Intelligent Vehicle-Highway Systems
A Vision and A Plan

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I V H S

Until recently development of "smart" cars and highways in the United States has been coordinated by Mobility 2000, a voluntary, informal assembly of individuals from public and private sectors whose mission and membership have evolved from a series of meetings and activities over the past few years. This ad hoc group has planned a national cooperative program to advance the development of electronics, communication, and control technologies that will address growing highway operational needs—especially mobility and safety. It will evolve into the technical operating arm of the Intelligent Vehicle-Highway Society of America (IVHS America), an organization recently incorporated to coordinate the use of advanced technology for intelligent vehicle-highway systems (IVHS) in the United States. The focus here is the work of Mobility 2000, which sponsored conferences in 1989 and 1990 on issues and opportunities for IVHS.

National IVHS Workshop

A 3-day meeting in Dallas in March 1990, billed as the National IVHS Workshop, was the result of the efforts of more than 100 volunteers organized into 5 groups, each of which produced a technical working paper on one of the following areas:

- Advanced Traffic Management Systems (ATMS) permit real-time adjustment of traffic control signals and variable signing for driver advice. Application of ATMS in selected corridors has reduced delay, travel time, and the number of accidents.
- Advanced Traveler Information Systems (ATIS) inform drivers of the drivers' location and how to find desired services. ATIS also permit communication between travelers and ATMS for continuous advice on traffic conditions, alternate routes and modes, and safety issues. ATIS previously were called Advanced Driver Information Systems.
- Advanced Vehicle Control Systems (AVCS) provide additional technology to vehicles to identify obstacles and adjacent vehicles, thus assisting in the prevention of collisions and in safer operation at high speeds. AVCS will interact with fully developed ATMS to provide automatic vehicle operations.
- Commercial Vehicle Operations (CVO) select from IVHS those features

RENAULT

IVHS technology will provide travelers with information on traffic conditions, alternate routes, and potential safety hazards.

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critical to commercial and emergency vehicles. CVO expedite deliveries, improve operational efficiency, and increase safety.

- Benefits of IVHS.

Workshop attendees were organized into groups to review the working papers and produce a plan for moving the IVHS program forward. The groups focused on program milestones, research and development needs, field operational tests, program funding requirements, institutional issues and concerns, and IVHS benefits.

Workshop participants developed the following statement.

Vision of Intelligent Vehicle-Highway Systems

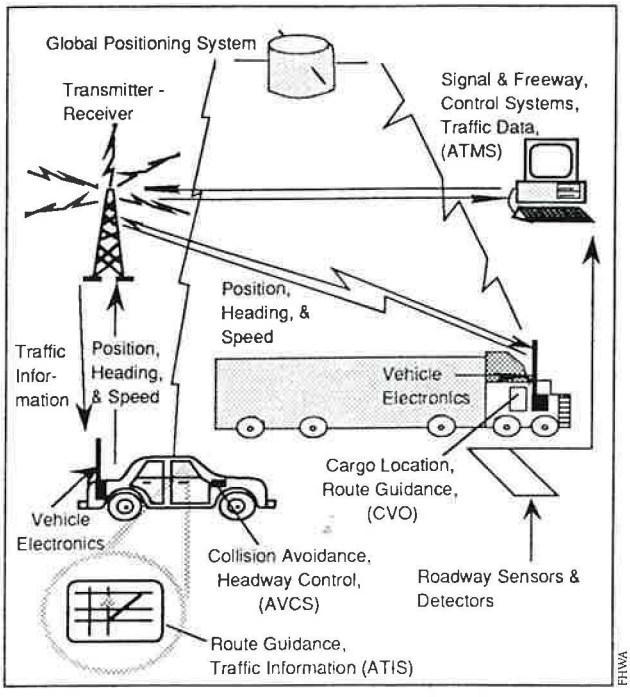
The United States is now moving from the enormously successful Interstate highway construction program to programs that will set the course of highway transportation well into the twenty-first century. These present program decisions will determine the mobility, safety, and viability of highway operations for present and future generations—just as the Interstate program did 35 years ago.

A significant part of the post-Interstate highway program is expected to be a national cooperative program of Intelligent Vehicle-Highway Systems (IVHS). This program will involve public-private partners in joint ventures. It will develop, test, and deploy advanced electronics technology and systems to meet the increasingly critical operational needs of the highway transportation system. IVHS will be a major complement to other highway improvement programs such as preservation and new construction. These programs are essential to maintain the viability of the highway system.

IVHS include a range of technologies and ideas that can improve mobility and transportation productivity, enhance safety, maximize the use of existing transportation facilities and energy resources, and protect the environment. IVHS are based on modern communications, computer and control technologies. The program contains four broad, interrelated areas.

The program will involve significant cooperation among government at all levels, universities, and industries such as those producing motor vehicles, electronics, communications, computers, and transportation services.

The results of this national undertaking will continue over many years. Many near-term benefits will come from applying existing, state-of-the-art technology. Long-term benefits will accrue well into the next century. These long-term benefits will, in some cases, require extensive research and development. Profits from short- and medium-term benefits will justify the longer term research and development needs.



Components of IVHS.

Transportation Improvements

National Mobility

IVHS technology is expected to significantly improve mobility in the United States. Existing streets and freeways in urban areas will be more efficiently managed through improved traveler information and traffic control systems. Rural and urban area travelers will benefit from improved security, comfort, and convenience. Experience gained from better management of existing facilities will further improve the design and use of new facilities. With the time and energy saved through enhanced travel efficiency, the cost of producing goods and services will decrease, resulting in improved industrial profitability and international competitiveness.

All vehicle operators will benefit from more efficient, less stressful travel. Through IVHS, drivers may access information that allows them to select a route on the basis of variables such as speed, fuel efficiency, scenic views, interesting places, and others. Older drivers will have more mobility because advanced technologies can augment vision and judgment at night or during bad weather, for example. Significant improvements in service levels and transportation information systems will increase the attractiveness of transit, car and van pools, and other multiple-occupancy vehicle systems.

Measured, quantified improvements in mobility will include reduced congestion, accommodation of increased travel and higher trip speeds, enhanced driver capabilities, and decreased cost in the transportation of goods and services. Another improvement will be less driver confusion, fatigue, and frustration.

IVHS technology is applicable to urban mass transit systems as well as to private automobiles. These systems may, in fact, find their earliest application in commercial vehicles. IVHS, believed to be the present and future of transportation, are expected to eventually contribute as significantly to mobility, safety, and international competitiveness in the United States as did the Interstate highway program.

Safety

IVHS are expected to significantly improve safety on streets and highways in the United States. In fact, many believe that IVHS technologies such as driver information systems that provide in-vehicle advisory and warning messages and future control assist systems will usher in a new, substantially increased level of motoring safety. Future IVHS technology will include obstacle detection, collision warning, and collision avoidance features to help drivers avoid serious accidents. Such

systems will be especially useful in rural areas, where the fatality and serious injury accident rates are significantly higher than the national average.

Safety benefits, including a reduction in fatalities, injuries, and property damage, will be substantial. Reducing the number of accidents will keep lanes open and minimize the frustration that can contribute to further accidents. The economic benefits resulting from fewer accidents will be realized by all society, not just transportation system users.

Energy and Environment

By reducing congestion and improving travel planning and routing, IVHS technology is expected to improve energy efficiency. IVHS offer environmental benefits through fuel savings and reduced vehicle emissions and noise levels, improvements that are especially helpful in metropolitan areas. Additional benefits that have been measured include enhanced use of high-occupancy vehicle lanes and transit and more efficient use of existing facilities.

Benefits

From Improved Mobility

The greatest expected benefit from IVHS is the role it will play in reducing traffic congestion. The daily commuter knows well the route from home to work but may not always know of impending congestion, accidents, road maintenance, or other obstacles. IVHS technology enables commuters to choose less congested routes, and commercial delivery businesses and travelers can derive even larger benefits from more advice and direction on optimum routes and alternate transit opportunities.

Obviously, the benefits from IVHS will occur only when the systems are deployed. The greater the deployment, the greater the benefits. The benefit target is large. A Texas Transportation Institute study of 39 major cities estimated that $41 billion is lost in the United States annually because of congestion. Losses exceeding $1 billion annually have been estimated in each of the 12 largest metropolitan areas.

IVHS mobility benefits include the following:

- ATMS have been shown to reduce stop-and-go traffic by up to 30 percent and travel time from 13 to 45 percent.
- ATIS are expected to further reduce travel time by about 10 to 15 percent.
- CVO systems will contribute significantly to the efficient use of trucks. Experience in the airline, railroad, and trucking industries indicates that CVO systems contribute significantly to fleet efficiency. More efficient truck operations will increase national productivity.
- AVCS will reduce the number of accidents and increase traffic flow in early partial control systems as well as in full control configurations. Advanced versions are predicted to at least double traffic flow on current freeways.
- Reducing congestion will improve air quality. Results of experiments completed in 1989 demonstrated that a reduction in congestion resulted in a 15 percent reduction in carbon monoxide and an 8 percent reduction in hydrocarbon emissions.
- Exposure to hours of congestion is known to increase personal stress and affect health and job performance. Thus, reduced congestion can be expected to benefit worker attitude and productivity.

From Improved Safety

Although many aspects of transportation improvement will be explored through IVHS, a primary concern is safety of motorists. Accidents can be grouped into collision types, each of which poses particular technological requirements for effective prevention. IVHS are expected to be effective in preventing the following accident types:

- Off-road accidents: IVHS technology uses an electronic imaging system and cooperative lane-edge markings to sense the location of lane boundaries.
- Angle collisions: Technology that automatically senses oncoming vehicles and otherwise knows the right-of-way status can directly advise drivers that it is unsafe to proceed.
- Head-on collisions: Lane-edge detection and path-prediction technology warns drivers when their vehicles cross the center line.
- Rear-end collisions: Antilock braking technology is seen as another way to provide early safety benefits through IVHS technology. Future radar-controlled braking technology could be even more effective.
- Side-swipe collisions: Accidents in which drivers' blind spots are a factor are currently the subject of innovations using ultrasonics, infrared, and radar-type sensing technologies.
- Aggravating environments: Major improvements in nighttime acuity have been experimentally demonstrated through infrared enhancement of the forward field of view.

Milestones

Participants at the National IVHS Workshop addressed the question, "Given the present state of development of IVHS in North America, what are the major program milestones that can be identified and promoted?" Policy, legislation, funding, organization, programs, projects, and technology were identified as major subject areas, and a plan for research, development, and deployment over a 20-year period was prepared. The milestones presented in Table 1 are envisioned during the next 10 years.

Research and Development Needs

IVHS represent immediate opportunities for reducing congestion, improving safety, and contributing in other ways to more effective use of the highway system. Although ATMS, ATIS, and CVO systems are already being deployed, each will benefit from additional research. AVCS, however, will generally require additional research before it becomes operational.

Research on ATMS will include the development of sensors, improved software for management of traffic signals, and expert systems to assist in incident management. Further work will advance the development of optimum communication

TABLE 1 IVHS MILESTONES

IVHS AREA	BY 1995	BY 2000
ATMS	Major field tests under way	Major urban areas equipped
	Real-time, adaptive signal control	Several cities communicating real-time traffic information to ATIS-equipped vehicles
ATIS	In-vehicle, real-time traffic information operational	Operational ATIS systems in use in major congested areas
	ATIS systems in use and routing systems tested	Safety advisory and warning capability standards deployed in selected areas
	Vehicle-highway communication developed	
	Safety advisory and warning capability developed and being tested	
CVO	Demonstration of Crescent technologies (WIM, AVI, etc.) completed	Crescent systems operational on most major interstate routes
	Operational deployment on 2–3 national Interstate routes	AVI systems operational on most toll facilities
	Major research complete on commercial driver safety advisory and warning systems	Driver safety assists commercially available
AVCS	Many autonomous control assists developed and demonstrated	Partial control assists commercially available
	Research and development for vehicle control complete and testing under way	Pilot operational use of automated control on selected HOV lanes

and data processing systems. Research is necessary to determine the response of drivers to ATMS and operator effectiveness in managing ATMS. In addition, studies are needed to identify means of ensuring that systems are integrated across jurisdictional boundaries.

ATIS research will address improvement of vehicle navigation systems and the development of communication systems to link vehicle navigation systems with traffic information provided by ATMS. There is much to learn about driver response to ATIS from human factors research. In addition, issues of liability and standardization must be resolved before ATIS becomes fully operational.

Transponder development to ensure vehicle-to-roadside communication of essential information will be included in CVO activities. Research on route guidance and communications technology will lead to improved systems; research on vehicle dynamics and sensors will improve control and reduce accidents. Human factors research to ensure compatibility of drivers within these systems is essential. In addition, many legal and institutional issues must be resolved to ensure driver acceptance of some functions.

Research on AVCS will include studies on the availability and reliability of devices that detect the distance of a vehicle from obstacles or other vehicles and the use of this information for automatic control. The automatic control system of the vehicle must control speed and position at a rate compatible with equipment and human limitations. Extensive full-scale testing facilities will ultimately be required in order to evaluate promising concepts. Introduction of these systems will require special traffic lanes for AVCS-equipped vehicles. Automatic inspection procedures must be developed to check for functional AVCS before a vehicle enters the lane.

Field Operational Tests

To show the public the benefits of IVHS, operational field tests will be conducted in a real-world environment under actual traffic conditions (both large- and small-scale) to analyze technology performance and cost-effectiveness and to assay market support. Field tests not only evaluate the readiness of the technology but try new institutional and financial relationships. Effective tests require a substantial commitment of resources. Because the field tests are so important to developing market support, test locations should be carefully selected. Urban and rural sites that host tests should have or be willing to install the necessary infrastructure and should demonstrate a willingness to form partnerships. If the tests are successful, host agencies must be prepared to support operations and maintenance of the test infrastructure.

IVHS Implementation Partnership

Transportation improvements resulting from IVHS technology will be accomplished through a thoughtfully planned and coordinated national cooperative program carried out by a partnership of public and private organizations. Partners in this program will include federal, state, and local governments; universities; and private sector industries, including those that produce motor vehicles, electronics, communications, and computers and those that provide transportation services. This cooperative program is essential to the successful implementation of IVHS technologies.

To achieve its potential, the IVHS program must culminate in the extensive deployment of technologies throughout urban and rural America. Deployment of some elements of ATMS, ATIS, and CVO has already begun, and commitments have been made in Arizona, California, Florida, Michigan, New York, Oregon, Texas, Washington, and other states.

In the long term, the various IVHS elements must be integrated into an overall system having a common systems architecture and standardized interfaces. This is essential both for effective performance and to ensure national coverage and uniformity. Deployment also must include a commitment to fund the annual operating

and maintenance costs required to keep these systems functioning effectively.

Because the IVHS program is a partnership between private motorists and public highway agencies, successful IVHS deployment will require close cooperation between private and public sectors in the form of innovative contracting, leasing, or entrepreneurial approaches for the portion of the systems that has historically been the responsibility of local or state governments.

Program Investment Requirements

Linking IVHS funding requirements to realistic but visionary milestones, and, concomitantly, showing sensitivity to the institutional issues that a comprehensive IVHS program must address, are major challenges. The Mobility 2000 conferees at the Dallas workshop believed that the recommended investment levels presented in Table 2 are a sound initial estimate.

TABLE 2 IVHS INVESTMENT LEVELS RECOMMENDED BY MOBILITY 2000

	1991–1995	1996–2000	2001–2010
R&D	$ 627	$ 523	$ 245
Field tests	504	1,290	1,325
Deployment	3,105	10,880	15,950

NOTE: Table does not include operation and maintenance costs, which may amount to 15 percent of capital costs. Dollar values are in millions.

The estimated $35 billion investment in IVHS research and development, field testing, engineering, and deployment over 20 years will support the following major elements of the IVHS program, but does not include individuals' costs for in-vehicle equipment.

- Instrumentation of 18,000 miles of freeways integrated with approximately 200,000 signalized intersections in 250 of the largest metropolitan areas for greatly improved traffic management;
- Communications systems to interact with ATIS in the 250 largest metropolitan areas and in rural areas in every state, as well as statewide traffic control centers to monitor incidents on intercity road networks;
- Instrumentation to interact with the CVO systems on the 42,500-mile Interstate system, and the remainder of the roads in the National Network for Trucks;
- Systems to interact with AVCS in 16 platooning highway systems to achieve headway, speed, and merge control; and
- Forty-four electric-propulsion highway systems in 25-mile increments in the most congested metropolitan areas with a population of more than 1 million.

Next Steps

"Where do we go next? Does it all stop here?" are questions commonly asked at conferences. To partially answer those questions, a statement was issued at the Dallas conference that called on the federal government, state and local agencies, universities, and private industry to work together to accomplish the following goals:

- Develop national goals and establish a strategic plan to achieve them, maintaining the flexibility to accommodate changes in assumptions, predictions, and expectations.
- Establish policy, legislation, and funding programs for IVHS at the federal, state, and local levels to undertake needed research, conduct operational testing and evaluation, deploy systems on a broad scale, and operate and maintain systems on a continuous basis as an integral part of IVHS programs.
- Identify and propose solutions to public-private institutional issues, including combined public and private research support; opportunities and partners for joint ventures; antitrust, insurance, and liability issues; state and local jurisdictional conflicts; and personal and organizational privacy.

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IVHS Activities Within TRB

The Koltnow Report (*Advanced Vehicle and Highway Technology and Opportunities for TRB*, April 1988) noted that the Transportation Research Board has long been active in matters relating to advanced highway technology, but not in any comprehensive or predetermined manner. The report identified eight standing committees that, either directly or indirectly, conducted activities related to advanced vehicle and highway systems. Presented below is an overview of TRB activities relating to intelligent vehicle-highway systems.

IVHS Task Force

As a result of the Koltnow Report, a TRB Task Force on Intelligent Vehicle-Highway Systems was formed in the fall of 1988. The task force held its initial meeting at the TRB Annual Meeting in 1989. A midyear meeting was held in the summer of 1989 at the University of California, Berkeley, at which presentations were given on Project PATH, and the *U.S. Department of Transportation Report to Congress on Intelligent Vehicle-Highway Systems* was presented. The task force continues to sponsor reporting sessions on domestic and international developments in IVHS at TRB Annual Meetings. At the 1990 meeting a report was given to the task force on Division A committee activities related to IVHS. The task force issued its first newsletter, *Advanced Vehicle and Highway Technologies*, in July 1990. Members of the task force also have been active in Mobility 2000.

Standardization of IVHS

One of the major impediments to the widespread implementation of IVHS is

the absence of standards, which are necessary for communications, data bases, and human factors. Communications standards are required to ensure that equipment installed in a vehicle can be used wherever a vehicle is likely to travel. The value of a motorist's investment in IVHS equipment (and hence the desirability of acquiring this equipment) will be significantly reduced if its use is restricted to a limited geographic area.

Data base standards are required to encourage the development of new functions and features for IVHS equipment. Because IVHS is also a mobile information system, its value to motorists will be enhanced by the availability of multiple functions.

Human factors standards are required to ensure the safe operation of IVHS equipment and to minimize or eliminate the need for educating motorists in its use. Situations in which multiple vehicles are used require that a driver can readily operate the IVHS equipment without an extensive review of the operator's manual.

The TRB Committee on Communications sponsored a Communications Standards Workshop in Los Angeles in June 1990 to address the issue of IVHS standards. The objectives of the workshop were to

- Develop a consensus on the need for initiating the communications standard process,
- Identify the types of communications standards that are required,
- Define the research required to support the process of developing standards,
- Determine whether compatibility with standards being developed in other countries is desirable, and
- Recommend organizations that might lead these activities.

Perhaps the most significant conclusion of this workshop was the unanimous recommendation that work on IVHS communications standards be initiated immediately. Participants believed that every effort should be made to achieve compatibility with international standards. In addition, it was recommended that a committee sanctioned by the American National Standards Institute should be created to oversee the creation and approval of IVHS standards.

Advanced Vehicle and Highway Technologies Study

To assess the role that IVHS could play in the solution of congestion, safety, and other highway transportation problems, TRB has convened a study committee. The committee is evaluating the public and private sectors' roles in research and in deployment of IVHS, interjurisdictional issues, and the process for developing a system architecture, or framework, to guide the evolution of IVHS in the United States. The study is sponsored by the National Highway Traffic Safety Administration, the Federal Highway Administration, the Urban Mass Transportation Administration, the American Association of State Highway and Transportation Officials (through TRB's National Cooperative Highway Research Program), the Motor Vehicle Manufacturers Association, and several private companies. The committee is composed of state and local transportation officials; private sector motor vehicle, finance, and electronics executives; and experts in traffic engineering, automotive engineering, systems analysis, public policy, and human factors. Its report will be issued in the late spring or early summer of 1991.

NCHRP Research in IVHS

Under the sponsorship of AASHTO, and in cooperation with FHWA, a research study of interest to the IVHS community is being conducted by TRB. The study, Assessment of Alternative Technologies for Relieving Urban Traffic Congestion, is being conducted as NCHRP Project 3-38(1).

Project objectives are to (a) identify and assess advanced technologies and systems that can improve urban highway traffic operations by achieving increases in capacity and traffic flow; and (b) formulate a plan for research, development, testing, and demonstration for the most promising of these technologies and systems.

In the first phase, a preliminary assessment was made by identifying 18 technologies or systems applicable to IVHS. The assessment included estimates of costs and benefits and an identification of institutional issues, public-private sector roles, funding mechanisms, and economic benefits of wide-scale implementation. An interim report on the first phase, which has served as a resource to the work of Mobility 2000, is available on loan from TRB, NCHRP, 2101 Constitution Avenue, N.W., Washington, D.C. 20418.

The second phase of the study will result in a research, development, and demonstration plan for each IVHS area, recommending the next stage of development needed to advance the technology to demonstration and implementation in the 1990s. Before completion of the second phase, UMTA provided additional funds to assess the potential of advanced technologies in the areas of ridesharing and mass transit. This work was completed in late 1990.

A comprehensive report will be published covering the technological, institutional, and economic assessments, together with a recommended national IVHS program and funding plan in the IVHS areas and in transit and ridesharing applications of IVHS technologies. The final report, to be published early in 1991, will complement the work of Mobility 2000 and serve as a technical resource for the future national IVHS program.