicles. Faster dispatching, efficient routing, and more timely pick-ups and deliveries will be made possible, which will have a direct effect on the quality and competitiveness of businesses and industries at both the national and the international level. IVHS technologies can reduce the time spent at weigh stations, improve hazardous material tracking, reduce labor costs to administer government truck regulations, and minimize costs to commercial vehicle operators.

IVHS technologies will manifest themselves in numerous ways in commercial vehicle operations. For example, for long-distance freight operations, onboard computers will not only monitor the other systems of the vehicle, but could also function to analyze driver fatigue and provide communications between the vehicle and external sources and recipients of information.

Applications could include automatic processing of truck regulations (for example, commercial driver license information, safety inspection data, and fuel tax and registration data), thus avoiding the need to prepare redundant paperwork and leading to "transparent borders"; provision of real-time traffic information through advanced traveler information systems; proof of satisfaction of truck weight laws using weigh-in-motion scales, classification devices and automated vehicle identification transponders; and two-way communication with fleet dispatchers using automatic vehicle location and tracking and in-vehicle text and map displays. Regulatory agencies would be able to take advantage of computerized record systems and target their weighing operations and safety inspections at those trucks that are most likely to be in violation. Vehicle dynamics systems that warn of impending problems related to vehicle roll may also prevent many accidents from happening.



Automatic vehicle identification toll plaza. Cars with proper "tags" or transponders bypass toll booths. (Reprinted with permission from HNTB.)

Research and development and initial testing of many of these applications have already been completed. For example, truck drivers are communicating with dispatchers and receiving route guidance information in real time. The missing links are real-time traffic information to supplement the route guidance system and ties with state truck regulatory requirements.

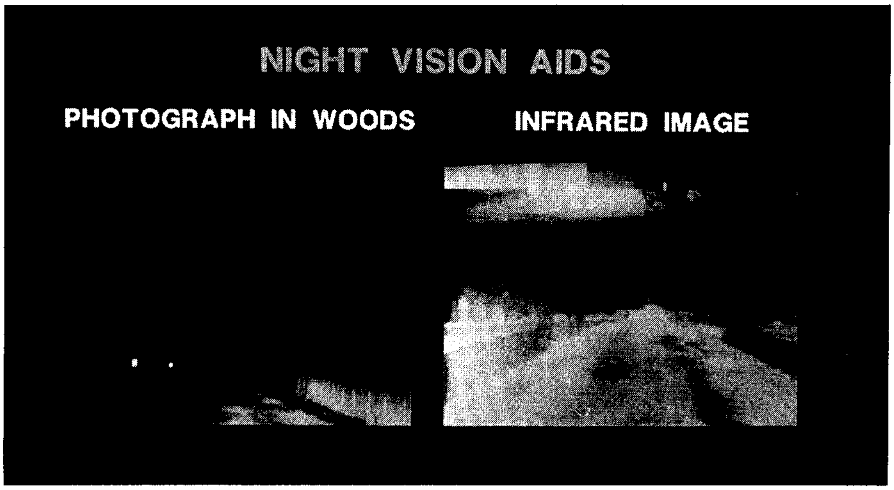
Applications of IVHS technologies could also lead to significant improvements in bus and paratransit operations in urban and rural areas. Dynamic routing and scheduling could be accomplished through on-board devices, communications with a fleet management center, and public access to a transportation information system containing information on routes, schedules, and fares. Automated fare collection systems could also be developed that would enable extremely flexible and dynamic fare structures and relieve drivers of fare collection duties.

Advanced Vehicle Control Systems

Whereas the other three categories of IVHS primarily serve to make traveling more efficient by providing more timely and accurate information about transportation, AVCS serves to greatly improve safety and potentially make dramatic improvements in highway capacity by providing information about changing conditions in the vehicle's immediate environment, sounding warnings, and assuming partial or total control of the vehicle.

Early implementation of AVCS technologies may include a number of systems to aid with the driving task. These include hazard warning systems that sound an alarm or actuate a light when a vehicle moves dangerously close to an object, such as when backing up or when moving into the path of another vehicle when changing lanes. Infrared imaging systems may also be implemented that enhance driver visibility at night.

AVCS technologies may also include adaptive cruise control and lane keeping systems that automatically adjust vehicle



Infrared imaging systems can enhance night vision. "Normal" vision at left; infrared image at right.

speed and position within a lane through, for example, radar systems that detect the position and speed of a lead vehicle, or possibly through electronic transmitters in the pavement that detect the position of vehicles within the lane and send messages to a computer in the vehicle that has responsibility for partial control functions.

As technology advances, lanes of traffic may be set aside exclusively for automated operation, known as platooning highway systems. Small groups of vehicles, perhaps up to 12 per platoon, will travel together at high speeds, maybe 65 miles per hour with very short headways, controlled through obstacle detection and automatic speed control and braking systems. These automated facilities have the potential to greatly increase highway capacity, while at the same time providing for safer operation. Eventually, AVCS technologies will provide for complete control of the driving function for vehicles operating on specially equipped freeway facilities.

Roadway electrification may also assist in the recharging of electric vehicle batteries, enabling small delivery, transit, and other electric vehicles to be easily integrated into an electric roadway network. Totally automated facilities may also be implemented in high-speed intercity corridors to make business travel more productive and to ease the burden on tourists.

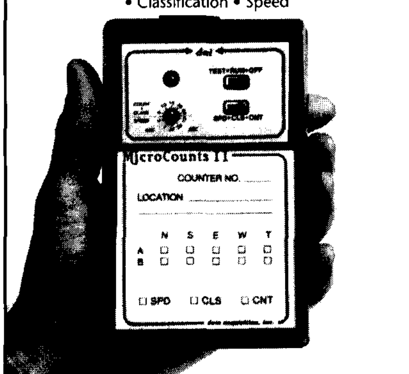
There is, of course, much research and development work and testing to be done before these kinds of systems can be built and implemented. Applications involving alternative technologies will have to be developed and evaluated. Complicated software will have to be written and tested. Perhaps the most important issues, though, relate to the role of humans in the system—that is, public acceptability, and how it is likely to affect system effectiveness. Other human factors issues include driver reaction to partial or full control—whether it will cause them to lose alertness or to drive more erratically. Another important area of research is the assessment of AVCS technology performance, reliability, and cost effectiveness. A final important issue is the effect the threat of liability may have on the willingness of potentially creative and innovative private developers of AVCS applications to get involved.

Benefits of IVHS

Attempting to quantify the benefits of widely deployed IVHS technologies at this stage must be similar to what planners of the U.S. interstate highway system tried to do in the 1950s. It is impossible to anticipate all of the ways that applications of IVHS technology may affect society, just as planners of the interstate highway system could not have anticipated all of its effects on American society. Recognizing the importance of the issue, however, Mobility 2000, an *ad hoc* coalition of industry, university, and federal, state, and local government participants who have been meeting to coordinate IVHS activities in the United States, addressed the potential benefits of applying IVHS technology in the United States. One of the more interesting findings was that IVHS was not just for urban areas: Numerous benefits were also predicted for rural areas and for targeted groups, such as elderly and disadvantaged travelers. Positive benefits were also found in regard to the environment.

Some of the specific findings that were reported include the following:

- Fully deployed ATMS/ATIS combinations can reduce congestion costs in urban areas from 25 to 40 percent. This was projected from some initial simulation work and estimates for the Smart Corridor project in Los Angeles.
- It was estimated that the cost of delay in the United States in 1990 was approximately $100 billion. The value of time saved alone would therefore be at least $25 billion in 1990 and would grow substantially since total travel is expected to increase by about 50 percent by the year 2005.
- Unchecked traffic congestion is the single largest contributor to poor air quality and wasted fuel consumption. Reductions in traffic congestion will lead to improvements in these areas.
- By 2010, annual savings of approximately 11,500 lives and $22 billion in accident costs could be realized, based on an analysis that considered safety technology features, projected market penetrations, and estimated effectiveness in reducing various accident types.
- By 2020, a similar analysis estimated that annual savings of 33,500 lives and $65 billion in accident costs could be realized, as advanced vehicle control strategies achieve a large market penetration.
- Rural areas have the most to gain in relation to safety improvements, since 57 percent of fatal accidents occur in rural areas where collision speeds are likely to be higher.
- Older and disadvantaged drivers can benefit by having specific devices available to offset the slowing down of their capabilities; these devices could include infrared imaging, obstacle detection and warning systems, radar braking and steering override, and onboard replication of maps and signs.
- Motor carrier productivity can be significantly increased and fuel costs can



be decreased through automated toll collection, the provision of real-time routing information and yellow pages services, automated processing of permits and licenses, and on-board computers that provide information on vehicle performance.

Assuming that the benefits and cost effectiveness are proven and the public exhibits a willingness to pay for these systems, it is estimated that the U.S. market alone for automotive electronics will amount to $28 billion annually by the year 2000, and that the U.S. highway infrastructure costs for these systems would total $30 billion through the year 2010. Thus, there will be a very substantial international market for IVHS products and services that can be supplied by the private sector, contributing to economic growth.

IVHS—Fad or Fact?

Is IVHS a buzzword that will quickly pass away, or will it be a program that leads to real and substantial improvements in our transportation systems? Time will surely tell, but indications are that IVHS is fast becoming an accepted concept that is generating a lot of excitement, not only on the part of researchers and advanced technology developers, but also on the part of those responsible for providing transportation services. The challenge is to do it, and this will take time, money, and talented people. The kinds of people needed will not only be technical wizards, although certainly those are needed, but also the "dreamers" and the "doers" among us, those who have vision and those who can get things done.

Perhaps the most exciting aspect about IVHS is that it will provide plenty of opportunities to invent and to dream and to do, to unleash creative thinking to address our pressing transportation problems. The ultimate answer to the fad/fact question may lie in our ability to develop programs that will take advantage of those forces. If we can do this, surely we will succeed, and our efforts will continue into the 21st century.

Acknowledgments

Much of the material in this article was derived from the Mobility 2000 working group reports. The individuals that prepared these reports are too numerous to mention here, but their contributions and volunteer efforts are deserving of recognition.

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