Proceedings of a
National Workshop on IVHS
Sponsored by
Mobility 2000

MOBILITY 2000

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Hosted By

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The national IVHS Workshop in Dallas, March 19-21, 1990 was sponsored by government, university and industry members involved in Mobility 2000, and hosted by the Texas Transportation Institute, The Texas A&M University System, The workshop was a forum for the exchange of ideas, plans and definitions. Reports of five working groups were published by the Texas Transportation Institute and distributed at the Workshop. A summary of the Workshop was published by the Texas Transportation Insititute under the title. Mobility 2000 PresentsIntelligend Vehicles and Highway Systems 1990 Summary. This report of the Workshop includes rcporta of the break-out sessions held during the workshop and the reports of the five working groups. Both the summary report and this full report are available from:

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[1] **The** word **Driver was** changed **to Traveler** at this workshop to include transit patrons.

Forward

Lyle SAXTON
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Mobility 2000 is pleased to provide this report which is a more detailed account of the national IVHS program developed at the Mobility 2000 IVHS National Workshop held in Dallas, Texas on March 19-21, 1990. A primary source of information for the workshop were five papers developed by national Mobility 2000 Working Groups which outlined background positions and recommendations in five key areas during the Fall of 1989.

The IVHS program has received rapid and substantial national support because it is based on serious operational needs and the evolving opportunities afforded by modem systems and technologies, especially in communications and control. Several key individuals and organizations became an informal core group for examining these issues and opportunities. Mobility 2000 formally evolved in 1988 from earlier activities and provided an informal, flexible and singularly focused forum for developing what has become known as i v h s Mobility 2000 rapidly emerged nationally and internationally as a unique and vital entity which provided the networking and common direction supportive of national program development efforts.

With this report, Mobility 2000 completes its national activities. It is extremely pleased to have performed a major national role in establishing consensus for the Intelligent Vehicle Highway System program. Through its volunteer participants, Mobility 2000 became the focal point of IVHS activities which established broad support and agreement on the vision, goals and approach of a national program. A highlight was Mobility 2000's unique blend of public, private, and academic interests, informal working relationships and commitment to common objectives.

Mobility 2000 was never intended to be a long term organization. In fact, an early joke evolved in early meetings as to whether we had met our initial goals or whether we should schedule additional meetings! In our first national workshop we described ourselves: *Mobility 2000 is self-appointed and informal. It is fortunate to be in a position to inform those who make policy and who appropriate finds. Mobility 2000 was not established in anticipation of a long term future for itself As soon as decisions are made and implemented to create major programs in this field. existing or new agencies are expected to supersede Mobility 2000 and assure effective activity in the public and private sectors and cooperation between the two. But those who have enjoyed the opportunity to join together to make Mobility 2000 useful in this critical interim period will recall its vigor, its, informality. and its responsiveness with great satisfaction. (Mobility 2000, San Antonio, Texas, 1989)*

A major early recommendation of Mobility 2000 was to establish a formal, public-private organization for the continued coordination and communication essential to a national IVHS program. With the formal incorporation of the Intelligent Vehicle Highway Society of America, Mobility 2000 has completed its mission. Its participants and functions are now being integrated into IVHS America with a sense of pride and accomplishment.

The credit and accolades associated with the role and accomplishments of Mobility 2000 in its short 2-3 year existence go to many, many dedicated, quality individuals. Although it is dangerous to single out any specifically, clearly those listed for Special Thanks in the Executive Summary deserve just that. As for myself, it has been a truly unique and rewarding experience to have been associated with Mobility 2000 and the vital role it has performed.

Lyle Saxton

December 10, 1990

Executive Summary

Introduction

Work on advanced transportation technology has been underway for several decades. Early work was supported by the Federal Highway Administration and included a several efforts by General Motors Corporation both with and without FHWA support. During the middle 1970's, the California Department of Transportation (Caltrans) pursued a variety of studies and engaged the Institute of Transportation Studies of the University of California at Berkeley to pursue some research in this field. Over a period of about two years, the staff of ITS encouraged other states to join in this effort. The University of Michigan Transportation Research Institute, the Texas Transportation Institute at Texas A&M University and the Center for Transportation Studies at the Massachusetts Institute of Technology agreed to join with the Federal Highway Administration staff and state departments of transportation to study this field.

The National Workshop

The National IVHS Workshop in Dallas March 19-21, 1990 was sponsored by government, university, and industry members involved in Mobility 2000, and hosted by the Texas Transportation Institute, The Texas A&M University System. The Workshop was a forum for the exchange of ideas, plans, and definitions. An Executive Summary was published by TTI to brief executives at the May 3-5 IVHS National Leadership Conference on the progress of the Workshop. One very important purpose of the Workshop was to open a dialogue between all involved parties – in government, industry, and research. A dynamic dialogue took place in Dallas, and continued through the Executive Summary. This publication is an update and reprinting of the Executive Summary.

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 21st 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 existing transportation facilities and energy resources, and protect the environment. IVHS are based on modem communications, computer and control technologies. The program contains four broad, interrelated areas: advanced traffic management systems, advanced traveler information systems, commercial vehicle operations, and advanced vehicle control systems.

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 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 research and development needs.

National Mobility

IVHS will significantly improve mobility in the United States. Urban areas will more efficiently manage their existing streets and freeways 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 and less stressful travel. Through IVHS, drivers may access routing information that allows them to select a route based on speed, fuel efficiency, scenic views, interesting places, or many other variables. Older drivers will have more mobility because advanced technologies can augment vision and judgment, for instance at night or during bad weather. Significant improvements in service levels and transportation information systems will increase the attractiveness of transit, car pooling, van pooling, and other multiple-occupancy vehicle systems.

Measured, quantified improvements to mobility include: reduced congestion, accommodation of increased travel and higher trip speeds, reduced motorist confusion and aggravation, augmented and enhanced driver capabilities, reduced cost in the transportation element of producing goods and services, and reduced driver fatigue and frustration.

Safety

IVHS will significantly improve safety on highways and streets in the United States. In fact, many believe that IVHS technologies, such as traveler information systems providing in-vehicle advisory and warning messages, plus future control assist systems, will usher in a new, substantially increased level of motoring safety. Future IVHS systems will include obstacle detection, collision warning, and collision avoidance features to help drivers avoid serious accidents. Such systems will be especially useful in rural driving situations, where the fatality and serious injury accident rate is significantly higher than the national average.

Safety benefits will be substantial. They include reduced fatalities, injuries and property damage. Further, reducing accidents will keep lanes open and minimize the frustration that can contribute to further accidents. The economic byproducts of reduced accidents will benefit all society, not just transportation system users.

Energy and Environment

IVHS improve energy efftciency by reducing congestion, and improving travel planning and routing. Drivers may obtain information on recommended routes, based on traffic conditions, time of day, weather, construction, or other variables. Rural and urban drivers will find travel time decreases in a smoother traffic stream.

IVHS has environmental benefits through fuel savings, reduced vehicle emissions, and reduced noise levels. These improvements are especially helpful in metropolitan areas with particularly severe needs.

Direct benefits that have been measured include: reduced vehicle emissions, enhanced use of HOV and transit, and more efficient use of existing facilities.

Organizations and Institutions

These IVHS-based improvements will be accomplished through a partnership of public and private organizations carried out through a thoughtfully planned, coordinated National Cooperative Program. Partners in this program include federal, state and local government , universities, and private sector industries including those producing motor vehicles, electronics, communications, computers, and transportation services.

This cooperative program is essential to the successful implementation of IVHS technologies. It must recognize the complex matrix of government, industry, society, and individuals who are responsible for and users of the transportation system. The vision of IVHS will become a reality through coordinated efforts among these many partners. This reality, in concert with other highway programs, will continue the mobility that helped the United States develop preeminence in the world. Mobility enabled the U. S. to excel in the world marketplace, for we could move people and products more efficiently and safely than other countries. IVHS will also strengthen our position as a major supplier to world markets of transportation products, services, and systems. Our quality of life will improve and our transportation infrastructure will continue to be the standard of the world.

What Are Intelligent Vehicle/Highway Systems?

Many modem communication, computer, control, and electronic technologies have been incorporated into isolated traffic management applications. Traffic signal timing is a good example. IVHS combine component technologies to provide a more productive highway system. IVHS is, therefore, not a single, static technology, but a continually evolving group of technologies. Each advancement will build upon previous advancements, and provide increased benefits to highway operators and users. For example, existing technologies streamline operation of urban traffic systems and commercial vehicle operations. Soon, improved traveler information and navigation systems will enable informed route selection. Other technologies will enhance individual and system performance. Further along, systems will help drivers avoid accidents, and improve the mobility of physically impaired drivers. Eventually, streams of vehicles may be fully automatically controlled to permit substantially improved and safer traffic flow.

Mobility 2000 grouped IVHS technologies into four functional areas. The functional areas depend on similar technologies. For example, increased communication capacity depends on increased channel capacity. The total vision must always be considered so that initial installations are suitable to become permanent installations. A system engineering prospective is key to the successful evolution of IVHS.

- Streamline trafic operations
- Enable informed route selection
- Enhance individual and system performance
- Help avoid accidents
- Improve mobility
- Automatically control vehicles
- Safer traffic flow

Advanced Traffic Management Systems (ATMS) permit real-time adjustment of traffic control systems and variable signing for driver advice. Their application in selected corridors has reduced delay, travel time, and accidents.

Advanced Traveler Information Systems (A TIS let drivers know their location and how to find desired services. ATIS permit communication between driver and ATMS for continuous advice regarding traffic conditions, alternate routes, and safety issues.

Commercial Vehicle Operations (CVO) select from ATIS those features critical to commercial and emergency vehicles. They expedite deliveries, improve operational efficiency, and increase safety. CVO will be designed to interact with ATMS when ATMS is fully developed.

Advanced Vehicle Control Systems (A VCS) apply additional technology to vehicles to identify obstacles and adjacent vehicles, thus assisting in the prevention of collisions in safer operation at high speeds. AVCS will interact with the fully developed ATMS to provide automatic vehicle operations.

Advanced Transportation Management Systems (ATMS)

ATMS involve detection, communication, and control. A surveillance system detects traffic conditions in a metropolitan area and transmits the information to a traffic management center. The traffic management center processes the information and combines it with information obtained from other sources, including from other vehicles acting as probes in the traffic stream. The processed information is used to:

advise people about current and expected traffic conditions

inform people of the location, severity, and expected duration of incidents

recommend the best routes for people to take to reach their destination.

The information is also used to develop ramp metering rates and traffic signal timing to meet current and anticipated conditions. To implement the best control strategies, adjacent jurisdictions must cooperate, for example, when diverting traffic from a freeway to an arterial. Competent operating staff and maintenance crews will also be required to keep trafftc moving.

ATMS are being introduced with current technology, and will benefit from advanced technology. Where installed, they are reducing congestion by improving traffic flow, and reducing accidents and emissions.

In Minneapolis/St. Paul freeway speeds increased 35 % , and accidents declined 27%.

In Seattle, ramp metering reduced travel time from 22 to 11.5 minutes while volume rose and accidents decreased.

On Long Island, travel time decreased 13 to 20%) fuel consumption fell 6.7%) hydrocarbon emissions fell 13.1% , and carbon monoxide emissions fell 17.4%.

Traffic management during incidents may reap the largest benefits.

An accident blocking one of three lanes reduces capacity by 50 % .

A 20-minute blockage wastes 2100 vehicle-hours, makes a queue almost 2 miles long, and takes 2 1/2 hours to clear. During peak periods, waste and delay may be fifty times worse.

Advanced Traveler Information Systems (ATIS)

ATIS equipment in the vehicle will use visual or auditory systems to inform the motorist of current traffic conditions, and provide real-time guidance on route decisions. ATIS will provide safety advisory and warning messages to the motorist, which will be especially beneficial in decreased visibility situations involving weather or sight distance. ATIS will also provide an on-board "Yellow Pages" type directory of motoring information.

Specific ATIS features include:

vehicle location, map-matching navigation system

traffic information receiver

route-planning for minimum distance of travel

color video display for maps, traffic information, and route guidance

an on-board database with detailed maps, business directory, specific locations of services, hospitals, and tourist-related information

information from traffic management centers on congestion, incidents, and other traffic problems

electronic vehicle identification for toll debiting

safety advisory systems

assistance for aged drivers

"mayday" signaling and response capabilities.

Commercial Vehicle Operations (CVO)

Global competition is forcing U. S. companies to change the way they do business. Carriers are being asked to provide faster, more reliable, and more cost-effective services. IVHS technologies are emerging as the key tools that carriers need to reduce costs and improve productivity. These productivity improvements have a direct impact on the quality and competitiveness of U. S. businesses and industries at both the national and international levels.

IVHS technologies, such as weigh-in-motion sensors, automated vehicle identification transponders, and automated vehicle classification devices – some already deployed

– will reduce the time spent in weigh stations, reduce labor costs to states, and minimize red tape for commercial operators.

Commercial vehicles are leading the way in the applications of IVHS technologies. Already they are using automatic vehicle location, tracking, and two-way communications; routing algorithms for dispatch; and in-vehicle text and map displays. IVHS technologies of use to commercial vehicles include:

automatic vehicle identification

weigh-in-motion

automatic vehicle classification

electronic placarding/bill of lading

on-board computer

two-way real time communication

automatic clearance sensing.

Advanced Vehicle Control Systems (AVCS)

AVCS enhance vehicle control by facilitating and augmenting driver performance. Ultimately, they could relieve the driver of most driving tasks in high-demand traffic corridors, or long-distance, high-speed trips. Three levels of enhancement are foreseen.

Early AVCS technologies should include vehicle-based systems that detect the presence of obstacles or other vehicles. Studies have shown that one-half of all rear-end collisions, and up to one-third of intersection accidents could have been prevented if the driver had an additional 1/2 second warning. Basic AVCS will use a radar-type technology and other on-board systems to:

provide additional warning time

observe presence of vehicles or obstacles in blind spots

warn drivers of loss of alertness.

Intermediate AVCS technologies will initially implement lateral and longitudinal vehicle control functions in specific applications such as high occupancy vehicle (HOV) lanes. Vehicles would enter the lanes voluntarily under manual control, but once in the lane, would be under full or partial control. Advantages include:

increased speed

increased safety and reduced collisions

platooning (the linking of a cadre of vehicles)

for private vehicles, vehicle-to-vehicle communication of travel paths.

The most comprehensive AVCS applications will build on early and intermediate technologies to completely automate driving functions for vehicles operating on specially-equipped freeway facilities. These systems will be especially effective in:

"automatic chauffeuring" of vehicles from on-ramp arrival to off-ramp departure.

increasing the throughput of traffic in both urban and intercity, high-demand traffic corridors

realizing a new level of safety and mobility through high-speed operation in Interstate travel.

Benefits From Improved Mobility

The benefit most often visualized 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 on the route, accident locations, road maintenance, or other factors. IVHS technologies enable the daily commuter to choose routes that minimize congestion. Commercial delivery businesses and travelers can derive even larger benefits from more advice and direction on optimum routes.

Benefits from IVHS will occur only when the systems are deployed. Present information suggests that the greater the deployment, the greater the benefits. The target is large. A TTI study including 39 major cities estimates that $41 billion per year is lost in the U. S. because of congestion. Losses exceeding $1 billion/per year have been estimated in each of the twelve largest metropolitan areas.

Advanced Traffic Management Systems have been shown to reduce stop-and-go traffic by up to 30%, and to reduce travel time from 13% to 45%.

Advanced Traveler Information Systems are expected to contribute another 10% to 15% in travel time reduction.

CVO systems will contribute significantly to the efficient utilization of trucks. Experience in airline, railroad, and trucking industries indicate these systems contribute significantly to fleet efficiency. More efficient truck operations will increase national productivity.

As a consequence of sensors and controls, AVCS will reduce accidents and increase traffic flow. They are predicted to double traffic flow on current freeways.

Reducing congestion will improve air quality. Experiments completed in 1989 yielded a 15% reduction in carbon monoxide, and an 8% reduction in hydrocarbon emissions.

Exposure to hours of congestion is known to increase personal stress, and affect health and job performance. Thus, additional benefits can be expected in terms of worker attitude and productivity.

AVCS-controlled HOV facilities may double or triple through-put in the HOV lane.

Intercity and vacation routes will benefit from reduced congestion.

The introduction of IVHS can be expected to yield unexpected benefits just as the introduction of the Interstate System made changes in transportation that were not predicted.

Benefits From Improved Safety

Although the IVHS program will explore many aspects of transportation improvement, a primary concern is safety to motorists. The technology developed for safety measures will greatly benefit the highway travelers of tomorrow.

Accidents can be grouped into collision types, each of which poses certain requirements for effective prevention through technology. The following selected accident types are those seen as most amenable to prevention by IVHS technology.

Off-road accidents: IVHS technology can sense the location of lane boundaries, using an electronic imaging system, and cooperative lane-edge markings.

Angle Collisions: Technology which automatically senses oncoming vehicles, and otherwise knows the right-of-way status can directly advise the driver that it is unsafe to proceed.

Head-on Collisions: A lane-edge detection and path-prediction technology warns the driver when the vehicle crosses the center line.

Rear-end Collisions: Reduction of rear-end accidents is seen as another prime candidate for relatively early benefits through IVHS technology with the security provided by anti-lock technology. Future radar-controlled braking technology should be even more effective.

Baseline Estimates of IVHS Safety Benefits

Lives Saved

11,529 by 2010
927 by 2000
88 by 1995

Injuries Saved

442,000 by 2010
35,500 by 2000
3,060 by 1995

Dollars Saved

22.2B by 2010
1.8B by 2000
167M by 1995

Side-swipe Collisions: The "blind spot" problem is currently the subject of developments using ultrasonics, infrared, and radar-type sensing technologies.

Aggravating Environments: Major improvements in nighttime acuity have been achieved through infrared enhancement of the forward field of view.

Milestones

Program milestones were addressed during the Mobility 2000 National Workshop. The question addressed was straightforward: "Given the present state of development of IVHS in North America, what are the major program milestones that can be identified and promoted?" The Workshop identified policy, legislation, funding, organization, programs, projects, and technologies as major subject areas. The time line on these pages shows development of IVHS technologies over the next 25 years. The milestones below summarize optimal developments for the next ten years.

By 1995	By 2000
ATMS major field tests underway real-time, adaptive signal control	ATMS major urban areas equipped several cities communicating real-time traffic information to ATIS-equipped vehicles
ATIS in-vehicle, real-time traffic information operational ATIS systems in use in and routing systems tested Vehiclehighway communication developed safety advisory and warning capability developed and being tested	ATIS operational ATIS systems in use in major congested areas safety advisory and warning capability standards deployed in selected area5
c v o demonstration of Crescent technologies (WIM, AVI, etc.) completed operational deployment on 2-3 national interstate routes major research complete on commercial driver safety advisory and warning systems	c v o Crescent systems operational on most major interstate route5 AVI systems operational on most toll facilities driver safety assists commercially available
AVCS many autonomous control assists developed and demonstrated research and development for vehicle control complete and testing underway	AVCS partial control assists commercially available pilot operational use of automated control on selected HOV lanes

Research and Development Needs

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

Research on ATMS will include development of sensors, improved software for management of traffic signals, and development of expert systems to assist in incident management. Further work will advance the development of optimum communication and data processing systems. Much study 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 assuring systems integration across jurisdictional boundaries.

ATMS
monitoring traffic conditions
communications
controlling and managing traffic
program execution issues
system planning
systems analysis

sensory channel tradeoffs
expert systems for incident detection and management
useprediction model
preference and attitude attributes
ATIS
traffic data fusion
link-time database and statistics
origin-destinationstatistics
congestion leveling strategies
communications
productivity and time savings
transmitting and receiving information
artificial intelligenceto prioritize messages
rerouting algorithms
optimal visual and auditory characteristics
models for coordinated routing and traffic control
multimodal urban systems
communications architecture
vehicleto-vehiclecommunication
format and wording of traffic information
format and symbology for navigation
intelligibility-cognitivespatial mapping
cognitive time scaling
driver performance
c v o
human factors
vehicle performance
bridge height sensor
transmitting and receiving information
vehicle identifiers
AVCS
sensors: distance, velocity, acceleration, torque, rotation
computation
image processing and pattern recognition
reliability/safety/faulttolerance
communication
nonlinear and adaptive control
electric propulsion

Research on ATIS will address improvement of vehicle navigation systems, and the development of communication systems to link vehicle navigation systems with traffic information provided by ATMS. Much needs to be learned about driver response to ATIS from human factors research. In addition, there are many issues of liability and standardization that must be resolved before ATIS can become fully operational.

Research on CVO will include transponder development to assure vehicle-to-roadside communication of essential information. Research on route guidance and communication technology will lead to improved systems.

Human factors research to assure compatibility of the driver within these systems is essential. Research on vehicle dynamics and sensors will improve control and reduce accidents. In addition, many legal and institutional issues must be resolved to assure driver acceptance. CVO may be perceived as intrusive when it manages lane entry, controls driving in platoons, or monitors unsafe driving.

IVHS cannot be deployed without more research. Much more must be learned about the availability and reliability of devices that detect the spatial relationship of a vehicle to obstacles or other vehicles, and to use this information for automatic control. The automatic control system of the vehicle must change speed 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 the AVCS-equipped vehicles. Automatic inspection procedures must be developed to check for functional AVCS before a vehicle enters the lane.

Field Operational Tests

Field tests analyze technology performance and cost-effectiveness. They will also assay market support. Conducting these tests is essential to show the public that the IVHS program works.

1990-1995

Real-time travel information

Route guidance

Corridor systems that integrate freeways and arterials

Automatic vehicle identification and classification, weigh-in-motion, and on-board computers

Roadway hazard warning

1996-2000

Real-time two-way communications

Modeling techniques manage congestion

Vehicle-to-vehicle hazard warning

In-car enhanced images of roadway signs and hazards

Adaptive cruise control, automatic braking, automatic lane keeping

Platooning

Roadway powered electric vehicles

Automated parking facilities

2001-2010

Network of fully automated freeways, traffic information and management systems, and arterials

High-speed intercity and rural travel

Electric vehicles for commercial delivery and public transit fleets

Aggregate Funding: Field Operational Tests

(millions)

	91-95	96-00	01-10	Total
ATMS	158	315	—	483
Transit	15	20	25	60
ATIS	160	237	511	908
CVO	96	48	24	168
AVCS	75	670	765	1,510
Total	504	1,290	1,325	3,119

Effective tests require a substantial commitment of resources. Because the field tests are so important to market support, test locations should be carefully evaluated. Urban and rural sites hosting tests should either have or be willing to install the necessary infrastructure. They should have demonstrated a willingness to form partnerships. If the tests are successful, host test sites must be prepared to support operations and maintenance of the test infrastructure. They should have in place institutional arrangements needed to operate the system.

Aggregate Funding: Research and Development

(in millions)

	91-95	96-00	01-10	Total
Applications	70	60	—	130
Systems	135	20	15	170
Dynamics and Control	300	335	160	795
Human Factors	122	106	70	300
Total	627	523	245	1,395

An operational field test is conducted in a "real world" environment under "live" traffic conditions (both large and small scale). The field test will not only evaluate the readiness of the technology, but will also try new institutional and financial relationships. Partnerships between federal, state, local, private, and other institutions will be essential to the success of the program.

Deployment

To achieve its potential, the IVHS program must culminate in the extensive deployment of technologies throughout urban and rural America. Implementation is most important, but depends on research, development, and field testing. Portions of the program, such as advanced traffic management, commercial vehicle operations, rural safety elements, and initial driver information systems, are proceeding into deployment. Other segments, such as automated highways, require significant research and development before extensive implementation may begin. Work must begin immediately on these elements if they are to become available within the time frame needed to achieve the greatest benefits of IVHS.

Major deployment issues include:

IVHS embraces many specific systems and technologies which are at different stages of availability. Many of these systems have proven elements which should be aggressively deployed now. Others will require additional research and field tests, which should be pursued simultaneously to have them when we need them.

The various IVHS elements must be integrated into an overall system having a common framework and standardized interfaces. This is essential both for effective performance, and to assure national coverage and uniformity.

Deployment must also recognize a commitment to the annual operating and maintenance costs necessary to keep these systems functioning effectively.

IVHS is a partnership between private motorists and public roads. Therefore, successful IVHS deployment will require the close cooperation between private and public sectors.

Successful deployment and operation may require new innovative contracting, leasing or entrepreneurial approaches for the portion of the systems that have historically been the responsibility of local or state government.

Program Investment Requirements

Deployment of ATMS, ATIS, and CVO have already begun. Major commitments have been made in Texas, Florida, California, Oregon, Arizona, Michigan, New York, Washington and several other states.

A $35 billion investment in IVHS R&D, field testing, engineering, and deployment over 20 years will buy the following:

Recommended IVHS Investment Levels
(millions of constant dollars)

elements	91-95	96-00	01-10
R&D	627	523	245
Field Tests	504	1,290	1,325
Deployment	3,105	10,880	15,950

Linking IVHS funding requirements to realistic but visionary milestones, and concomitantly showing sensitivity to the institutional issues that a comprehensive IVHS program must address, is a major challenge. The Mobility 2000 conferees at Dallas/Ft. Worth believe that the recommended investment levels shown in the table above meet that challenge. Note, operation and maintenance costs, which may amount to 15% of capital costs, were not included in the table.

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 a statewide traffic control center to monitor incidents on the intercity network of roads

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.

Forty-four electric-propulsion highway systems in 25-mile increments in the most congested metropolitan areas with a population over 1 million.

The investment for ATIS is viewed as a consumer investment in equipped vehicles. Full performance systems will cost $800 to $1200 per vehicle (est.).

Public research and development investment will improve ATMS, assure effective interaction of ATMS and ATIS, and provide the basis for AVCS. Private investment will develop ATIS.

Without the research investment, ATMS can proceed with current technology, ATIS will be limited to in-vehicle systems with incomplete capability to interact with ATMS, and AVCS will not be developed.

Field tests will discover system errors, and correct them before full deployment. Field tests help define what research is needed. Finally, they will yield comprehensive data on benefits that will justify the entire program.

Action Items

The federal government, state, and local agencies, universities, and private industry need to organize a cooperative IVHS national effort to accomplish the following:

Develop and coordinate national goals, and establish a strategic plan to achieve these goals. The plan will need flexibility to accommodate changes in assumptions, predictions, and expectations.

A national IVHS policy should be formed using input from federal, state, and local levels. From that policy, legislation and funding programs should be developed to guide needed research; conduct operational testing and evaluations, and deploy systems on a meaningful scale.

Actions are essential to an IVHS national cooperative effort. Immediate action is needed to consider, revise, and act upon these steps.

Operate and maintain systems on a continuous basis as integral part of IVHS programs

Identify and propose solutions to public/private institutional issues. These issues include merging public/private research support, finding opportunities and partners for joint ventures, resolving state/local jurisdictional conflicts, protecting personal and organizational privacy, and identifying antitrust, insurance and liability issues.

Create a national organizational structure to provide the public/private coordination necessary to address the institutional issues of IVHS.

Determine appropriate IVHS system architectures, and corresponding divisions of responsibility between public and private sectors.

Provide mechanisms for international cooperation and compatibility.

Promote technical standards that assure hardware and software compatibility between large computers and small ones.

Identify current and long-range educational and manpower needs, and take steps to meet those needs.

Identify and take steps to accommodate special needs segments of society.

Provide for a continuing exchange of information within the transportation community, and assure reliable flows of information to the public, media, and elected officials.

These actions are essential to a national cooperative IVHS effort. Immediate action is needed to consider, revise, and act upon these steps.

Mobility 2000

Work on advanced transportation technology has been underway for several decades. Early work was supported by the Federal Highway Administration. During the middle 1980's, the California Department of Transportation (Caltrans) focused renewed emphasis on advanced technology as a critical part of dealing with growing urban traffic congestion. Other government organizations, universities, and industries have since become active in this field.

Mobility 2000, a self-appointed informal assembly of interested individuals from the public and private sectors, has evolved from a series of meetings and activities resulting from these initiatives. In its meetings, it sought to define a national cooperative program to advance the development of technology that would address highway problems. Mobility 2000 sponsored major meetings in San Antonio in February 1989 and in Dallas in March 1990, which served to focus attention on issues and opportunities for the several elements that constitute Intelligent Vehicle Highway Systems (IVHS) .

The work of Mobility 2000 is also stimulated by the awareness that both Europe and Japan have major projects. In Europe, the projects are coordinated throughout the European Community. DRIVE is largely sponsored by the governmental units with the primary objective of defining "road transport informatics" for the communities. A high priority of the European Community is to integrate DRIVE with the industry-sponsored projects of EUREKA, of which PROMETHEUS is the best known in United States. Japan has three major projects designated as AMTICS, RACS, and IVS. AMTICS and RACS combine vehicle navigation with real-time traffic information. Unless the United States establishes an active IVHS program, it will be entirely dependent on foreign developments.

IVHS technologies are applicable to urban mass transit systems as well as private automobiles. They may, in fact, find their earliest application in commercial vehicles. When and where these systems are fully deployed, IVHS are expected to contribute as significantly to U. S. mobility, safety and international competitiveness as did the Interstate Highway program, which is now essentially completed. IVHS are the present and future of transportation.

Special Thanks

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Interfaces Within IVHS

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Traffic managements systems are currently in place that depend on driver response based on seeing or hearing information requiring appropriate action. In IVHS, the nature of the traffic management systems will change. More information will be made available to the driver and to the manager of the system. As ATIS is available, the direct interaction of vehicles with highways become available. It is this interaction between vehicles and roadways that makes IVHS truly unique. Communications from the roadway to vehicles is common, but the current systems use a broadband communication technique so that the same message is delivered to each of the vehicles on the roadway. The two common techniques are roadway signs and highway advisory radio. Newer techniques include changeable message signs which allow, like highway advisory radio, the message to be changed to me-et conditions at various times during the day. IVHS, which has the potential of communicating a different message to each vehicle on the road increases the power of traffic management systems by orders of magnitude.

This increased power of individual communication is the basis of a vehicle navigation system now available in England and Germany. The system called either Autoguide or Lisb depending on the country uses an active infrared communications strategy to give each equipped vehicle directions to its chosen destination at each traffic signal controlled intersection. In those cases the vehicles do not have a map system on board and are completely dependent on the roadway management to have knowledge of their destination and the best route to that destination.

The power of individual vehicle communication can improve current traffic management systems. For example, at the present time if there is an accident on the freeway that closes multiple lanes, the freeway manager would not advise vehicles to detour from the freeway. If he did so the surface street system would not be capable of handling all of the vehicles that would detour. Also, there may be heavy trucks and trucks carrying hazardous materials in the traffic stream. There are many surface streets that could not accommodate such special traffic. However, if most vehicles are ATIS equipped, separate detour messages may be given to various vehicles. Also, in vehicles that are equipped for navigation, the detour message can be customized to the destination of the vehicle. Also, trucks would be detoured only to those surface streets that are able to accommodate them.

ATIS equipped vehicles would be able to operate more efficiently. Consider vehicles assigned to pickup and delivery of packages. With knowledge of current traffic conditions, the driver will be able to dynamically alter his route to avoid becoming a part of the traffic problem.

Another interface between ATIS and ATMS is the use of real time communications techniques to increase the use of transit facilities. In the case of an integrated freeway and HOV facility, the increased use of the facility by HOVs would facilitate the flow of people over all of the freeway. Efficiency is gained as vehicle occupancy is increased on the freeway. Should the real time communications be successful in increasing the use of car pools and bus transit on the HOV lanes, those increases may improve freeway control by as much as the application of current technology to freeway management systems.

The Advanced Vehicle Control systems have responsibility for providing safety information to the driver. This will include collision warning, impaired driver warning, and similar notices which may require immediate driver response. It is likely that the driver interface for these functions will share many of the devices (video display, synthesized voice, . ..) used by ATIS. For this reason, a shared design philosophy must be developed between the two systems. Joint systems analysis and human factors development and testing should take place to insure the proper prioritization of information and driver notification.

The commercial systems are leading in the applications of ATIS features because they do reduce driving time and improve service, both contributing to profits. Federal Express and United Parcel Service, among many other commercial carriers, are making wide use of navigation and related features right now. Public transit systems throughout the nation are using very sophisticated systems for bus location in order to efficiently utilize their available fleets.

Through cooperation with the commercial vehicle systems, the ATIS electronic vehicle identification feature could be extended to permit automatic vehicle identification. Further development of the ATIS vehicle capabilities and infrastructure support should explicitly consider the needs of the commercial operator both to improve overall transportation system performance and to increase the market for ATIS equipment, thus reducing its cost and making it more widely available.

ATMS must collect, format, and transmit the real-time information on incidents and congestion. This will include procurement and management of the traffic data center and communications network. ATMS could also be used to provide the infrastructure-side of automatic toll debiting.

Integration will be reached when the vehicles and the traffic management centers automatically exchange information to optimize the flow and safety of traffic over the entire network. Vehicles will continually report the traffic conditions they encounter. The traffic management centers will combine this information with its other sources of information and use predictive models to provide coordinated routing and traffic signal control. Individual vehicles requiring emergency assistance will automatically summon the proper services (police, medical, mechanical, . ..) which will be efficiently routed to the vehicle.

In achieving this integration of ATIS and ATMS the system must achieve a high degree of communication and an agreed allocation of tasks. These agreed allocations are necessary in the plating phase, but they will remain so during the operations phase. The traffic management centers, the traffic network, and the vehicles operating over it will become individual elements of a single intelligent system. IVHS will be a reality.

Commercial vehicles will not only benefit from the technologies and applications discussed here, but also from the research, field tests, and deployment activities proposed by other IVHS efforts dealing with advanced traveler information, traffic management and vehicles on highways. On the other hand, CVO will provide an early field test opportunity for the ATIS and ATMS applications.

Other IVHS efforts which involve the creation of databases for routing algorithms and traffic control must be cognizant of the special requirements of CVO, especially heavy vehicles, in developing alternative routing plans.

Equipment is now available which allows two-way verbal and print communication between the truck driver and his/her home office. The ability for two-way communication automatically brings with it the opportunity to provide a driver with current traffic information and revised pick up and delivery scheduling.

An automated highway/vehicle system, on the other hand, is a concept which is just beginning to be developed as an IVHS component. As incremental developments in automated vehicle technology come on line, they will be considered for adoption by commercial operators. There is support for commercial driver assisted technology but some industry representatives and drivers have expressed concern over technology which would take vehicle control totally away from the driver.

The existing network of highways that support and guides the transportation system is often referred to as the infrastructure. AVCS will equip this infrastructure with technology that can permit communication with and physically guide the vehicles on the roadway. The vehicles using the highway must also be fully equipped or "smart." By linking the smart highways to smart vehicles, the infrastructure will evolve to accommodate the latest technology and efficiently provide the best transportation system possible.

The fully controlled highway may be 20 years into the future, but its deployment will be associated with the following attributes:

- Considerable increase in traffic throughput
- Significant reduction in travel times
- Significant reduction in accident frequency and severity
- Improvement in air quality due to reduced congestion, improved vehicle efficiency, and cleaner propulsion systems
- Improved comfort and convenience of travel

Transition from the present infrastructure system to a fully automated system will require several years. It is important to plan and implement those AVCS improvements in concert with the longer-term evolution of the overall advanced transportation technologies. For example, existing freeways can be improved by implementing traffic management systems technologies that include advanced traffic signalization systems, traveler information and warning systems, and special control applications such as ramp control systems. Infrastructure requirements for such technology may include the following:

- Maintenance and operation of the system,
- Lane widths and clearances,
- Grade and geometry, and
- Freeway location and traffic volumes.

Equipping the infrastructure for a higher level of automation, means that the following additional requirements are addressed:

- Start-up and diagnostic procedures,
- Communications link between the highway and the vehicle,
- Types of vehicles accepted on the highway,
- Mixture of controlled and non-controlled vehicles,
- Emergency breakdown procedures and facilities,
- Incident management, and
- Information on non-controlled sections.

Future implementation of the advanced vehicle highway system will heavily impact the existing infrastructure. Requirements for proper planning, design, and safety must be incorporated into the project scope for these projects. Critical requirements include the following:

- Define roles and responsibilities. Determine the appropriate nature and degree of involvement for various levels of government and private organizations.
- Develop a marketing strategy to promote the benefits to be gained from AVCS. The plan fosters positive public relations and education regarding AVCS concepts and benefits. Detailed milestones, schedules, and costs are outlined.
- Maintain rigorous controls and evaluation protocols. Establish facilities, procedures, roles, and milestones for evaluating AVCS development throughout the system development cycle.

Standards

Since motor vehicles are by their very nature able to move from place to place, it is essential that there be North American-wide, perhaps world-wide standards for IVHS. These standards should cover the interface between the system in an individual vehicle and the infrastructure which must support it. These should include communications standards, data collection standards, database standards, functionality standards, and human factors standards.

Program Milestones

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Abstract

Intelligent Vehicle/Highway Systems (IVHS) represent sufficient potential in transportation benefits to become the next major public works/private sector program in North America and the developed world. IVHS and transportation are vast and complicated subjects. IVHS is in its formative stages. Transportation more broadly is nested in an ever-changing setting. Standards of living and rising consumer expectations create an increasing demand for travel. Energy availability, environmental quality concerns, the needs for highway and traffic safety improvements and the growing congestion in many cities create supply side issues.

There is now consensus that IVHS can contribute to resolution of all of these questions, concerns and issues. It is felt that IVHS and its advanced technology will do so as a complement to more conventional approaches – new highway construction, rehabilitation and improvement; improved public transportation, van-pooling and ride sharing; revised land use planning and even changes in future life style.

The assignment for Mobility 2000 here in Dallas was to define the detail of a national cooperative program in IVHS. The assignment for the Program Milestones Group was to identify, summarize and to augment as needed the major IVHS program milestones. This was accomplished through the efforts of a dedicated group, working from the resource documents developed by the Technical Working Groups (Advanced Transportation Management Systems, Advanced Traveler Information Systems, Commercial Vehicle Operations, Advanced Vehicle Control Systems and Benefits).

This report, then, summarizes the results of the Program Milestones deliberations and recommendations. It represents a start, not an end in itself. Therefore, it should be considered as a working document, offered in the spirit of providing another small step along the path to a national cooperative, public sector-private sector program in Intelligent Vehicle/Highway Systems.

Discussion

As a first step in the process, the Program Milestones Breakout Group was provided with Summary Program Milestone charts as shown in Figures 1 and 2. These summary charts were derived from the program milestones identified in the Working Papers of the Technical Working Groups augmented by information on earlier related IVHS actions and events in North America and elsewhere obtained from a variety of sources. As shown in Figures 1 and 2, these milestones are organized by topic, namely Advanced Traffic Management Systems (ATMS), Advanced Traveler Information Systems (ATIS), Commercial Vehicle Operations (CVO) and Advanced Vehicle Control Systems (AVCS), plotted against a time scale from 1986 to the year 2015.

The Program Milestones Group made several observations in a preliminary review of the Milestone charts:

1. There is a need for a greater level of coordination between groups, e.g., ATMS, ATIS and CVO.
2. There is a need to expedite the ATMS schedule in order to take greater advantage of what is happening in ATIS and CVO.
3. There is a need to establish more consistency in financial calculations and projections.
4. There is a need to obtain greater participation from transit professionals, from regional and local governments and from freight carriers and truck drivers.
5. There are cross-cutting Program Milestone questions that need to be addressed at the overall policy, legislative, funding, and

organizational issue levels as well as the programs, projects, and technologies level,

Figure 3 Perspective of Group

- Policy
- Legislation
- Funding
- Organization
- Program Projects and Technologies

worked toward four or five key milestones in each area iternting with other groups. .

The Program Milestones Working Group proceeded to the perspective shown in Figure 3, working to develop four or five key milestones in each of the five subject areas.

Each of the subject areas is discussed in turn as follows:

Policy

Working Group considerations in the policy area are listed in Figure 4. The distribution of the National Transportation Policy by Secretary Samuel K. Skinner and the U.S. Department of Transportation **in** March of 1990 is a key program milestone.

Figure 4 Policy Considerations

- National Transportation Policy released in March 1990.
- Surface Transportation Assistance Act of 1991 (STAA)
- Attention
  - R&D Incentives 1991
    - Tax Relief
    - Anti-Trust Adjustments
- Streamining Procedures 1991
- Tort and Liability Issues 1992
- Organizational Responsibilities 1990

The National Transportation Policy provides bases for IVHS elements and initiatives in the Highway Re-authorization Program and the anticipated Surface Transportation Assistance Act (STAA) of 1991. The timing of the STAA '91 places urgency on the detailed definition of an IVHS program and on the creation and staffing of a national, cooperative, public sector-private sector organization to contribute to and participate in that IVHS program definition.

Attention is needed, as well, to the provision of incentives for IVHS research and development, particularly for encouragement to the private sector and particularly for the communications, computer, electronics and motor vehicle industries. Examples of incentives that were discussed include tax credits and adjustments in current anti-trust laws that make cooperation between organizations that normally compete commercially and economically or between government and industry diffucult if not impossible.

It was agreed that such actions needed to be done early on, in 1991, as a part of the program planning process.

Given the expected significantly different nature of advanced technology applications in transportation improvements as compared to conventional highway practice (different suppliers, different specifications, the pace of technological change, etc.) it is anticipated that government procurement procedures (particularly at the state, regional and local level) will need to be reviewed, revised and streamlined.

Again, these procurement revisions need to be addressed early on in 1991 as a part of the overall program planning process.

The inclusion of advancing technology in transportation raises questions of systems reliability and safety. In turn this raises questions of tort liability for government agencies and consumer risk and liability for supplier companies. Such issues need to be addressed and resolved, probably in 1992.

Finally, there are a set of questions in organizational responsibilities. Who should be responsible for what in IVHS? Especially, what are the relative responsibilities for government – at the Federal, State, Regional and local levels? One example could be ATMS data and communications. Should there be standards to provide consistency and compatibility on a national scale or will each city be expected to pursue its own local (and perhaps different) approach? Action is needed in 1990.

Legislation

Clearly, there are strong interactions and interdependencies between policy and legislation. The Group addressed IVHS legislative topics as shown in Figure 5. Key legislative milestones include passage of the highway re-authorization program and an IVHS program as part of the Surface Transportation Assistance Act (STAA) of 1991.

Figure 5 Legislation

- STAA 1991
- New anti-trust laws 1991
- Revised R&D Incentive Bill 1991
- Procurement streamlining 1991
- Revised Tort and Liability Laws 1992
- Federal/State/Industry Standards Activity 1992
- STAA 1995

They include passage of new and revised anti-trust laws at the Federal and State levels in 1991 with special references to IVHS and the National Cooperative Program in IVHS.

Key program milestones include a revised IVHS research and development incentive bill in 1991, procurement streamlining in 1991 and revisions to tort and advanced IVHS technology liability laws in 1992. These latter laws might include provisions for sharing of dollar responsibility and caps on maximum dollar awards.

There will be significant, cooperative Federal/State/Industry IVHS activity in 1992, probably administered through a National WI-IS organization and participation of technical and professional societies from the communications, electronics, motor vehicle and transportation industries.

Finally, the legislative scene is dynamic. There will be numerous opportunities to adjust IVHS-related program legislation in future Surface Transportation Assistance Acts (STAA) in 1995 and beyond.

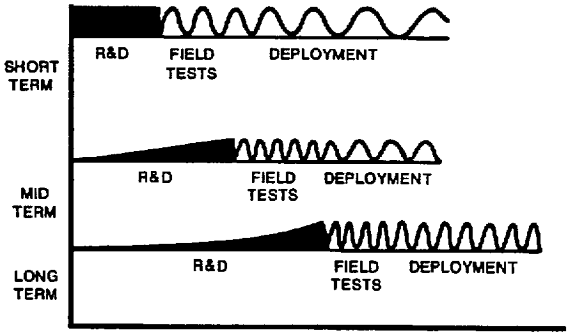
Both the Policy and Legislative actions require substantial background work and preparation. There is need for development of further definitive information on benefits and costs and at a high level of confidence. There is need for increased involvement by government at the State, Regional and Local levels. There is need to expand the IVHS constituency and to obtain "grass roots" support. There is need to schedule and hold public hearings on these topics. There is need to draft specific, proposed legislation for the re-authorization program. These elements are key program milestones and need to be front-loaded into the very early stages of the IVHS National Cooperative Program.

Funding

Funding is but one of the classic "chicken-and-egg" challenges confronting the IVHS community. Obviously, the availability and flow of funding are key program milestones. However, to define program costs one needs detailed program definition. To provide program definition, one needs an organization of responsibility, delineation of goals and objectives, consideration of alternatives, determination of benefits against costs and consensus on a set of recommended programs. It is still early in that process so confident funding numbers are also in development.

The Breakout Croup considered funding in a more generic sense as shown in Figure 6. There is a need for front loading IVHS research, development, experiments and demonstrations in the short term over the next several years. This

Figure 6 Front Loading Research & Field Tests



is needed to help answer questions on overall IVHS program definition and benefits and costs. Again in the short term there are IVHS programs now ready for field test and actual deployment, e.g., ATMS, ATIS and CVO.

In the mid-term, principally five years and beyond, there are some promising but more advanced IVHS projects where there will be a ramping up of funding for research and development activities, leading to field tests and deployment. Finally, in the longer term (principally 10 to 20 years into the future and beyond) there are yet unproven IVHS technologies, products and systems that will go through the research and development, field test and deployment process.

These activities are not mutually exclusive but interdependent and additive. They are not replacements for but complementary to traditional highway, transit and inter-modal transportation programs. They must include provisions for operations and maintenance over time.

Clearly, there is an urgent need for additional studies, beyond what is accomplished during this meeting of Mobility 2000, on required funding levels, revenue sources and funding policy. Hopefully, given the results from this meeting, the formation of a national IVHS organization in 1991 and preparation for and passage of STAA '91, an IVHS funding policy will be set in place to allow release and investment of significant IVHS research and development, field test and deployment funds in 1992.

Figure 7 Funding

- Studies of Funding Policy 1990
- Funding Policy and Timing 1990
- Release of IVHS R&D Funds 1992
- Coordination with ATMS Deployment 1992
- Class II ATIS Deployment 1995
- AVCS II Infrasturcture 1997
- Class III ATIS/ATMS 1998

As shown in Figure 7, this all suggests further studies of funding policy and conclusions and recommendations on funding policy and timing yet during 1990. These actions would contribute to the key milestone of the release of a substantial level of research and development funds in 1992. Then, as gleaned from the efforts and the Working Papers of the Technical Groups, that could lead to accelerated deployment of ATMS in 1992, improved coordination of ATMS and ATIS deployment in 1992, Class II ATIS deployment in 1995, AVCS infrastructure provisions in 1997 and Class III ATMS/ATIS availability in 1998. These key milestones are attainable with concerted efforts and should be pursued vigorously.

Organization

That brings us to consideration of another critical milestone — the creation and staffing of a national cooperative organization to help define, justify and promote an IVHS program for North America. This organization will be created in a fashion which will allow it to perform an IVHS technical advisory function for the U.S. Department of Transportation.

This new organization will incorporate and build on the valuable results of Mobility 2000 to date. Additionally, it is expected it will apply the knowledge, capability and interest of the Mobility 2000 constituency — all of its members, participants and supporters — in all of its responsibilities and activities, and particularly the technical advisory function.

Figure 8 Organization

- Mobility 2000 Now
- National Leadership Conference May 1990
- Selection of Organizational Form 1990
- Appointment of IVHS Advisory Board 1991
- IVHS Program Office 1991
- IVHS Contractor 1991
- R&D Program 1991

Key milestones in the formative process and activity of a national cooperative organization are shown in Figure 8 and as follows:

The U.S. Department of Transportation, the Highway Users Federation for Safety and Mobility (HUFsam) and General Motors are cosponsoring an IVHS National Leadership Conference in Orlando, Florida on May 3-5, 1990. Organizational alternatives for a National IVHS Organization will be considered. Hopefully, that will led to selection of a recommended organizational form and creation of the recommended organization in this year. Staffing and appointment of the organization's initial staff and advisory activities would be accomplished in 1991. Assuming there would be a need for an overall IVHS systems advisory contractor, that would be accomplished in early 1991, leading to pursuit of an overall IVHS program definition during the remainder of 1991.

Programs, Projects, Technologies

Now to discuss the program activities. First, the process. The IVHS program process is large, complex, interactive, covers a long period (perhaps as long as 40 years), melds traditional (and conservative) transportation responsibilities with futuristic (and risky) and (in some cases) still developing technology for the improvement of transportation services and the resolution of important social and institutional needs. This all makes progress in IVHS important but very difficult.

Figure 9 Programs, Projects, & Technologies

- Systems Definition 1991
- R&D Plan 1991
- Field Operational Tests
- Systems Evaluation
- Deployment

Still there is progress to be made building from the results of this conference, as shown in Figure 9. Key milestones (with substantial contributions from the increased definition of the IVHS program provided by past and present efforts of Mobility 2000 and the creation of a National IVHS Organization) include IVHS Systems Definition and an IVHS Research and Development Plan during 1991.

Field Operational Tests, Systems Evaluation and Deployment follow but the timing varies for ATMS, ATIS, CVO and AVCS activities. Please see Figures 1 and 2 for specific examples.

Closing

The activities leading to and the events of this week represent a tremendous surge in the detail of a broad, national cooperative program in Intelligent Vehicle/Highway Systems. Mobility 2000 can savor with great pride what has been accomplished and the critical value those accomplishments represent to the Nation.

Now is the time to build on that success. Some suggested actions are listed in Figure 10. Mobility 2000 and its successor organizations should pursue and promote demonstrated short term accomplishments; "success stories" in areas of highway and traffic efficiency, travel efficiency and congestion relief, environmental quality and energy conservation.

These accomplishments should be promoted in a variety of ways. One example would be in a Bi-Annual Conference on IVHS successes beginning perhaps in 1993.

Figure 10 Special Events

- Demonstrated Accomplishments in:
  - Highway & Traffic Safety
  - Travel Efficiency
  - Environmental Qulaity
  - Energy Conservation
- Bi-annual Conference on Successes 1993
- International Cooperation 1990

Another area for pursuit is IVHS cooperation on an international scale. Transportation and transportation needs are global and international in scope, not strictly local and domestic, Improvements, especially IVHS-related improvements, can benefit from international cooperation. It is recommended that the North American IVHS Program take the initiative to invite and encourage international participation.

The mission of the Program Milestones Breakout Group was “to develop major, key program milestones for a National IVHS Program.” That was accomplished here in Dallas, over a relatively short period of time, building from the past and current efforts of the ATMS, ATIS, CVO, AVCS and Benefits Working Groups. The mission was framed from the perspectives of policy; legislation; funding; organization and programs, projects and technologies.

Much has been accomplished. Much more needs to be done. The effort continues. The next critical milestone is the creation of a National Cooperative IVHS Organization, Commitment and diligence of effort will provide the rest.

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There are many technologies that are immediately applicable to IVHS. It is possible to proceed with extensive deployment of ATMS without waiting for more research. Second generation ATMS more fully compatible with ATIS will require additional research. Some aspects of ATIS are already in demonstration, but others depend on additional research. The same situation exists in CVO. However, before AVCS can be deployed, extensive research must be completed. The following programmatic discussion covers research and development essential to mature IVHS.

The execution of the IVHS research and development program should proceed on several fronts:

First, the research and development program should be coordinated with other public and private research programs, for example, the PATH program in California, TRAVTEK in Florida, the FAME program in Washington, and research programs in Michigan, Minnesota, Texas and other States, as well as research sponsored by domestic industrial partners. Coordination should also be maintained with international research programs, especially in Canada, European Community's programs, and the Japanese programs. Obviously, the ATMS program is very much dependent on the results of research and development in the advanced traveler information systems area.

Second, the Request For Proposal and contract award processes should be streamlined. RFPs should be less prescriptive and more flexibility should be provided in contracts to make possible pursuit of promising avenues of research.

Third, a university research program should be established to encourage innovative ideas and to entice students to do graduate work in this area. This program could supplement the Advanced Institutes established within the University Transportation Research Centers by UMTA and FHWA. However, those Research Centers receive very modest funding and their objectives are not focussed on IVHS. The program could also serve to provide potential staff support for operational tests. Under this program, contracts could be awarded on the basis of a "best idea" competition, using criteria such as technical merit, technology advancement potential and application potential. Work statements would be problem and approach oriented rather than product specific, and would be oriented towards basic or fundamental research.

Fourth, public, private, and academic partnerships or consortia must be encouraged and facilitated. The government should sponsor basic, fundamental and long-term research, and should focus on technology applications (e.g., software, system integration). Private development of new technological applications, especially new trafftc control hardware, could be accomplished as part of the operational testing program. One idea is for government agencies to provide research and development contracts to one or more industrial and academic partnerships and then license products that result from the programs. The legal ramifications of public, private, and academic agreements must be studied and well understood by all parties.

Fifth, laboratory and operational facilities for conducting research, and testing equipment and software, must be available to public and private firms engaged in the development of ATMS technology.

Systems analysis should address the overall system design issues, benefits studies and tradeoffs among the different elements which constitute ATIS and its supporting infrastructure. This analysis should deal with the system at least three levels:

1. the complete IVHS system design including technical, societal and economics issues,
2. the complete ATMS and ATIS system design, including users, vehicles and infrastructure, and
3. individual subsystem designs for vehicles, stationary elements and communications links required to interface ATMS and ATIS.

The results of these studies should be corroborated by the field operational tests and experiments described in a later section of this report. Research to support these analyses should include:

- Modelling and simulation of specific urban traffic networks to estimate level of benefit for the different stages of ATIS optimal allocation of tasks between vehicle and infrastructure
- Channel capacity requirements for real-time traffic information
- Communications architecture and technology
- Methods of collecting, formatting and disseminating real-time traffic information
- How, where and when real-time traffic information is provided
- How to create predictive real-time trafftc information
- Cost-benefit analysis for various alternative system features (e.g., electronic maps, guidance displays, real-time traffic information, automatic toll debiting, . . .) and architectures (e.g., centralized or distributed dissemination of real-time traffic information)
- Content requirements for a national digital map data-base

Research and Development Program for ATMS

A $70 million Federal research and development program is proposed. This does not include currently funded programs, state programs (HP&R, NCHRP, and others) that could be expected to sponsor ATMS R&D, evaluation funds which may be included in operational tests, nor does it include potential contributions from the private sector. The program can be divided into three broad areas: monitoring trafftc conditions, communications, and controlling and managing traffic. The issues to be addressed in these three areas are generally described below. Some of these R&D issues are also described in reports prepared as part of a technology assessment being done under the National Cooperative Highway Research Program.

The successful deployment of ATMS and other IVHS systems depends on being able to obtain reliable and accurate data on traffic conditions on freeways and major streets in real-time. Loop detectors continue to be the dominant form of monitoring technology used today and will be for the immediate future. It is imperative that the technology be improved to provide the quality, quantity, and reliability of data that will be required to develop, operate, and evaluate advanced traffic management strategies. An important part of the research and development program should be directed to developing new types of sensors. One or more of these sensors may become the primary source of information for ATMS, reducing or eliminating the need for inductive loops. These sensors include sonic, infrared, laser, and wide-area detection systems. The latter use radar, infrared, or video image processing.

Information on traffic and roadway conditions will come from multiple sources, including the monitoring systems, but also potentially from police reports, scheduled maintenance or construction activities, fleet managers, and radio traffic reporters. All information would be processed and stored in a database that would be available, on a real-time basis, for several applications: traffic control, traveler information, and in-vehicle route guidance. Methods must be developed for integrating as well as managing this data to ensure that the information that will be provided is reliable, accurate, timely, and consistent.

There is also a need to have historical information relating the effects on capacity and operational characteristics of freeways and arterials of bad weather conditions, roadway construction, and incidents. Research should be conducted to define this need and to develop a uniform data collection format to guarantee consistency and timeliness of data. The results of this research would be used in advanced traveler information and diversion strategies. The database could also provide information for system performance evaluations and the development of artificial intelligence and expert systems traffic management applications.

An important research and development issue is two-way communications between vehicles and traffic control centers in real-time. Currently, traffic information to travelers is principally communicated through commercial broadcast, low Rower radio, and sideband carriers (such .as the Radio Data System used in Europe). Area wide two-way communications, cellular telephone, and roadside beacons (such as infrared or microwave) offer practical options. The information needs of drivers, commercial vehicle operators, and fleet managers must be identified. Also, the ability of the different communication technologies to handle the load must be determined. Alternate technologies must be assessed in terms of their performance, cost implications, and other issues (e.g., availability of radio frequency spectrum).

Specifications and protocols for communications interfaces and specifications for in-vehicle displays must be established early. The impetus for developing compatible hardware must come from industry, and must be done in a willing and cooperative manner, with government and other organizations playing a guiding and facilitating role. While specifications/standards cannot be ratified before the system architecture is defined, standards considerations will be important for defining future system limitations or constraints, and should be developed in parallel with system studies.

The major goal of ATMS is to apply the information collected through monitoring processes to implement control strategies which guarantee optimized corridor or area-wide traffic operations. To do this, new traffic models and trafftc control and management strategies must be developed to take advantage of the real-time information that will be available. The general objectives of the research and development program in this area would be to:

- Gain a better understanding of traveler behavior issues (e.g., willingness to divert) and travel information needs, including those of commercial vehicle operators and potential transit users, and considering pre-trip versus enroute differences. Insight is needed in how people make decisions about whether and when to travel, and what routes and modes to take.
- Develop real-time dynamic traffic assignment, simulation, and corridor or area-wide optimization models that can be applied to anticipate where congestion will occur and evaluate the effects that various control and management strategies will have on travel patterns and traffic operations. New theories of traffic flow should be investigated.
- Develop applications of advanced support systems, such as artificial intelligence and expert systems, for use by traffic management operators to, for example, interface with the traffic models, rapidly detect incidents, draw upon historical data, and recommend the best control and management strategies.
- Develop demand management strategies for use by advanced traffic management systems that could be implemented when special events are planned, when congestion is predicted to be especially severe, or perhaps

during times when air quality standards are predicted to be exceeded.

- Develop corridor or area-wide traffic control and management strategies that provide accurate and reliable information on traffic conditions to the public, commercial vehicle operators and fleet managers in real-time, rapidly detect and respond to incidents, efficiently manage saturated flow and control traffic in an integrated, real-time fashion.
- Develop an interactive real-time traffic control system that uses real-time origin-destination data obtained from vehicles equipped with an in-vehicle device and two-way communications capability (automatic vehicle identification or location). The system will predict where and when congestion will occur, and integrate the traffic control and management strategies to provide accurate information on predicted traffic conditions, the best routes, and best modes to provide optimum control of traffic.

Research to Interface with ATMS and ATIS

The following system tasks are required to properly interface ATMS and ATIS. The entire concept of IVHS is to develop an integrated system where "smart cars" can operate on "smart roads" or where "smart commuters" can ride on "smart transit." Specific projects that need to be carried out are:

- Traffic strategies for link-time prediction
- Development of link-time data-base and statistics
- Development of origin-destination statistics for traffic management purposes.
- Congestion leveling strategies that can be achieved by modulating predicted link-times
- Analysis of productivity and travel time savings
- Information exchange between commercial fleets and traffic information center
- Efficient algorithms for rerouting vehicles when traffic link-times are continually changing
- Concepts for increasing the availability of real-time traffic information and link-times to other potential users
- Development of models, simulations, and algorithms to support coordinated routing and traffic control
- Vehicle routing algorithms to provide near-minimum travel time to all vehicles in the network
- Fusions of traffic probe reports, origin-destination data, and other traffic information to manage complete urban traffic network
- Potential for using the real-time traffic, origin-destination, and routing information of the Traffic Management Center for planning and managing a multi-modal urban transportation system
- Optimal architecture and protocols for two-way communications between vehicles and the Traffic Management Center

Research and Development Required for ATIS

Much of the systems analysis and human factors research described for the ATIS Information Stage should continue during the Advisory Stage with the emphasis gradually swinging more toward dealing with rapidly changing dynamic information and with decision making.

Systems analysis should address traffic data acquisition, data fusion and traffic network balancing issues. Specific projects should be carried out in the following areas:

- Communications architecture and technology to support additional features of the Advisory Stage
- Content and information priorities for in-vehicle signing
- Tradeoffs between passive and cooperative approaches to in-vehicle signing

The integration of ATIS with ATMS requires additional systems analysis in the following areas which are closely linked to ATIS:

- Allocation of coordinated vehicle routing tasks between individual vehicles and the Traffic Management Center.
- Relationship between the proportion of fleet equipped with Coordination Stage ATIS and the level of efficiency achievable by the traffic network.
- Potential benefits of having vehicles communicate directly with each other and evaluation of alternative architectures to do so.

Even though the last two items are related to architecture it should be noted that system architecture decisions should be made as early as feasible so that earlier stage technologies are not rendered obsolete.

Human Factors Research for ATIS

Human factors research for ATIS can be grouped into (1) ergonomic and anthropometric issues, which are generally understood, and (2) cognitive, utilization and acceptability issues, which are less well understood. Issues in the first category will require applied research to support specific designs, while issues in the second category require more basic research to ensure the ultimate efficiency and acceptability of ATIS. Recommended studies include:

Driver Interface:

Optimal Display Characteristics

Optimal Voice Characteristics

Sensory Channel Tradeoffs

Format and Wording for Traffic Information

Format and Symbology for Navigation Information

Intelligibility-Cognitive Analysis

Cognitive Spatial Mapping

Cognitive Time Scaling

Sensory Mode Evaluation

Analysis of Cognitive Errors

Driver Information – Driving Performance Coupling

Vehicle Guidance Analysis

Vehicle Control Analysis

Sensory Mode Interactions

Information Capacity Analysis

ATIS Utilization

Factors that affect perceived benefits:

Route Suitability Perception

Route Risk Analysis

Subjective Time Metrics

Use-Prediction Model

User Demographic Analysis

Cognitive Attributes

Performance Attributes

Preference and Attitude Attributes

Define User Clusters

Determine Specifications, Utility, and Acceptability by Cluster

Human Factors Research for the Information Stage

Many of the human factors research topics described for the Information Stage would continue during the Advisory Stage. Additional studies should include:

- Driver Interface

  Communication of in-vehicle sign information

  Communication of route guidance instructions

  Potential of head-up displays

  Treatment of recurrent congestion information

Use of in-vehicle signing to increase the safety and mobility of special groups

- Behavioral Issues

  What types of routes do drivers prefer?

  Do drivers prefer complete routing or only routing around congested areas?

  How drivers analyze and select routes?

  How drivers analyze and select routes?

  What information do they need to select routes?

  What information will influence modal choice?

  What is the time-savings threshold for rerouting?

  What types of alternate routes will drivers accept?

Research and Development Needs to Support the Commercial Vehicle Program

The research and initial testing of equipment has been completed for many of the technology applications mentioned earlier. However, there is also other simultaneous research needed to optimize the potential of the technology applications needed to resolve ongoing problem areas.

Research on the human factors aspect of information processing by commercial vehicle drivers must be expanded. While some research is underway, more is necessary to focus on the more complex on-board computer function capabilities which commercial vehicle operators will experience. It appears that technology is ultimately going to provide all drivers the opportunity to obtain real-time highway and vehicular system information. The optimum way of displaying this information needs to be determined so that a commercial driver is not overloaded and retains the ability to react in a safe, predictable manner.

Traffic incidents which affect public safety are critical because they often cause complete blockage of a roadway for what may be an extended period, and often involve fatalities and/or injuries. The truck-tractor, semi-trailer combination vehicle is likely to remain the backbone of heavy vehicle operations in the foreseeable future. It is quite likely that there will be increased use of multiple trailer combination vehicles including Turnpike, Rocky Mountain, and standard doubles as well as triple bottom units. Roll indicators, collision avoidance systems, and vehicle specific grade warning systems, for example, could improve vehicle dynamics, provide operator warnings, and prevent many of these incidents from occurring.

A summary of the proposed research necessary to fulfill the goals of the commercial vehicle operations section which should be initiated is listed below.

Human factors

- “best” layout of cab equipment
- “no hands” message receipt and transmission (heads up displays)
- driver fatigue self-detection and countermeasures
- driver identification systems
- driver trip pretest (real-time suitability to drive)

It is recognized that any items which involve unique driver identification raise extremely sensitive privacy issues, and these need to be addressed in the research and development phases.

Vehicle Performance

- real-time vehicle systems monitoring (including status of brakes, other mechanical systems, vehicle dynamics, etc.)
- near-obstacle detection and warning systems
- out-of-lane/run-off-the-road detection and warning systems
- dynamic grade severity warning systems
- dynamic ramp and sight distance warning systems

Improvements to existing technology applications

- bridge height clearance sensors
- two-way communication terminal receipt, i.e., screen, verbal transmission medium, i.e., satellite, radio, etc.
- unique vehicle identifiers with respect to combination vehicles
- Improved efficiencies which are expected to be identified by the HELP and Advantage 75 projects

Research and Development Requirements for AVCS

The following principal technological AVCS research and development issues that need to be addressed are:

- Low-cost high-performance sensing of distance, velocity, acceleration, torque, rotation, etc.
- Low-cost high-performance computation
- Image processing and pattern recognition
- Reliability/safety/fault tolerance
- Low-cost high-performance communication (vehicle-to-vehicle and highway-to-vehicle)
- Nonlinear and adaptive control
- Electric propulsion

One specific R&D need associated with AVCS is the need for AVCS roadway test facilities. Test facilities representing a range of conditions (speeds, curves, grades, weather) are needed. Following test and evaluation utilizing test facilities and other evaluations, AVCS systems will be subjected to field operational tests on specially-designated and instrumented freeway lanes.

About $815 million will be needed to fund the research, development, and test programs that will ensure the deployment of AVCS technologies.

About $1,390 million will be needed to fund the research, development programs required to bring the AVCS systems into widespread application on urban freeways.

AVCS Research and Development Summary

AVCS is the most complicated and longest-range of the IVHS technologies. As such, it needs the largest investment over the longest period of time to reach fruition. The research for AVCS total $300 million during the period from now through 1995 and $523 million for the next five years. The total research program for the 1991 through 2010 period is expected to be $1,395 million reflecting the increasing complexity of the higher levels of functionality. The annual funding peaks at $280 million in the year 2000 in this plan. Although this may seem to be a great deal of funding on the scale of transportation R&D programs, it is very low compared to the amount DOT spent on the supersonic transport project two decades ago. At that time expenditures topped $300 million in the peak year, a figure which has not been inflated to current-year dollars.

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Operational testing serves as the transition between research and development and full scale deployment of IVHS technologies. Operational tests must be an integral and major part of a national IVHS program to evaluate how well newly developed IVHS hardware and software products work under real operating conditions. Decisions on major investments in IVHS technology, by both the private and public sectors, will be made based in large part on the results of the operational tests.

Over 40 people participated in the operational tests breakout session. They are identified in the appendix. The following summary is the essence of the discussions that occurred over the day and a half.

What is an Operational Test?

The group agreed to define an operational test. as one conducted in a "real-world" environment under "live" traffic conditions. This definition distinguishes operational tests from other kinds of testing, for example, simulation testing, test tracks, or tests on facilities that are temporarily closed to public travel. The group recognized the importance of these, but to be true to the defined nature of operational testing, felt that they belonged under the banner of research and development.

Since the aim of a national program would be to deploy IVHS technologies to solve transportation problems, the group felt it was important to emphasize that operational tests should be needs-driven. That is, the goal of operational tests should be to evaluate IVHS products that hold the most promise for successfully addressing some transportation problem, as opposed to evaluating the most exotic technology available.

Finally, the group agreed that operational tests may be small or large in scale. Operational tests of new vehicle detection technology may be done at a relatively small number of locations, operational tests of new adaptive signal control strategies may be done in a portion of a transportation network, operational tests of new in-vehicle information technologies may be done with a relatively small number of vehicles at first. Eventually, operational tests will become systems-oriented and much larger in scale, for example, areawide advanced transportation management strategies, two-way communications with large numbers of vehicles, and vehicle-platooning systems.

In the same vein, it was also recognized that there may be reasons to focus some operational tests on specific issues. Among those suggested were effects on elderly drivers, measurement of environmental impacts, and demand management applications.

What are the Objectives?

The group identified the following objectives for operational tests:

- To evaluate the reliability and viability of the IVHS products involved. Reliability includes how well the products worked under actual operating conditions and is a very important issue as it pertains to liability. Viability includes how well the products were accepted by the system operators and the users.
- To determine the public benefit. In order for a national IVHS program to be successful, the public must perceive that there is benefit to them, as companies or individuals, in order to ensure markets for the producers and to gain acceptance for public investments in IVHS technologies.
- To determine cost effectiveness. Operational tests must produce accurate data on the total benefits and costs. Deployment can only be justified if, over the expected life of the products, the total societal benefits accrued as a result of deploying them exceed the total costs of deployment, operations and maintenance.

- To “prime the pump” for tests of future IVHS technologies.

  Assuming that the IVHS R&D program follows a u building-block” approach, steps should be taken to provide for continued operation of IVHS technologies that have been successfully tested, thereby facilitating tests of future IVHS R&D products.

- To stimulate commitment to deploy and operate IVHS systems. An effective marketing program must be established to disseminate the results of the operational tests to those that should know. There is a need for a national clearinghouse of technical information on the tests, to avoid needless and costly duplication and “reinventing of the wheel”, and there is a need to widely disseminate success stories to spark interest in deployment.

Where Will Operational Tests be Conducted?

Rather than identifying a limited number of IVHS test sites, the group believed that operational tests should be considered at any location that demonstrates its interest and commitment to operating TVHS systems. To generate as much interest and enthusiasm as possible, the group recommended that operational testing should be performed not only in large metropolitan areas, but also in mid- and small-sized metropolitan areas, and in rural areas as well. Available funding will dictate at how many different locations a given product could be tested, the group recognized the issues of variability, repeatability and transferability as related and important ones. The group also suggested that possibilities for international cooperation in operational testing should be explored.

To increase the probability of producing “early winners" , the group agreed that operational tests in the first years of a national IVHS program would be in “pioneering” areas that were already deploying advanced systems. Early tests would also very likely incorporate fleets of vehicles, for example, emergency response vehicles, transit vehicles, taxis, and trucks. Other areas and personal vehicles would be incorporated as the program progressed and early deployments of successfully tested IVHS technologies occurred.

The group identified the following ideal characteristics of an IVHS test site:

- The **necessary** infrastructure to conduct the test would exist or there would be a firm commitment to install it within the required time frame. Satisfaction of this characteristic would serve to keep the cost of conducting the operational test reasonable by separating it from the cost of building the needed infrastructure, while still allowing those that do not already have the needed infrastructure to qualify by demonstrating their commitment to build it.

- The institutional arrangements needed to operate the system being tested would have been made. Satisfaction of this characteristic would facilitate successful execution by making sure that responsibilities for conducting the operational test, for deploying, operating and maintaining the technologies being tested, and for operating and maintaining the rest of the system while the test is being conducted, have been defined and agreed to by all of the parties that would be involved.

- The agencies involved would have demonstrated their willingness to become part of public/private/academic partnerships. To ensure successful transition between R&D and deployment, the group felt it was important to form these partnerships to represent perspectives on theory (academic), market potential (private) and public cost effectiveness (public).

- The agencies would have demonstrated their intent to provide for operations and maintenance of the public sector infrastructure upon successful completion of the test. This characteristic supports the objective of “priming the pump” for tests of future IVHS technologies by addressing the issue of continued operation and maintenance up-front. This is intended to facilitate tests of future IVHS technologies, and to prevent leaving wrong impressions about the success of the test that could occur if operation is not continued.

What Will be Tested?

The Mobility 2000 working groups identified over 60 individual technologies that should be operationally tested. These are listed in Appendix B. The group recognized the overlap that existed among these, and felt that this amount of detail was too much to digest for somebody interested in learning what IVHS is all about and what products could be expected and when out of a national IVHS R&D program. Therefore, the group wanted to shrink the list to a more manageable size, while portraying an exciting picture of what IVHS is in understandable terms.

To do this, the group attempted to identify the most critical operational tests from the working group reports, and to combine tests from individual reports or from several of the reports. The group also wanted to make the tests systems-oriented and multi-modal, and to identify possibilities of "early winners" during the first five years that could generate even further interest and excitement about a national IVHS program. The exercise the group followed was to divide itself into three sub-groups that were to identify a series of operational test milestones in the following areas: systems oriented to alleviating congestion, systems oriented to improving safety, and systems oriented to increasing productivity. The group found that even this exercise resulted in overlapping systems, in other words, the same kind of system could contribute towards achieving some combination of congestion, safety and productivity objectives. This smaller set of operational test milestones was used to generate the final set that is included in this report.

The intent of the group was to identify each operational test milestone by a descriptive, but catchy title, to explain what the system would be in terms understandable by the layman, and then, as a separate and more technical part, identify the individual operational tests that would have to be conducted before the complete system could be operationally tested, as per the working group reports. While the group fell short of that goal due **to** time constraints, a set of 15 operational testing milestones in 3 time increments, 1991-1995, 1996-2000 and 2001-2010, was defined in terms that at least approach being understandable by laymen. The group felt this was a good start towards achieving its goal, and that time would be well-spent by somebody to develop such a product for inclusion in a proposed national IVHS program.

The operational testing milestones identified by the group were as follows:

1991-199s

- Provision of real-time pre-trip and in-route travel information to the public and commercial drivers through a variety of sources, including in-vehicle devices
- Provision of route guidance information to the public and commercial drivers
- Corridor traffic control systems that integrate the operation of freeways and adjoining arterials and adapt to changing traffic conditions
- Commercial vehicle productivity technologies such as automatic vehicle identification and classification, weigh-in-motion, and on-board computers that would allow State regulatory procedures to be automated
- Electronic technologies that warn drivers of personal and commercial vehicles of potential roadway hazards

1996-2000

- Real-time two-way communications with large fleets of vehicles, both personal and commercial
- Advanced modeling techniques that anticipate where congestion will be occurring

and recommend the best management strategies

- Electronic technologies that permit hazard warning through vehicle-to-vehicle communications, and enhance the image of the roadway under adverse visibility conditions
- Vehicle control systems such as minimum headway maintenance (adaptive cruise control), automatic braking and automatic lane keeping
- Platooning systems for headway, speed and merge control that will greatly increase lane capacity and safety
- Roadway powered electric vehicle systems
- Automated parking facilities as an early test of automated highway concepts

2001-2010

- Cooperative vehicle/roadway facilities in which vehicles travelling on freeways are under fully automated control and able to interact with advanced traffic information and management systems in the adjoining arterial network
- High-speed automated facilities for intercity and rural travel
- Use of electric vehicles by commercial delivery and public transit fleets

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Introduction

Three ingredients of a visionary and successful national IVHS program were quickly recognized and embraced by the Program Funding Requirements Work Group (PFR) as work began on preparing a 20 year proposal:

- Early Winners — In order to capture the imagination and excitement of the nation relative to the potential of IVHS technology, to build and maintain support, and to overcome the often stated view that IVHS is "Buck Rogers stuff," it is essential that the IVHS program demonstrate some immediate successes. In the words of Chairman Richard P. Braun of the University of Minnesota,. . . . "Early winners will enable us to showcase the results and thus build support for the IVHS program as we move into the deployment state."
- Investment Requirements rather than Funding Requirements — The funding needs of the program must be viewed as an investment which provides a solid return. Both the public and private sectors must share the view that IVHS is an investment that will, for the public sector, produce efficiencies in the operations of transportation infrastructure, and, for the private sector, produce a profit or a market for their products.
- Deployment Must Be Our Goal — The investments in research, development, and testing **must** be viewed not as the end product of this national program but as the predicate to full deployment of IVHS technologies. Thus, cooperative projects for research and field testing must verify IVHS technology *and* provide compelling and convincing evidence that the technology is worthy of further public and private investment.

The PFR organized into 3 subgroups according to the three major funding components of the 20 year program, i.e., Research & Development, chaired by Dr. Tom Humphrey of the Massachusetts Institute of Technology; Field Operational Tests, chaired by Tom Griebel of the Texas Department of Highways and Public Transportation; and Deployment, chaired by Jack Kay of JHK and Associates. The R&D and Field Tests subgroups were to coordinate and collaborate with their breakout group counterpart in arriving at the funding requirements for a national program. The Deployment subgroup was to be influenced by all the breakout groups, and especially the Milestones Group, so that an orderly and systematic program that met national objectives could be proposed.

The 5 technical reports produced by Mobility 2000 prior to the Dallas conference are excellent stand-alone documents that became the principal references of the conference. However, as recognized when commissioned, these technical reports were not integrated nor coordinated with respect to their recommendations. Nevertheless, it was the place to start building a national program with the above essential ingredients. For example, the funding requirements as calculated independently by these technical reports are shown in the table.

While the independent technical reports were useful in determining priorities and costs, as can be seen in the table below, some important data were missing. The ATIS and AVCS reports did not estimate deployment costs. The ATMS report did not include private sector costs. Some research needs were duplicated and the costs shown more than once. And the CVO report stopped at 15 years, whereas the others made cost estimates for 20 years.

Finally, some basic assumptions were proposed and adopted to assure consistency in the calculation of total costs. First of all it was decided **to** use 1990 costs for each of 3 time periods, with no adjustments for inflation. The

3 time periods were 1991-1995, 1996-2000, and 2001-2010. Furthermore, the costs shown for both R&D and field tests would consist of both public and private sector costs, in recognition of the importance of the public/private partnership in the conduct of research and testing. However, with reference to deployment, the total costs shown represent only the public sector cost. The private sector costs for deployment were viewed as a per unit cost, such as $800 to $1200 for each car or truck, and, therefore, would not be shown in the total cost for the 20 year program.

Program Funding Levels
(in millions)

Technology	R&D	Testing	Deployment	TOTAL
ATMS	$150*	$450*	$18,060*	$18,660*
ATIS	220	908	------	1,128
CVO	31	80	725	837
AVCS	965	1,510	------	2,475

Note: All costs shown include both estimated public and private costs, except those marked with the *, which are public costs only. Deployment costs were not estimated for ATIS and AVCS.

Additional assumptions were made about the availability of funding for an IVHS program. It was particularly assumed that special Federal funding, unique to IVHS, and sufficient to support a large, robust, and long term program well beyond 1996, would be available for the R&D and field testing phases, and that as a consequence of this expression of leadership and confidence in IVHS technology, the private sector would step forward with an equally impressive amount of financial support. It was also assumed that deployment expenses would be eligible under existing and future Federal and State programs, and that any barriers to their use would be removed.

Thus the PFR began with a vision of what was needed, 3 well staffed and managed subgroups, a good understanding of the funding estimates of the previously prepared technical reports, and with some basic assumptions about funding. The remainder of this report provides the results of their efforts.

Research and Development Funding Needs

Dr. Humphrey and his subgroup worked closely with the R&D breakout group to arrive at well supported cost estimates. Furthermore, efforts to remove the duplication that exists in the 5 technical reports were successful. While estimates were made for the entire program period, obviously the first few years of a program tend to be more accurate in terms of cost estimates and resource needs. A rationale and approach for a 20 year research and development program is described very well in other parts of the Mobility 2000 report, and will not be repeated here.

Perhaps what needs expounding on is the weak part of the cost estimate, and that is the non-hardware part. For example, as educator Mr. Humphrey pointed out, within the R&D effort it is recognized that a tremendous number of technically qualified scientists and engineers will be needed to perform the work proposed. The cost of educating, training, and equipping these scientists must be better estimated and included in the total cost.

In like manner, costs pertaining to human factors research and analysis are not well defined. Nor are the costs associated with research and studies that address the removal of institutional barriers to IVHS technology. And finally, costs pertaining to a public information program aimed at letting the public know about research that shows exciting promise are not well defined.

Special attention to these areas are essential throughout the entire IVHS program period.

But what is very clear is that the execution of a joint public/private IVHS research and development program as proposed, especially when coordinated with the field testing program, will result in near term successes and more rapid deployment of useful technology so badly needed for our transportation system. The cost of such a program, according to the elements described by the R&D breakout group, and in the 3 standard time periods, is illustrated in the following table.

Notice that R&D needs are heavy in the first time period, but begin to diminish over the next 2 periods.

As a final note, the PFR group recommends that the boundaries of IVHS R&D be better defined for a national program to assure that it is properly integrated with the field testing effort and with deployment needs.

Field Operational Testing Funding Needs

A slightly different tack was used by Tom Griebel's subgroup to illustrate the field testing costs. The Field Testing breakout group, with whom the subgroup worked, projected its efforts in defining a national program in terms of field testing systems pertaining to congestion, safety, and productivity. That effort is described elsewhere in the Mobility 2000 report. And yet the cost estimates are in terms of the 4 commonly described IVHS technologies, i.e. ATMS, ATIS, CVO, AVCS, rather than by the cost of testing specific systems. It will suffice for the purposes of this report, however, because the cost estimates assume that many of the field tests will involve integrating technologies such as ATMS and ATIS, thus requiring a commingling of the field testing funds.

Field testing should be aggressively used because of the many opportunities it offers to evaluate the readiness of new technology. It also allows the testing of new institutional and financial relations, including partnerships of public agencies and private bodies. It is the method by which the new findings from R&D are tested in a real world setting, fine tuned as needed, evaluated as to its applicability, verified for use, and then released for deployment. And as stated above, it will be the method by which IVHS technologies are integrated and tested as systems under which the technologies are likely to be deployed. Of equal importance is the value of field testing to confirm what Tom Griebel refers to as... "the consumer's willingness to buy the product."

The following table projects 20 year field testing funding needs:

In developing these costs, the following was considered:

ATMS — The $490 million investment will instrument approximately 150 miles of urban freeways during the first period and an additional 350 miles in the second 5 year period. The estimate also specifically provides for transit applications to be field tested. ATMS testing and verification is crucial for the other IVHS technologies, and especially ATIS. Therefore, heavy funding is recommended for 10 years.

ATIS — This technology starts off slowly, while building on ATMS, and then

IVHS R&D FUNDING (IN MILLIONS)

Elements	1991-1995	1996-2000	2001-2010	Total
Functional/ Applications	$ 70	$ 60		$ 130
Systems Analysis	135	20	15	170
Human Factors	122	108	70	300
AVCS	300	335	160	795
Total	$627	$523	$245	$1,395

FIELD OPERATIONAL TESTS (IN MILLIONS)

Technology	1991-1995	P*	1996-2000	2001-2010	Total
ATMS	$165	L	$ 325		$ 490
ATIS	168	H	247	$536	951
CVO	96	M	48	24	168
AVCS	75	H	670	765	1,510
Total	$504	L-H	$1,290	$1,325	$3,119

*Private sector opportunity — High, Medium, Low

accelerates in the 3rd and final period. This area offers a big market potential for the private sector and, therefore, substantial private sector investments are foreseen in this technology.

CVO — The CVO program complements the others by providing field testing unique to the motor carrier industry. Similar to ATIS, a substantial private sector interest is likely. While over half of the needs are projected in the first 5 years, new technologies are expected to emerge in the later periods that will need field testing and verification.

AVCS — This portion of the IVHS field tests represents the largest total funding requirements ($1,510). However, it also requires substantial research to be conducted before testing can occur. Thus the heavy funding is not anticipated until the final years of the program.

Deployment Investment Needs

If the estimated $4.5 billion needed for research and testing during the 20 year program does not boldly lead the nation into widespread deployment, then the effort will have been wasted. In fact it is in this area that excitement really builds for the IVHS program. Jack Kay and his subgroup were not timid. In their attempts to be visionary but practical, to be optimistic but realistic, and to be bold but cautious, they met little resistance from those they worked with at the conference. The mood was one of optimism. With a strong Federal interest in the IVHS program, and a likely leadership role guaranteed, deployment opportunities were seen as highly likely early in the program, allowing successful projects to be showcased. This will naturally lead to more deployment. The trick is to initiate cycles of R&D, field testing, and deployment that are complementary and coordinated during the 20 year program.

The following table illustrates the recommended 20 year investment for deployment:

The following points relative to the above table are important:

1. System operation and maintenance is an essential element of IVHS deployment and includes critical staff development and training. As Jack Kay points out, recurring maintenance must include replacement of system elements as failures and obsolescence requires. A value of 15 percent of capital costs for annual system operation and maintenance is recommended.
2. ATMS technology generally exists. ATMS is critical as an autonomous element and as a base for several other elements. Early deployment is therefore recommended.
3. The CVO deployment costs assumes that commercial vehicles will take advantage of ATIS in urban areas.
4. AVCS deployment needs to be encouraged and accelerated to experience capacity increases and air quality gains in major urban areas as soon as possible.
5. AVCS III deployment costs are not included. They are considered post 2010.

So what will almost $30 billion buy in the 20 year period?

- ATMS — Will instrument 18,000 miles of freeways, integrated with approximately 200,000 signalized intersections in 250 of the largest metropolitan areas for greatly improved traffic management.

DEPLOYMENT INVESTMENT COSTS (IN MILLIONS)

Element	1991-1995	1996-2000	2001-2010	Total
ATMS	$3,000	$8,000	$7,000	$18,000
ATIS		1,810	3,620	5,430
CVO	105	620	350	1,075
AVCS		450	4,980	5,430
Total	$3,105	$10,880	$15,950	$29,935
Avg Annual Ops & Mt Costs	$240	$1,260	$3,185	

- ATIS — Will establish communication systems with ATMS in the 250 metro areas and will establish ATIS in rural areas in every state, including a Statewide Traffic Control Center.
- CVO — Provides instrumentation on the 42,500 mile Interstate system plus the remainder of the National Network for Trucks.
- AVCS — Provides increased capacity through 16 platooning highway systems for headway, speed, and merge control, and 44 electric propulsion highway systems (in 25 mile increments) in most of the metropolitan areas over 1 million population.

Summary

The following table summarizes the recommendations of the PFR Group.

While this is a considerable amount of money, in comparison with the $68 billion annually currently spent on highways, it is a very small percent. But the benefits to safety, congestion mitigation, and productivity clearly justify the investment.

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RECOMMENDED IVHS INVESTMENT LEVELS (IN MILLIONS, USING CONSTANT 1990 DOLLARS)

Elements	1991-1995	1996-2000	2001-2010	Total
R&D	$ 627	$ 523	$ 245	$ 1,395*
Field Tests	504	1,290	1,325	3,119*
Deployment	3,105	10,880	15,950	29,935**
Total	$4,236	$12,693	$17,520	$34,449

*Includes both public and private funding.
**Add 15% annually for operations and maintenance.

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Organizing for IVHS

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This group split time at the Workshop with the Benefits Group which spent their time in refining the Benefits Document which was distributed prior to the Workshop. The revised Benefits Document is found in the appendix to this document. Thanks go to Joe Sussman, leader of the Benefits group and to Don Ome, who served as recorder and to all on the Benefits group for preparing an excellent document as a part of this report.

A consensus supports immediate steps to organize a cooperative IVHS national effort that includes the federal government, state and local agencies, universities and private industry. A national organizational structure could be designated to provide the coordination necessary to address the institutional issues of IVHS. This first step needs to be taken promptly to push forward the development, implementation and. operation of a national IVHS system.

Purpose and Functions of au Organizational Structure

This organization could: provide a national focal point for discussion and coordination of national IVHS goals and the establishment of a strategic plan to achieve these goals; help to identify and recommend national standards, specifications, and protocols; identify opportunities and partners for joint ventures; discuss policies on international cooperation; conduct pilot research; maintain data and information bases; organize information transfer activities; and issue periodic progress reports.

The organization could make major policy and legislative recommendation on IVHS to the Secretary of Transportation, the President, Congress, and the states. It could by its make-up be in a position to strongly influence the amount and allocation of funding available for IVHS.

This organization would not have authority to mandate particular research projects or the enactment of standards. Each of the parties participating in the program would retain the authority and budget for their particular IVHS-related programs.

Institutional Issues That Could be Addressed Through A National Organization Structure

Starting from a tabulation of institutional issues identified in the five Mobility 2000 working group reports, the workshop identified the following broad categories of the IVHS Institutional Needs:

1 Identify and propose solutions to institutional issues.

a) coordination of public/private research support;

b) anti-trust issues;

c) Issues of liability at specific test sites;

d) state/local jurisdictional conflicts.

2. Legitimize a voice which can speak to national, state, legislative and/or regulatory agencies and others on IVHS issues.
3. Provide a continuing point of contact between government, industry and research communities.
4. Provide a framework within which standards can be developed for interface, upward compatibility, public/driver communication.
5. Provide a mechanism for international cooperation and compatibility.
6. Provide for common compatible database.
7. Provide for third-party evaluations of WI-IS projects.
8. Assure flow of reliable information to the public.
9. Consider long range manpower, educational impacts.

10. Consider public policy issues of privacy, access to public facilities, special need segments of society.
11. Provide for a continuing exchange of information within the research community.

Support for National Cooperative Effort

While many separate domestic programs dealing with IVHS exist, no central organizational structure is coordinating the separate elements or directing IVHS research and activities. For IVHS to be successful in the long term, there needs to be more formal coordination among the activities underway, those planned and those not yet thought of.

Support for a national cooperative IVHS effort has been expressed to the U. S. DOT, by private companies, state and local governments, universities, individual researchers, as well as industry and highway user groups. This support has been echoed in the reports prepared by the Mobility 2000 working groups, including a call for a national organizational structure to oversee and coordinate public/private partnerships.

One of the six key themes of Secretary Skinner's National Transportation Policy is to advance U. S. transportation technology into the 21st century. Speaking to this theme, the policy states: "We need a more active partnership for innovation and commitment by all parts of the transportation industry and the academic community, alongside the federal, state and local governments. "

Finally, the U. S. DOT's March 1990 "Report to Congress on IVHS" recommends: "A national cooperative effort to foster the development, demonstration and use of IVHS technologies. We further propose that this effort be formulated and coordinated jointly by industry and government.. . Such a national cooperative effort would not be primarily a federal program, but would instead be a true cooperative partnership. "

A Coordinated but Flexible Approach

Efforts should be made to fully coordinate the ATMS, ATIS, AVCS and CVO elements. At the same time, it must be realized that there will be some differences in timetables, players, funding and other aspects of these elements. Any national organizational structure must be flexible enough to accommodate changes in assumptions, predictions and expectations.

For example, assumptions about system architecture carry implicit decisions about the appropriate division of responsibility between the public and private sectors. Will portions of the system be commercially driven with subscribers paying fees to companies that have been licensed or franchised to provide IVHS service? Or will this system be driven by government agencies providing the research, testing, deployment and operation of the roadway communications and processing infrastructure? Or will the system be a combination of both approaches?

We do not yet know the answers to these and many other basic questions. A national organizational structure should therefore not only help to develop answers to these questions, but should be able to evolve itself to provide the most efficient coordination of research, testing, deployment, operation and maintenance of IVHS.

Reliance on Existing Institutions and Ongoing Projects

It is also desirable for the cooperative effort to use existing institutions and incorporate ongoing projects as much as possible to simplify program delivery. Mobility 2000, for example, should become an integral part of any national cooperative IVHS organization as an ongoing forum which participants can use to exchange information. AASHTO and the Highway Users Federation can bring the states and many of the major private sector players into such an organizational structure. Building upon this base, the national organizational structure can evolve as developments occur and move toward fully integrated involvement of the public and private sectors.

Legal Basis for Organizational Structure

The National Cooperative Research Act of 1984 (NCRA), and the Federal Technology Transfer Act of 1986 (FlTA) will be useful in carrying out the cooperative effort. The NCRA permits companies to engage in research and development under certain conditions without fear of antitrust liability. The FITA allows companies to provide funds in exchange for the use of Federal resources. The Department of Transportation should immediately determine whether additional authority is needed, and, if so, try to obtain such authority.

The national organizational structure can be designated by the Department of Transportation as a "utilized group" – a legal entity that is to perform certain technical functions for the government. Such an organizational structure would be independent of the government and would determine its own membership and agenda, but would also have to operate many of its activities under the "sunshine" provisions that govern advisory committees.

Structure and Operation

The governing board of the national organization could be made up of 12 to 15 senior executives from private industry, state government, federal government, universities, and local government.

Working under the general direction of the governing board would be technical committees and working groups. Their functions could include other activities necessary for the development and coordination of the national IVHS program. A permanent staff could provide secretarial functions, staff support for the governing board and technical committee/working groups.

Funding support for the organization could be provided by the member groups, including the federal government. Adequate and predictable funding for the formation and operation of the organization should be secured as soon as possible.

Conclusion

This proposal will be the starting point to build a national cooperative effort for IVHS. Major players, including the U.S. DOT, AASHTO and the Highway Users Federation and others should take immediate steps to consider, revise and act on these proposals. Time is of the essence.

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The Next Steps

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A series of steps need to be taken to develop, test, implement, and operate intelligent vehicle highway systems (IVHS) on a broad enough scale to make a real difference. The partners involved in IVHS — federal government, state and local agencies, universities, and private industry — will need to organize a cooperative IVHS national effort to accomplish these steps:

DEVELOP A NATIONAL STRATEGIC PLAN

National goals for the development and implementation of IVHS should be developed as soon as possible. Concurrent with this should be the establishment of a strategic plan to achieve these goals. The goals and plan must be specific enough to give the nation direction, but flexible enough to accommodate future changes in assumptions, predictions, and expectations that will undoubtedly occur.

CREATE A NATIONAL ORGANIZATIONAL STRUCTURE

Every evaluation of IVHS technology begins and ends with the observation that no formal national organization exists to direct or coordinate IVHS activities. This is portrayed in direct contrast with activities in Europe and Japan, where specific public/private coordinating mechanisms have been established and are operating.

The fragmented nature of the numerous organizations which have been or will be involved in U.S. IVHS activities makes coordination both vital to insure and difficult to achieve. A national organizational structure needs to be created to provide the public/private coordination necessary to address institutional and technical issues of IVHS.

Such an organization could: provide a national focal point for discussion and coordination of national IVHS goals and the establishment of a strategic plan to achieve these goals; help to identify and recommend national standards, specifications, and protocols; identify opportunities and partners for joint ventures, discuss policies on international cooperation; foster pilot research; maintain data and information bases; organize information transfer activities; and issue periodic progress reports.

Work has begun to create that organizational structure for IVHS, leading to the formation and activation of a new public-private, non-profit educational association. Participants at the May 1990 National Conference on Implementing Intelligent Vehicle — Highway Systems supported efforts by the Highway Users Federation to initiate an effort leading to the incorporation of such an organization by the end of 1990. The Mobility 2000 effort would serve as the technical arm of the new organization.

It has been proposed that DOT designate such as organization as a chartered, utilized committee as authorized by the Federal Advisory Committee Act. A model exists within DOT, in the manner that the Radio Technical Commission on Aeronautics (RTCA) serves as a utilized committee for the Federal Aviation Administration. Its charter is formalized by FAA and a letter of agreement between the two organizations provides the duties and responsibilities of each.

DEVELOP AND IMPLEMENT PROGRAMS

Policy, legislation and funding programs need to be developed and implemented by the public and private sectors to undertake needed research, conduct operational testing and evaluations, deploy systems on a broad enough scale to make a real difference, and to operate and maintain systems on a continuous basis as an integral part of IVHS programs.

Federal

A coordinated federal program is needed to coordinate and facilitate IVHS research and development, assist in the planning and conduct of demonstrations and other evaluative programs coordinate the standards and protocols, and to participate in other elements directly related to the federal operating and regulatory responsibilities.

The federal portion of the IVHS program has been operated as an element of DOT's operating budget, with funds largely derived from FHWA and NHTSA research budgets. DOT has proposed a sizable increase in FHWA funds for FY 1991. (1990 = $4 million; 1991 = $13 million).

Yet, in an era of budget austerity, funds are not always predictable. Research is often vulnerable to cuts, and some highway interests have already indicated a preference to use the IVHS increases for construction projects. Yet, a long-term IVHS research and testing program needs some assurance of future program levels.

The present federal-aid highway, transit and highway safety programs are scheduled to expire in 1991. Congress will be debating a reauthorization bill this year and next, and many transportation interests propose a significantly larger federal-aid program with increased research programs and a specific IVHS component.

State and Local

State and local governments are responsible for the operations, management, and maintenance of our street and highway systems.

At the state level, early applications of IVHS technology are likely to be concentrated on major arterial roads, which will bring the various state DOT's into the picture. The federal-aid highway program has always been administered as a cooperative state-federal-local partnership. This will continue into the future, and should be an attribute of the IVHS program.

State legislatures, county commissions and city councils will need to enact comparable legislative programs to permit full IVHS activity to get underway. This might involve authorizing state matching funds, approval of specific demonstration projects, or other legislative features. State motor vehicle administrators and highway safety offices may be involved in early projects which focus on vehicle regulation.

Finally, state and local programs will need to consider provisions for implementing areawide traffic management control centers. Widespread implementation of these systems throughout the United States will be essential in order to have in place the infrastructure for existing and evolving IVHS technology.

Private Sector

The development and marketing of IVHS technologies, particularly for the vehicle, will continue to be primarily the responsibility of the private sector. Programs need to be undertaken to assure that the full innovations as well as short term product development should be encouraged through tax regulations and other means. In addition, if a publicly supported IVHS infrastructure is developed, it would be desirable for the vehicle technologies now being developed and deployed to be compatible with the public systems.

Research

There is currently no national IVHS research program that lays out the total array of research needs or relates them to each other or to the concept of IVHS as a whole.

A coordinated research program needs to be developed. In additional to additional sources of funds, a mechanism to allocate relative priorities to proposed research activities will clearly be needed. This process must involve representatives of all major public and private organizations to insure equitable treatment and avoid the appearance of favoritism.

Testing

There will be a similar need to coordinate the priority and timing of specific testing activities, particularly when field demonstrations are proposed as a test of concept or product feasibility. The results of a given project may lead to follow-on research, or could cancel an entire line of investigation. The timing of these

IVHS activities should be guided by a known schedule.

Deployment

The level of deployment of IVHS will be determined not by regulations imposed from the top down, but rather by market need. Research and testing of IVHS will determine the cost-effectiveness of the various IVHS elements. This information will be necessary for public and private sector decision makers and the general public to determine what portion of their available resources they will be willing to apply to deployment and use of the systems.

Operations and Maintenance

Programs will need to be committed to in the project planning stages to provide for adequate funding and staff resources to operate and maintain these systems once they are in place. The conventional practice of waiting to address operation and maintenance considerations until after the project is implemented will not suffice for M-IS.

Experience has already shown that the visibility of the various elements of advanced highway technologies will cause any failure in their operation and maintenance to be immediately apparent to the user. Public support for these systems will evaporate quickly unless these needs are provided for from the very beginning.

The concept of government agencies contracting with private firms to provide operations staff and to maintain hardware and software components will need to be explored. Consideration will also have to be given to allowing state and local governments, at their discretion, to use a portion of their federal-aid allocation for funding IVHS operations and maintenance costs. Finally, hardware and software that will perform reliably in real world applications will need to be developed.

ADDRESS PUBLIC/PRIVATE INSTITUTIONAL ISSUES

The success of IVHS in helping to address the nation's highway mobility and safety problems will in large part be determined by the ability of the public and private sectors to cooperate and coordinate their efforts in addressing a number of institutional issues. In addition to providing for funding for IVHS, the Congress and state/local legislatures should address these issues :

Merging of Public/Private Research Support

Research in IVHS should include provisions for combining efforts and fiscal resources from federal, other public, and numerous private and corporate budgets. The coordinating process will need to provide a schedule for requesting, justifying, budgeting, and administering these mixed-source programs.

IVHS research would be enhanced if government contract processing procedures are made less cumbersome and inefficient, particularly as practiced within Departments of Transportation. Specific procedures to marry the talents of the pubic and private sector in carrying out IVHS research should be considered, much as has been done with other recent initiatives. Alternative contracting procedures should be considered.

Creating Opportunities and Partners for Joint Ventures

American competitiveness in the development and delivery of IVHS technologies will be enhanced by the pooling of knowledge and expertise of key players. Opportunities for partnerships and joint ventures in the U.S. can be created if antitrust laws and regulations are flexible enough to allow for joint development work up to the point where private firms decide upon the appropriate technology. These firms would then be free to design new products in competition with each other.

Opportunities for joint ventures will also be enhanced if a technology transfer protocol is developed to protect private sector proprietary technology, but at the same time allow all participants to learn from the work of each other and avoid reinventing the wheel. Patent rights would have to be worked out for these technology development partnerships.

Solving Antitrust, Insurance, and Liability ISSUES

An effort is needed to investigate and recommend ways by which the potential impact of automotive accident litigation, insurance, and liability issues can be minimized in the future. The findings of such an investigation, together with recommendations, should be reported to Congress and other appropriate bodies as soon as possible.

IVHS is expected to greatly decrease accidents overall, but it is inevitable that some accidents will be associated with system performance. Ways are needed to limit the liability risk of IVHS developers in both the public and private sector. Options might include stronger consideration of overall system benefits, narrower definitions of negligence, limitation of awards, limitations of joint liability, and better training of juries. Federally subsidized liability insurance and/or federal development of standards are other approaches to reducing liability risk.

Collaboration among IVHS innovators, suppliers, and users will be particularly important. As stated above, however, antitrust laws and regulations must be flexible enough so as not to restrain innovation by inhibiting collaboration among competitors. These provisions need to be re-examined to assure needed cooperation among IVHS developers and between government and the private sector.

Alleviating State/Local Jurisdiction Conflicts

Efforts are needed to determine how to facilitate coordination across jurisdictional boundaries. Traffic problems do not stop at jurisdictional boundaries, and neither should the available solutions.

Regional traffic management systems will need to be explored. Related to this will be consideration as to whether an area's traffic operational functions could be undertaken by private firms.

Protecting Personal and Organizational Privacy

Government agencies, vehicle and equipment manufacturers, and carrier managers will need to demonstrate sensitivity and provide appropriate safeguards to protect personal and organizational privacy.

Deployment of these technologies could provide almost constant information on a vehicle and accordingly closer surveillance of individual drivers. This fact by itself could present a substantial obstacle to system evolution and deployment. Consideration of desires for privacy must be an integral consideration in system development.

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Advanced Traffic Management Systems

1.0 BACKGROUND

Traffic congestion is one of the most important problems identified by citizens in the U.S. In the last three years, the problem has become so well recognized that magazines such as Time [l] and U.S. News and World Report [2] have run cover stories on the transportation crisis. From Phoenix to San Francisco to Washington, D.C., citizens are identifying transportation as their number one concern [3], and saying that it outweighs issues such as pollution, overpopulation, unemployment, and crime. Traffic congestion is certainly the primary reason for their concern about transportation issues.

Several factors have led to the increase in traffic congestion. From 1950 to 1986, the population in the United States grew by about 60 percent. The majority of the growth occurred in urban areas and the formerly undeveloped rural areas surrounding those major urban centers. This pattern of population increase would be expected to increase the demand for transportation. As evidence of this increased demand, over the same time period, the number of motor vehicles increased even faster than population, by almost 2.57 percent [2]. In addition, Americans placed even more reliance on their automobile as their primary transportation mode. From 1960 to 1980, transit's share of work trips in urban areas dropped from about 13 percent to about 6 percent. In the same time period, work trips by the automobile jumped from 61 percent to 82 percent [4].

The increased reliance on the automobile and the growth in population, jobs, and households, have combined to create severe and alarming levels of congestion. In 1987, there were over 2 billion vehicle-hours of delay on urban freeways in the United States, a 60 percent increase over 1984. If urban freeway travel grows at 2.1% per year, there will be 11 billion vehicle-hours of delay in 2005, a 450% increase [5]. Earlier projections also indicated that from 1985 to 2005 delay on urban signalized arterials would increase 240 percent to almost 500 million vehicle-hours of delay in 2005 (a 6.3 percent increase per year) [6]. The times when demand is exceeding the capacity of the roadway system are rapidly increasing in many urban areas, both large and small. Additional demand during these times causes delay to increase exponentially, resulting in the steep delay projections above.

Three strategies are available for accommodating the increased growth in travel demand while minimizing traffic congestion. The first is to construct more roadways. The second is to manage the growth in travel demand by implementing policies that provide incentives for reducing the number of vehicles that are on the roadways during congested hours. This strategy is referred to as transportation demand management. The third is to increase the efficiency of our existing system by implementing operational improvements. These strategies are not mutually exclusive.

A balanced approach combining elements of all three strategies is the only realistic way to preserve future mobility. The implementation of advanced traffic management systems (ATMS) will affect decisions made regarding all three. First, any new facilities constructed should have advanced traffic management systems designed and built in as integral elements, thus assuring more efficient operation. Second, advanced traffic management systems can be used to enhance the effectiveness of strategies used to manage the demand on our systems, for example, by providing real-time information on travel time savings by users of high occupancy vehicle lanes. Finally, advanced traffic management systems will encompass all strategic aspects of traffic management and control and will, therefore, provide the tool for implementing many different kinds of operational improvements.

This paper is one of a series designed to bring the concept of intelligent vehicle-highway systems (IVHS) to the attention of decision-makers across the country, to convince the decision-makers of the need to establish a strong national program for developing IVHS, and to recommend the direction that such a program should take. This paper discusses the advanced traffic management system (ATMS) element of IVHS. Other papers discuss advanced driver information systems, automated vehicle control systems, commercial vehicle applications, and benefits and costs of an IVHS program.

This paper will discuss the goals of advanced traffic management systems, the state of the art in traffic management systems, and the need for advancing that state of the art in order to implement IVHS. The characteristics of an advanced traffic management system will be presented, followed by the interface between advanced traffic management systems and other IVHS components, the general benefits that can be expected, and a description of a proposed ATMS program. The remainder of the paper will detail the four parts of the proposed ATMS program: research and development, operational testing, systems planning and deployment.

2.0 GOALS OF AN ATMS PROGRAM

The goals of an ATMS program are the same as the goals for IVHS in general: to improve the efficiency of our transportation system thereby reducing the wasted time caused by congestion, enhancing the safety of the users of the system, and improving the timeliness of goods deliveries, and to continue to preserve our nation's unprecedented mobility and enhance its economic growth and international competitiveness, while at the same time protecting air quality and minimizing fuel consumption.

There are two primary objectives of an ATMS program. First is to apply new technology and control strategies and implement state-of-the-art traffic management systems in areas across the United States. Second is to continue to advance the state-of-the-art by researching, developing, testing, and evaluating advanced traffic management and control strategies and technological enhancements.

These two objectives work in concert with the objectives of the other IVHS components to meet the goals stated above. By implementing state-of-the-art traffic management systems, citizens can begin to realize the goals of improved efficiency, enhanced safety, air quality preservation, and efficient fuel consumption. By continuing to advance the state-of-the-art, not only will increased progress be made toward these first four goals, but the advance in technology will enhance this country's economic growth in technological fields by opening up markets domestically and by increasing our ability to compete in the world market.

3.0 TMS STATE-OF-THE-ART

A traffic management system provides the tool to increase the operating efficiency of and manage demand on a transportation network. A traffic management system (TMS) is an array of institutional, human, hardware, and software components designed to monitor, control, and manage traffic on streets and highways. There is a need to advance the state-of-the-art of traffic management systems to apply new technology and control strategies to better manage traffic congestion and maximize the usefulness of the IVHS concept. The use of the term advanced traffic management systems (ATMS) refers to systems where these advances in the state-of-the-art have been included.

Before ***advanced*** traffic management systems will be widely implemented though, we must use raise the level of awareness of the benefits of traffic management systems, and provide the resources and people needed to properly design, build, operate and maintain them. Currently, only around 6 percent of the almost 19,000 miles of urban freeways in the U.S. are actually covered by an operating system. Almost half of this mileage is in the Los Angeles area alone. While at least 25 of the 37 metropolitan areas with populations over one million have, or propose to have, some form of freeway TMS, only 4 out of the 37 metropolitan areas with populations between 500,000 and one million were known to have or propose to have one [7]. Nearly all of the larger urban areas have arterial traffic signal control systems, but the extent of system coverage varies widely. Most arterial systems in place today **do not** respond well to non-recurring congestion nor do they control from a network perspective, control is generally provided to move traffic along an arterial in a single direction. No area currently has a comprehensive areawide system that covers all of the freeways and arterial streets. Existing freeway and arterial street control systems do not optimize traffic flow on a corridor or areawide basis. Many of the systems that are in place are old, they do not reflect the current state-of-the-art and they are not operating or being maintained effectively. Clearly the state-of-practice in most urban areas lags far behind the state-of-the-art.

A great deal of emphasis is being placed on improving the state-of-the-art around the world. In Europe, traffic signal control strategies are in place that respond in real-time to network traffic conditions to optimize traffic flows. In addition, the European Community is sponsoring a major research and development program, called DRIVE, that is being jointly funded by European government and industry at a level of almost $150 million, and involves almost 12,000 person-months of effort [8].

In Japan, two major programs deserve note – AMTICS and RACS. Both combine advanced traffic management system elements and advanced driver information systems to provide real-time route guidance to motorists. Both systems have already been tested extensively, the major obstacle to wide-scale implementation of one of these systems is a political decision on which one to implement [9].

In the U.S., several programs are also already underway to advance the state-of-the art. The Smart Corridor project in Los Angeles involves integrated control of freeways and arterial signals, incident management on both freeways and arterials, and provision of real-time information to motorists through various means, including in-vehicle devices [10]. This latter aspect is being demonstrated through the Pathfinder project [ll]. The State of California has also embarked on a substantial program to develop IVHS systems called PATH, one element of which includes traffic management and driver information projects [12]. Many of the policy recommendations being made in regard to new highway legislation contain advice to substantially increase Federal research funding in this area. Two of the High Priority National Program Areas designated by the Federal Highway Administration are advanced traffic management systems and advanced driver information systems [13]. However, the funding required to develop a nationwide program that will compete with the advances being made in Europe and Japan is not yet in place.

4.0 CHARACTERISTICS OF ATMS

Advanced traffic management systems have six primary characteristics that differentiate them from the typical traffic management systems of today. First, an ATMS works in real time. They are responsive to traffic flow. Data transferred to a control center must be current so that an effective strategy can be devised and implemented quickly.

An ATMS responds to changes in traffic flow. The algorithms used to develop traffic management strategies recognize the changes in traffic flow patterns and, in fact, are one step ahead, predicting where congestion will occur. At present, control system actions take place after the system has already become congested. Advanced traffic management systems will estimate when and where congestion will take place, and take steps to prevent it from occurring. By informing drivers in advance of alternate routes, time advantages of alternate modes, advising them to delay trips, and by modifying control system strategies, congestion will be reduced. By doing this, many incidents will also be avoided.

An ATMS includes areawide surveillance and detection systems. Areawide surveillance and detection are crucial so that strategies can be devised which are truly optimal from an overall system perspective. The data collected by these systems, particularly origin-destination information, will also be very valuable for transportation planning purposes.

An ATMS integrates control of various facilities. Advanced systems will include the joint management of both freeways and arterials, and demand management considerations, thus providing for a much more efficiently operating transportation system.

An ATMS implies collaborative actions. Jurisdictional problems must be overcome so that the component control systems of adjacent jurisdictions can be managed such that the user perceives a seamless transportation system.

Finally, an ATMS includes rapid response incident management strategies. Incident management is crucial and includes rapid detection and verification, and appropriate response plans. The response plan must integrate incident site tactics (vehicle clearance, site clean-up, and required traffic control) and diversion strategies (routes involved, various forms of real-time motorist information and traffic control adaptation during diversion).

5.0 INTERFACE WlTH OTHER IVHS COMPONENTS

Other components of intelligent vehicle-highway systems will provide better information to an advanced traffic management system so it can do the following:

- better manage normal traffic flow,
- better cope with incidents, and
- interact with the intelligent vehicles that will be part of the advanced driver information systems.

To maximize its usefulness, the IVHS concept requires advanced traffic management systems that interface with all the other IVHS elements. Advanced traffic management systems are the umbrella under which the other IVHS elements will operate. ATMS provide the communication link between the system infrastructure and the vehicles. As advanced driver information system (ADIS) concepts of IVHS are implemented, traffic management systems will respond to the information gathered regarding location and destination. This information will provide a unique opportunity to optimize control strategies to serve predicted rather than historical demand. This will improve the system's ability to manage normal traffic flow and to cope with incidents.

Not only will advanced traffic management systems be able to collect data from vehicles, they will be able to provide systemwide traffic conditions to the drivers. An intelligent vehicle-highway system will communicate directly with equipped vehicles (intelligent vehicles), advise the drivers of impending traffic problems, and provide a variety of other kinds of information to provide safer and less stressful driving.

The same kinds of benefits that accrue to general purpose traffic will be even greater for commercial vehicles. The ATMS element of IVHS interfaces with the commercial vehicle operations (CVO) element in much the same way that it does with the ADIS element. In addition to the driver information and route guidance applications, there are a great many other potential benefits. Weigh-in-motion and automated permit processes will greatly benefit commercial fleet operations. These are already being investigated in the Heavy Vehicle Electronic License Plate (HELP) project [14]. In addition, automated toll collection will reduce delay time to commercial vehicles and automatic vehicle identification (AVI) will help fleet operators better manage their dispatching and reduce the risk of theft. All of these applications could potentially take advantage of the real-time communications capability and database system offered by advanced traffic management systems.

Finally, advanced vehicle control systems (AVCS) will also interface with ATMS. Although many of the vehicle control system elements can be implemented autonomously, the maximum benefits will come from a fully automated highway system that works with an advanced traffic management system to direct the vehicles through the network.

6.0 BENEFITS OF AN ATMS

Some idea of the potential of advanced traffic management systems is possible from information in the technical literature. The information presented below is somewhat inconsistent as to the degree of improvement, but what is important is the fact that all of the studies consistently report benefits.

Starting with the basics, some well-known work by Wagner [15] reported typical reductions in travel time of approximately 10-15%, and accompanying fuel savings on the order of 5 %, from installing computerized traffic signal control systems. Perhaps the most advanced signal control system in the U.S. is the ATSAC system in Los Angeles, CA. Reported benefits for that system [16] are:

- 13.2 % reductions in travel time
- 12.5% reductions in fuel consumption
- 10.2% reductions in hydrocarbon emissions
- 10.3 % reductions in carbon monoxide emissions

The degree of improvement depends on what kind of system exists in the before case. Many of the benefits can be attributed to the implementation of new timing plans as part of system installations. To the extent these can be maintained optimally, perhaps in a traffic responsive or traffic adaptive control system, the stream of benefits will presumably continue to accrue. One such system is the British SCOOT system. Tests in England showed further travel time savings on the order of 5% due to the systems' ability to adapt to changing traffic conditions [17]

Many evaluations of freeway ramp metering systems have been performed. Some of the reported benefits include [18}.

- Minneapolis and St. Paul, Minnesota – After 10 years of operation, evaluations show that average peak period freeway speeds increased from 34 to 46 MPH (35%), while peak period volume increased 32 % . In addition, the average number of peak period accidents declined 27 %, and the peak period accident rate declined 38 % .
- Seattle, Washington – Between 1981 and 1987, travel time on a specific 6.9 mile stretch of I-5 was reduced from 22 minutes to 11.5 minutes due to the implementation of ramp metenng.

This occurred while the peak period mainline freeway volumes increased 86 % northbound and 62% southbound. Over the same 6-year time period, the accident rate decreased by 39 % .

- Long Island, New York – An analysis showed that after two months of operation in the PM peak, mainline travel times were reduced from 26 minutes to 21 minutes (20%), and motorists entering at metered ramps also experienced an average travel time reduction of 13 %. The analysis also showed a 6.7% reduction in fuel consumption, 17.4% reduction in carbon monoxide emissions, a 13.1% reduction in hydrocarbons.

Perhaps the area where the largest benefits can be obtained is the area of traffic management during incidents. It has been estimated that an accident blocking one of three freeway lanes reduces capacity by 50 % . A 20 minute blockage would cause 2100 vehicle-hours of delay and a queue almost 2 miles long, and it would take 2 1/2 hours to return to normal assuming there were no secondary accidents or incidents [19]. Roper [20] estimates that during off-peak hours, each additional minute taken to clear an incident extends the duration of congestion by four or five minutes. In peak periods, this factor often soars to fifty to one, or more. Teal [21] found that the average incident on the freeways in Los Angeles County produced 999 vehicle-hours of delay, but that the standard deviation was very high because 23 % of the incidents were long-term and accounted for 74 % of the total delay (an average of 3,225 vehicle-hours), while the average delay for the remaining 77% was 342 vehicle-hours. Safety is also affected, a Minnesota DOT study found that 13% of all peak period accidents on one Minneapolis freeway were secondary, i.e., they were caused by a previous incident [22]. In 1987, it has been estimated that urban freeway congestion is responsible for almost 2 billion vehicle-hours of delay, 2 billion gallons of wasted fuel and almost $16 billion in user costs. Almost two-thirds of this waste was attributed to non-recurring incidents [5].

The problem significantly affects truck operations. Assuming trucks represent 5% of the traffic stream, and the cost to operate a truck is $23 per hour [23], the portion of the cost of the above delay that can be assigned to truck operating costs is $2.3 billion. And this does ***not*** include the costs being added to the price of goods caught in this congestion, nor does it include the costs to those industries relying on just-in-time deliveries.

Freeway surveillance and control and incident management systems on these urban freeway miles would, it is predicted, have reduced that total delay by 35%, or by 700 million vehicle-hours. Demand management strategies were predicted to be equally effective, removing one of every 10 single occupant vehicles would have reduced the total delay by 48% P21]. Considering demand management in the broadest sense of the term, there is evidence that demand reductions on the order of 40% - 50% were experienced in Chicago during the reconstruction of the Dan Ryan Expressway [24]. There is uncertainty about what happened to this demand (i.e, did people not make trips, use different routes or different times?), but the important point is that it occurred because of accurate, timely information bemg provided to the public in a number of different ways.

Advanced traffic management systems of the kind described in this report are only now starting to be implemented in the U.S. The FHWA is sponsoring a before-after evaluation of the INFORM system on Long Island [25], but the results are not available yet. As part of the planning for the Smart Corridor system, the following projections of benefits have been made [9]:

- 11% – 15 % reduction in total travel time in the corridor
- 2–3% reduction in fuel consumption in the corridor
- 8% reduction in hydrocarbon emissions in the corridor
- 15 % reduction in carbon monoxide emissions in the corridor
- Annual savings due to reduced travel time and fuel consumption of approximately $24 – $32 million

Finally, a number of academic studies have been done recently that have looked at the potential benefits of real-time motorist information systems in reducing congestion. Some of these results are summarized below:

- As part of the RACS project in Tokyo, Japan, Tsuji showed that travel time savings of between 9 and 14% could be realized in urban conditions [26].
- As part of the Autoguide project in London, Smith and Russam concluded that drivers who have their cars equipped with real-time route guidance systems could realize travel time savings of around 6%. Interestingly, unguided vehicles could also realize travel time savings of around 2 or 3 % [27].
- Jones, Mahmassani, et. al. found that travel times may be reduced by 15 % to 30 % through route change and 10% to 22% through departure time switching in a study of a corridor in Austin, Texas [30].
- Rakha, van Aerde, et. al. concluded that the availability of route guidance to motorists in a congested hypothetical network could reduce the total travel time to all motorists by around 20 % , assuming 20% of the drivers had such systems. There were little additional benefits for larger market penetration percentages, except in cases of long duration incidents. Real-time traffic signal control was also found to further reduce delay [29].

It is fair to say that the above results are situation dependent. These studies were all done in a specific location with differences in the availability of alternate routes and the level of congestion on these routes. The analysis tools used may also be considered preliminary, better results may be obtained in the future as the tools are refined based on actual experience.

What are the potential nationwide benefits? That's a question that deserves more thoughtful analysis, but cost effectiveness can be hypothetically illustrated. Lindley [5] found that there were 2.0 billion hours of vehicle delay on urban freeways in the year 1987, almost 1.3 billion of which was due to non-recurring incidents. Assuming that an advanced traffic management system could reduce the delay due to incidents by 35 % , and the 700 million hours of delay due to recurring congestion could be reduced by gives delay savings of 525 million vehicle-hours annually. Further assuming an average occupancy rate of 1.3 persons per vehicle and an average value of time of $6.85 per person, yields a time cost savings of $4.7 billion annually. This represents only the potential value of time saved on urban freeways in 1987. It does not include:

- Any savings on arterials
- Any projection of what future delays and time savings might be
- Any measure of vehicle operating cost savings (including fuel savings)
- Any measure of savings due to fewer accidents
- Any measure of savings due to reduced emissions
- Any measure of economic benefits, for example, savings because goods are delivered more efficiently, because just-in-time deliveries are delivered just-in-time, and savings because of a less frazzled and more productive work force.

In Section 11 of this report, the total cost to deploy advanced traffic management systems in urban areas over 100,000 population in the U.S. is estimated to be approximately $18 billion (current dollars), with an annual operation and maintenance cost of upwards of $2.5 billion (current dollars). Considering the $4.7 billion potential annual time savings on urban freeways estimated for 1987, and considering the value of the other kinds of benefits described above, one can easily see the cost effectiveness of implementing advanced traffic management systems across the U.S.

In summary, advanced traffic management systems are certainly beneficial, but wild expectations should be tempered. Advanced traffic management systems will not solve the congestion problem. Most, if not all, of the studies above assumed a static demand situation, i.e., benefits were estimated assuming current demand levels. But demands are projected to grow rapidly over the next 10 years. Perhaps the best way to conceive the benefits of ATMS is in their ability to increase throughput in a corridor or facilitate traffic flow on an areawide basis. While the roads will still be congested, spreading the demand over time, modes and routes and instituting integrated optimal control should improve mobility and facilitate economic and social activities. This will be especially true when incidents occur, perhaps the largest benefit of ATMS lies in their ability to help people avoid the major delays associated with long-term incidents. In these cases, substantial direct user cost savings can he expected.

7.0 DESCRIPTION OF THE PROPOSED ATMS PROGRAM

The ATMS program would include:

1. Research and development activities on advanced traffic management technologies and strategies, such as improved methods of detection and control strategies that adapt traffic controls to changing traffic conditions in real time. The research and development portion of this program would be designed to produce traffic control strategies that would take advantage of the ability of advanced electronic technology to provide accurate, real time information on traffic conditions. It would consist of elements of basic and fundamental research and development of software and new traffic control hardware.

2. Establishment of test sites in several areas around the United States to facilitate field tests and evaluations of research and development results. Traffic management systems in several areas across the United States would be used as test sites to evaluate research and development products. The evaluations would provide transportation officials with reliable information upon which informed decisions could be made about public investment to deploy these systems and strategies

3. Provision of Federal funds for planning the implementation of state-of-the-art advanced traffic management systems across the U.S., thereby creating the market for the advanced technologies and strategies to be developed.

4. Deployment of areawide, state-of-the-art traffic management systems. These systems would provide the basic infrastructure for, and thereby facilitate deployment of, the other advanced technology systems contained in the IVHS program. Funding for this part of the program is not included as part of the IVHS program, but it is crucial that reliable sources and innovative funding mechanisms be found.

8.0 RESEARCH AND DEVELOPMENT PROGRAM

A $150 million public research and development program is proposed. This includes a Federal program, as well as State programs (HP&R, NCHRP and others) that could be expected to sponsor ATMS R&D. It does not include potential contributions from the private sector. The program can be divided into three broad areas: monitoring traffic conditions, communications, and controlling and managing traffic. The issues to be addressed in these three areas are generally described below. Further illustrations of the expected products are given in the milestones section at the end of this report. Many of these R&D issues are also described in reports prepared as part of a technology assessment being done under the National Cooperative Highway Research Program [30].

8.1 MONITORING TRAFFIC CONDITIONS

The prime objective of the research and development program in this area would be to develop detection methods that will be more reliable and accurate, and that will provide more traffic information than current detection technology.

The successful deployment of ATMS and other IVHS systems depends on being able to obtain reliable and accurate data on traffic conditions on the freeways and arterial streets in real-time. Loop detectors continue to be the predominant form of surveillance technology used today and will be for the immediate future. It is imperative that the technology be improved to provide the quality and quantity of data that will be required to develop, operate and evaluate advanced traffic management strategies. A major part of the research and development program should be directed to developing new types of sensors. One or more of these sensors may become the primary source of information for ATMS, reducing or eliminating the need for inductive loops. These sensors include sonic, infrared or laser detection systems and wide-area detection systems using radar or infrared or video image processing.

Another major issue is to study the use of vehicles equipped with an in-vehicle device and two-way communications capability as a probe or supplement to other types of sensors. This issue must be thoroughly addressed as it has major implications on the cost of installing and maintaining advanced traffic management systems.

Information on traffic and roadway conditions will come from multiple sources, including the monitoring systems, but also potentially from police reports, scheduled maintenance or construction activities, fleet managers and radio traffic reporters. All of this information would be processed and stored in a database that would be available, on a real-time basis, for several applications: traffic control, motorist information and in-vehicle route guidance. Methods must be developed for managing this data to ensure that the information that will be provided is reliable, accurate and consistent. Artificial intelligence or expert systems techniques hold promise here.

There is also a need to have historical information relating the effects on capacity and operational characteristics of freeways and arterials of bad weather conditions, roadway construction and incidents. Research should be conducted to defme these needs and to develop a uniform data collection format to guarantee consistency of data. The results of this research would be used in advanced driver information and diversion strategies. The database could also provide information for system performance evaluations and the development of artificial intelligence and expert systems traffic management applications.

8.2 COMMUNICATIONS

The primary research and development issue in this area is the need for areawide, two-way communication of traffic and location information between vehicles and control centers in real-time. Currently, communication is primarily one-way, traffic information is transmitted from a surveillance system to a control center. A number of different communications technologies have been proposed for two-way areawide communications, these include radio data communications, cellular telephone, and roadside beacons use in conjunction with infrared or microwave transmissions or low-powered radio signals. The information needs of drivers, commercial vehicle operators and fleet managers must be identified and the ability of the different technologies to handle the load that would be imposed upon the communications system determined. The different technologies must then be assessed in terms of their performance, cost implications and other issues (e.g., availability of radio frequencies, ability to receive sideband transmissions). This issue is also, of course, a very key issue in the advanced driver information systems area.

Standards for communications interfaces must be established early. Early development of these standards, and standards for other things such as display methods, would not hinder technology development, but would greatly increase the efficiency of everyone's efforts. The impetus for developing standards must come from industry, and must be done in a willing and cooperative manner, with government and other organizations playing a guiding and facilitating role.

8.3 CONTROLLING AND MANAGING TRAFFIC

The major goal of ATMS is to apply the information collected through the monitoring processes to optimize corridor or areawide traffic operations. To do this, new traffic models and traffic control and management strategies must be developed to take advantage of the real-time information that will be available. The most complex and key research and development issues are in this area. Successful deployment of ATMS greatly depends on the success of this part of the research and development program. The general objectives of the research and development program in this area would be to:

1. Gain a better understanding of driver behavior issues (e.g., willingness to divert) and travel information needs, including those of commercial vehicle operators and potential transit users, and considering pre-trip versus in-vehicle differences. Insight is needed in how people make decisions about whether and when to travel, and what routes and modes to take.
2. Develop dynamic traffic assignment, real-time simulation and corridor or areawide optimization models that can be applied to anticipate where congestion will occur and evaluate the effects that various control and management strategies will have on travel patterns and traffic operations. New theories of traffic flow should be investigated.
3. Develop applications of advanced software techniques, such as artificial intelligence and

expert systems, for use by traffic management operators to, for example, interface with the traffic models, rapidly detect incidents and recommend the best control and management strategies.

4. Develop demand management strategies for use by advanced traffic management systems that could be implemented when congestion is predicted to be especially severe, or perhaps during times when air quality standards are predicted to be exceeded.

5. Develop corridor or areawide traffic control and management strategies that provide accurate and reliable information on traffic conditions to the public, commercial vehicle operators and fleet managers in real-time, rapidly detect and respond to incidents, efficiently manage saturated flow and control traffic in an integrated, real-time fashion.

6. Develop an interactive traffic control system that, using real-time origin-destination data obtained from vehicles equipped with an in-vehicle device and two-way communications capability (automatic vehicle identification or location), predicts where and when congestion will occur, and integrates the traffic control and management strategies developed above to provide accurate information on predicted traffic conditions .and the best routes and modes to take, and provides optimum, integrated control of traffic.

8.4 OTHER ISSUES

Other research issues that do not fit nicely in the above scheme but are no less important, include:

1. Development of a uniform methodology for conducting before and after evaluations of new traffic control strategies, so that there is consistency in the data being collected and how it is being collected, to ensure meaningful comparisons among different studies. The results of these studies would be used to make decisions about major investments of public and private funds.

2. Studies of the institutional issues that pose hurdles to the successful implementation of ATMS and other IVHS systems. Perhaps the most important issue here is the problem caused by multiple political jurisdictions. It will be impossible to operate a truly integrated traffic control system if agencies from different political jurisdictions are not willing to compromise on control decisions, for example, to increase traffic flow on an arterial when there is an incident on a freeway. Different techniques could be tried, traffic management teams operating in a single control center, franchising operation of the system, or a system operating authority.

8.5 PROGRAM EXECUTION ISSUES

The execution of the ATMS research and development program should proceed on several fronts: First, the research and development program described above should be coordinated with other public and private research programs, for example, the PATH program in California, the FAME program in Washington [31], and research programs in Michigan, Minnesota, Texas and other States, as well as research sponsored by domestic industrial partners. Coordination should also be maintained with intemational research programs, especially in Canada, and also the European Community's DRIVE program and Japanese programs. Obviously, the program is very much dependent on the results of research and development in the advanced driver information systems area, too.

Second, RFP and contract award processes should be streamlined. RFP's should be less prescriptive and more flexibility provided in contracts to pursue promising avenues of research.

Third, a university research program should be established to encourage innovative ideas and to entice students to do graduate work in this area. This program could supplement the Advanced Institutes now being established by the FHWA. The program could also serve to provide potential staff support for operational tests. Under this program, contracts would be awarded on the basis of a "best idea" competition, using criteria such as technical merit, technology advancement potential and application potential. Work statements would be problem and approach oriented rather than product specific, and would be oriented towards basic or fundamental research.

Fourth, public, private, and academic partnerships must be encouraged and facilitated. The government should sponsor basic, fundamental and long-term research, and should focus on technology applications (e.g., software, system integration). Private development of new technological applications, especially new traffic control hardware, could be accomplished as part of the operational testing program. One idea is for government agencies to provide research and development contracts to one or more industrial and academic partnerships and then license the resulting products. The legal ramifications of public, private, and academic agreements must be studied and well understood by all parties.

Fifth, laboratory and operational facilities for conducting research and testing equipment and software must be available to public and private firms engaged in the development of ATMS technology.

9.0 OPERATIONAL TESTING PROGRAM

A $450 million lo-year operational testing program is proposed. This again represents the Federal government's share, as well as contributions to be made by State and local governments. It does not include a private sector contribution, although significant private sector participation could be expected to test new hardware technology and software systems that private firms would expect to sell and profit from in the future.

The program would be designed to facilitate .development of new applied technology by public, private, and academic partnerships, ensure the reliability of new research and development products in "real-world" environments, and to provide data to promote and emphasize implementation of advanced traffic management systems.

A minimum of ten operational test sites would be established to facilitate testing of new ATMS monitoring systems, communications technologies and control and management strategies. To qualify as a test site, a metropolitan area would have to have a state-of-the-art traffic control system. The area would have to demonstrate their interest and commitment to install, operate and support more advanced systems in the future, by approving an agreement to let their systems serve as a site for operational evaluations of completed research and development products. Other factors to be considered in selecting test sites include geographical location (it wouid be desirable to have sites located across the country) and the potential and interest in implementing other IVHS technologies (e.g., HOV facilities and toll facilities might be ideal for testing some automated control systems in the future). It would also be to a site's advantage to have ideal institutional arrangements (i.e., administrative, political and legal), or be willing to serve as a site where these issues would be examined and new arrangements made.

The tests and evaluations would take advantage of the existing system infrastructure to the extent possible, but funding would be available to modify or extend the existing system to provide the necessary instrumentation and facilities to conduct the tests and evaluations. It is envisioned that many of the tests would be small in scale, sufficient to determine the effectiveness of the new technology or control strategy. The program would also consider the provision of operational support to the metropolitan area in the form of training for local staff, provision of temporary support staff with special skills and training, and funding for operations and maintenance of the new technology for the duration of the demonstration project.

Extensive benefit to cost data would be collected, and the results would be publicized nationally to educate and sensitize public administrators and the general public to the economic consequences of congestion and the benefits of advanced traffic management systems.

10.0 SYSTEM PLANNING

As part of a national IVHS program, Federal funds should be provided for metropolitan areas to undertake comprehensive areawide system planning to facilitate deployment of advanced traffic management systems. It is suggested that $60 million be made available over the ten year period for the conceptual planning for implementing state-of-the-art traffic management systems on an areawide basis, including consideration of the future requirements of other advanced systems. At an estimated cost of about $500,000 per study, the suggested funding could finance planning and preliminary design studies for 100 systems in the largest urban areas in the U.S., as well as many smaller areas.

Conducting effective planning studies will help ensure that the large public investment in building these systems is spent wisely by addressing, for example, the need for systems to be designed to meet ftmctional control needs, the need for interagency and public and private cooperation to be established, and the need for adequate funding and staff resources to operate and maintain the systems once they are in place.

Just as important, however, is the issue of national economic competitiveness. One way of fostering continued U.S. competitiveness in the advanced electronics area is to create a market where U.S. firms could readily sell their products. Since advanced traffic management systems would provide much of the basic infrastructure for the other more advanced systems in the IVHS program, the incentive of designated Federal planning money would help establish a long term, widespread market for these products. Providing the Federal funds for planning of these systems would be a clear statement of Federal interest in creating that market in an area that will achieve benefits for a very large cross section of the public. For this reason, the planning money should be made available immediately, and urban areas encouraged to develop their plans as soon as possible.

11.0 DEPLOYMENT

Widespread implementation of areawide advanced traffic management systems throughout the U.S. is essential in order to put in place much of the infrastructure for evolving IVHS technology. The application and deployment of advanced traffic management systems in U.S. metropolitan areas would also provide immediate, significant traffic flow benefits as more advanced IVHS technology comes on line.

11.1 SYSTEM DESIGN AND CONSTRUCTION

Stable sources of funds for system design and installation must be made available to take full advantage of the system planning funds provided as part of a national IVHS program. As a rough estimate, approximately $18 billion (current dollars) will be needed to design and construct advanced traffic management systems in all urban areas over 100,000 population in the U. S . This includes both some form of freeway surveillance and control system and computerized traffic signal system, operating in an integrated fashion from an operations center(s).

A reliable supply of Federal-aid money for system design and installation will be vital. Given current Federal budget constraints and other pressing national highway needs, however, Federal-aid funds will likely not be enough, these must be supplemented by State and local funds, and private sources must also be tapped. Innovative funding packages must be encouraged and facilitated, mixing funds obtained from Federal-aid and traditional State and local highway taxes, and other sources such as bonds, developer fees, tolls and special tax districts. Other innovative mechanisms, such as private financing and public leasing of systems, should also be explored.

11.2 SYSTEM OPERATION AND MAINTENANCE

The cost of operating and maintaining advanced traffic management systems must also be addressed. Technical advances in adaptive traffic control strategies, detection hardware and communications techniques may someday reduce these costs, but until these are developed and widely implemented, it will be especially imperative that adequate operating and maintenance staffs budgets be provided. Systems are, in essence, tools to be used to effectively manage traffic. Systems by themselves do not manage traffic, people using systems do. Provisions for adequately providing for system operation and maintenance must be included as part of the areawide system planning studies, and firm commitments obtained in regard to sources of people and annual budgets. Privatization concepts should be explored, e.g., hiring firms to provide operations staff and maintain the hardware and software components. Consideration should also be given to allowing State and local governments, at their discretion, to use a portion of their Federal-aid allocation for funding operations and maintenance costs.

Annual operating and maintenance costs should run as high as 10-15 % of the original installation cost of the system. Using this figure, once all urban areas have advanced traffic management systems installed, the total annual operations and maintenance cost for all of these systems will run on the order of $1.7 to $2.5 billion annually (current dollars).

Staffing is an especially critical issue. The best technology in the world will not be effectively used if there are no qualified individuals who know how to design, build, apply and maintain it. Programs that encourage excellent students to acquire an education in fields such as transportation and electrical engineering, systems analysis and computer programming must be developed. As IVHS research money is provided, it can be expected that more students will enter advanced degree programs in these areas. To complement this, fellowships, scholarships and co-op and professional exchange programs must be sponsored, and appropriate curricula and education materials developed. Training courses and materials and handbooks for State and local government personnel involved in the planning, design, operation and maintenance of these systems must also be developed.

12.0 MILESTONES

The deployment of advanced traffic management systems will not follow a tidy schedule. Many research and development activities can be accomplished simultaneously and independently. Urban areas will install systems at different points in time due to different priorities and preferences. But in any event, it will be imperative that some ATMS activities begin early in order to set the stage for later projects. These are characterized below as immediate action items. There will also be a need early in the program for basic and fundamental research, new traffic models, new detection hardware and exploration of artificial intelligence techniques. These are characterized as the building blocks of ATMS. Advanced ATMS strategies would be developed as this building block research is completed, and as other IVHS systems (most notably, advanced driver information systems) come on-line. Please refer to Figure 1 for a graphical illustration of how we see technology in this area developing.

The $75 million R&D costs and the $225 million operational testing costs would be spread through the life of the program. The largest share of this cost would be spent during the period between 1995 and 2000 when the advanced traffic control and management strategies would be developed and tested.

12.1 IMMEDIATE ACTION ITEMS

1. Agreements should be established with at least ten test sites.
2. System planning money should be made available.
3. Guidelines for conducting before and after evaluation studies should be developed to ensure that reliable information will be provided.
4. Studies of the institutional issues that pose hurdles to the successful implementation of ATMS and other IVHS systems should be conducted very early in the program. Issues must be identified and innovative ways of addressing them found.
5. Work to develop needed standards should begin as soon as possible to avoid wasted efforts.

12.2 THE BUILDING BLOCKS (1992-2000)

1. Fundamental research would be conducted into driver behavior and travel information needs.
2. Real-time traffic monitoring and data management capabilities would be developed. This would include development and testing of advanced vehicle detection technology, including image processing systems, automatic vehicle location and identification techniques, and software and expert systems to manage the plethora of real-time information being provided from multiple sources. The issue of whether vehicles equipped with an in-vehicle information device and two-way communications capability can be used as a probe or supplement to traditional types of detectors would be addressed.
3. New traffic models would be developed and tested, including real-time dynamic traffic assignment, real-time traffic simulation models, and corridor optimization techniques. Basic research into new traffic flow theories and optimization techniques would also be conducted.
4. The applicability of artificial intelligence and expert systems techniques would be assessed and applications developed and tested. Possibilities include fast response incident detection, congestion anticipation, and control strategy selection.
5. Demand management strategies would be developed and tested. This might include such things as pollution monitoring and response systems, and HOV or transit incentives, parking restrictions and congestion pricing during periods when heavy congestion is detected.

12.3 ADVANCED STRATEGY DEVELOPMENT (1995-2005)

Using the results of the above building blocks research and development, advanced traffic management strategies would be developed and tested in the last five years of the decade. These would include:

1. Short term forecasting techniques that would predict where congestion will be occurring in the near term. These techniques would use real-time origin-destination data provided by vehicle probes and/or mathematical techniques, and use dynamic traffic assignment and AI or expert systems models to make the predictions.

2. Rapid response incident detection techniques that would use the latest detection technology coupled with AI or expert systems to rapidly detect when an incident situation occurs. Traffic management incident response strategies may be selected with the help of other AI or expert systems techniques, traffic assignment and simulation or corridor optimization models.

3. Demand management strategies would be implemented when congestion is especially heavy, for example, during periods when air pollution standards are being exceeded, as measured by an automatic monitoring system. Incentives for using HOV's or transit, parking restrictions and congestion pricing schemes would be established in real-time and communicated to the public.

4. Saturated flow strategies would be implemented when demand or predicted demands will exceed available capacity. The strategies would be anticipative, restricting flow into bottleneck areas through use of upstream diversion and restricted control techniques (gating), in order to achieve overall system optimal flow, similar in concept to successful ramp metering systems.

5. Integrated, adaptive traffic control strategies would be implemented. These strategies would respond to current or predicted traffic conditions in real-time, and would jointly consider ramp metering rates, traffic signal timing and motorist information (diversion). Control would be provided in an integrated, corridor, or areawide basis.

12.4 DEVELOPMENT OF THE ULTIMATE TRAFFIC CONTROL SYSTEM (2000-2005)

The ultimate traffic control system is termed an interactive traffic control system. In these systems, in-vehicle devices have now achieved a substantial market penetration and accurate real-time origin-destination information is available. Accurate information on current and predicted traffic conditions and the best routes to take is now being provided to the public, commercial vehicle operators and fleet managers through the in-vehicle devices and at home, places of employment and at terminals. The advanced strategies developed above are now being implemented and integrated in traffic management centers across the country. The roads are still congested, but more travel is being accommodated with the accompanying economic and social benefits. Major delays due to incidents are being avoided, goods are being delivered on time and people are happier because they know when and why there is congestion, and they are able to make informed choices about whether and when to travel, and what routes and modes to take.

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APPENDIX A

COST ESTIMATES CONSTRUCTION

The Market

1. Freeway Systems

From 1988 data obtained from FHWA's Highway Performance Monitoring System, there are 8,621 miles of urban freeway in the U.S. currently operating at V over C's over 0.7 (based on peak period volume). We have assumed a system is needed on all of these miles. Subtracting the 1,100 miles already with systems leaves approximately 7,500 miles.

We have further assumed that these will be spread out over 100 different systems in about 75 urban areas (there are 74 urban areas over 500,000 population in the U.S.).

We have further assumed that the remaining urban freeway miles (18,800 total – 8,600 = 12,200 miles) would benefit from a system, but one that was not as intensely instrumented.

This covers all areas with populations over 50,000.

2. Signal Systems

We have assumed 1 signal for every 1,000 people in U.S. urban areas. There are about 120 million people in areas over 1 million population, or about 120,000 signals. There are about 50 million people in areas between 250K and 1 million population, or 50,000 signals, and there are about 25 million people in areas between 100 and 250k population, or 25,000 signals.

The Costs

1. Freeway Systems

a . Planning

(1) Assume $500,000 per study for an areawide planning study.

(2) 100 systems

$500,000 x 100 = $50 million

(3) Assume the cost of planning the remaining systems will be 20% of the above cost.

$50 million x .20 = $10 million

b. Design

(1) Assume $7.5 million per areawide system.

(2) 100 systems

$7.5 million x 100 systems = $750 million

(3) Assume the cost of designing the remaining systems will be 20% of the above cost.

$750 million x .20 = $150 million

c. Construction

(1) Assume $1 million per mile (for detectors, cameras, changeable message signs, ramp meters, communications)

(2) 7,500 miles

$1 million x 7,500 miles = $7.5 billion

(3) Assume the cost of constructing the remaining systems will be 30% of the above cost.

$7.5 billion x .30 = $2.25 billion

d. Operations and Maintenance

(1) Assume 10-15% of the total construction cost annually

(2) For all 18,800 miles

($7.5 billion + $2.25 billion) x .10 = $975 million

($7.5 billion + $2.25 billion) x .15 = $1.46 billion

2. Signal Systems

a. Planning

We have assumed this will be addressed as part of the areawide studies estimated above.

b. Design

(1) Assume $2,000 per intersection

(2) Approximately 200,000 intersections

$2,000 x 200,000 = $400 million

c. Construction

The following assumes extensive state-of-the-art monitoring capabilities will be installed, as well as a comprehensive state-of-the-art communications system, modem controllers, and a modem central control facility. Few of these types of systems exist in the U.S., none on an areawide basis, so for purposes of gross estimation, it is assumed that systems of this type are needed everywhere.

(1) For large areas, assume $40,000 per intersection

(2) 120,000 intersections

$40,000 x 120,000 = $4.8 billion

(3) For medium areas, assume $30,000 per intersection

(4) 50,000 intersections

$30,000 x 50,000 = $1.5 billion

(5) For small areas, assume $20,000 per intersection

(6) 25,000 intersections

$20,000 x 25,000 = $0.5 billion

Total = $4.8 + $1.5 + $0.5 = $6.8 billion

d. Operations and Maintenance

(1) Assume 10-15% of the total construction cost annually

(2) For all 195,000 signals

$6.8 billion x 10% = $680 million annually

$6.8 billion x 15 % = $1.02 billion annually

TOTAL DEPLOYMENT COSTS

a. Design and Construction

$750 million + $150 million + $7.5 billion + $2.25 billion + $400 million + $6.8 billion = $17.85 billion

b. operations and Maintenance

$975 million + $680 million = $1.65 billion annually (10%)

$1.46 billion + $1.02 billion = $2.48 billion annually (15%)

RESEARCH AND DEVELOPMENT AND OPERATIONAL TESTING

The popular estimate for the Federal share of the cost of the total IVHS program is $100 million per year for 10 years, or a total cost of $1 billion. Divided up evenly among the four component areas would give $250 million to ATMS. We have assumed that there will need to be a larger Federal participation in ATMS work than in some of the others, we have selected an arbitrary 36 % , which gives, of course, $360 million total. From the above, $60 million will be needed for the system planning studies that are part of the proposed ATMS program. That leaves $300 million, which we have arbitrarily divided up as $75 million for R&D and $225 million for operational testing.

We have further assumed 15 States will have significant ATMS R&D programs at an average investment of $500,000 per year (the current annual investment in Washington State's FAME program). Over the course of the lo-year program, this would be an additional $75 million, for a total $150 million public R&D program.

Finally, we have assumed that the States will participate in the operational testing program equally with the Federal government. Doubling the Federal $225 million investment gives a total IO-year investment of $450 million.

Intelligent Vehicle Highway Systems

Advanced Driver Information Systems

MOBILITY 2000

Dallas 1990

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PREFACE

Driving a vehicle generally requires us to execute five distinct types of tasks: (1) planning, (2) perception, (3) analysis, (4) decision making, and (5) control. An intelligent vehicle for Intelligent Vehicle-Highway Systems (IVHS) generally includes vehicle features that assist with some or all of these tasks. That is, planning a trip or maneuver, perceiving the condition of the vehicle and external environment, analyzing the resulting dynamic situation, deciding what action is required, and taking that action. Each of these five tasks can be further divided into two categories: (a) those generally high bandwidth elements that directly deal with the safety and security of the vehicle and its occupants, and (b) those generally lower bandwidth elements that directly deal with convenience and efficiency of travel and only indirectly with safety. In the work reported here, Advanced Driver Information Systems include only those tasks falling into this second category; the higher bandwidth tasks dealing with safety are included under the topic of Advanced Vehicle Control, to which they are directly related.

For the purposes of this study, then, Advanced Driver Information Systems are those vehicle features which assist the driver with planning, perception, analysis, and decision making to improve the convenience and efficiency of travel. These systems provide direct and immediate benefits to the driver and, indirectly, benefits to society. The benefits to society (less congestion, more efficient transportation of people and goods, reduced fuel consumption, improved air quality, and fewer motor-vehicle accidents) increase as the proportion of ADIS-equipped vehicles in the national fleet increases.

BACKGROUND

Information is a key to decision making, and well-informed drivers can make decisions which lead to safer, as well as more efficient, travel. A basic system of fixed signs and pavement markings aids the motorist in vehicle guidance, navigation, and other vehicular control activities. Speed limits, passing zones, curve warnings, and stop or yield signs have been used for many years to guide and control vehicular traffic. Travel is also aided by route numbers and streets signs, and by printed maps which help to orient and guide the traveler through unfamiliar territory. Recognizing that many drivers could not effectively use road maps, and that growing metropolitan areas contributed to navigation problems, the Federal Highway Administration sponsored research to develop an Electronic Route Guidance System (ERGS) which would provide in-vehicle directional guidance to the driver [l]. Using preselected origin and destination information, and a series of directional arrows displayed in the vehicle, ERGS was intended to improve driver navigation in urban areas. A planned operational experiment in Washington, D.C. was abandoned in 1971 when a Congressional Appropriations Committee questioned the cost, as well as the need, at that time. It should be noted that the proposed system included many of the characteristics of the Auto-Guide System [2] which is now being implemented in London.

In 1973, the Japanese Comprehensive Automobile Traffic Control System (CACS) project [3] began and, by 1979, established the feasibility of the ERGS technology. This work established the support for the current field operational experiments which are underway in Japan (RACS [4] and AMTICS [5]).

As traffic congestion increased in the United States in the 1970's, radio frequency (RF) transmissions were initiated to alert motorists of traffic conditions (traffic advisories through commercial radio stations) and to provide guidance to special attractions (highway advisory radio) [6]. There was also limited use of changeable message highway signs to provide speed and warning messages to motorists [7]. Since 1984, mobile communications have been available to the driver through cellular systems, and 10 million units are expected to be in use by the year 2000 [8].

Advances in electronic technology, with miniaturization of components and reduced unit costs, have allowed a wide array of information which can be provided to the driver through a broad assortment of communication systems and media. Fixed information such as electronic route maps, tourist guides, and service directories can be self contained within the vehicle and accessed through media such as magnetic tape or compact disc. Vehicle status and warning indications can also be provided through self contained, in-vehicle sensors.

While all these systems add convenience and security to the motoring experience, they lack an essential ingredient which can reduce individual travel time, reduce traffic system congestion, and improve travel safety. This ingredient is the dynamic, or real-time, traffic and roadway condition information which is necessary to optimize route selection and operational decisions. To obtain this information, it is necessary to establish communication linkages with the Advanced Traffic Management Systems (ATMS) described in the previous section of this report. One-way communication links to the vehicle from the ATMS can provide up-to-date information such as traffic congestion, safety advisories, parking lot status, and environmental conditions (ice, snow, etc.). With two-way communication, the vehicle can serve as a dynamic traffic sensor and provide feedback to the traffic management system, allowing the management system to anticipate congestion and provide operational relief measures.

Evolution of Advanced Driver Information Systems (ADIS) is expected to occur in three stages – an Information Stage, an Advisory Stage, and a Coordination Stage. These stages are projected to evolve in the 20-year period from 1990 to 2010, and the operational features expected in each stage .are described in the following sections. Advancement through the evolutionary stages is not expected to require major technological breakthroughs; but research and development, as well as significant operational field trials, will be required to apply the technology and assure that the systems operate in a safe and efficient manner. At a minimum, North American standards and protocols must be established to allow full compatibility among the communication systems provided by the public and private sectors. Alternative system architectures must be evaluated and key system decisions made through cooperative forums involving full government and industry participation.

The special needs of selected segments of the traveling public must also be considered. These include: (1) older drivers whose vehicle operation can be enhanced by in-vehicle signs or roadside encroachment warnings, and (2) public service and commercial vehicle drivers and fleet system managers whose travel navigation and operating efficiency can be enhanced by position location and communication systems.

Despite the expected benefits from the improved information systems, there are concerns that the driver should not suffer from information overload or distractions which will reduce attention to the driving task. Both the amount of information and the method of presentation to the driver must be carefully evaluated to ensure that highway safety is enhanced rather than degraded by the information systems. Human factors studies, including cognitive and user demographic analyses, will be required to establish the effectiveness and acceptance of the proposed communication and information systems.

STATE-OF-THE-ART

Advanced Driver Information Systems (ADIS) provide drivers with information on congestion, navigation and location, traffic conditions, and alternate routes. The information could involve local accidents, weather and road conditions, alternate routes, recommended speeds, and lane restrictions. In concert with crash warning systems, information could be provided on potentially dangerous driver, vehicle, road, or environmental conditions. ADIS could also provide information that would assist the vehicle operator to plan his or her trips.

There are a number of technologies available to provide drivers with such information. Some of these technologies use equipment external to the vehicle. For example, there are location and identification systems in use or under development relying on GPS, LORAN-C, GEOSTAR, or proprietary satellites. These systems use sophisticated triangulation techniques to determine vehicle locations. Other systems use "dead-reckoning" – that is, the current location of a vehicle is computed by measuring the direction and distance the vehicle has gone from a known starting position. In addition, another type of ADIS uses part of an FM radio signal to broadcast traffic information to motorists.

Specific types of ADIS technologies include:

- On-board replication of maps and signs;
- Pre-trip electronic route planning;
- Traffic information broadcasting systems;

- Safety warning systems;
- On-board navigation systems;
- Electronic route guidance systems.

The on-board display of roadside signs would provide a safety and navigation benefit; such devices could replicate warning or navigational roadside signs that may be obscured during inclement weather or when the message should be changed, such as to lower speed limits during ice, rain, or snow conditions. Roadside information and warning signs, displayed inside vehicles, would improve their effectiveness, especially for drivers with impaired vision or driving in bad weather. Messages could also be tailored to particular types of vehicles.

Route planning, improved maps, and more accurate and consistent signs can reduce trip distances and transit times. Pre-trip electronic route planning systems are being developed and are available at certain car rental counters. With these systems, the traveler's origin and destination are entered into a computer and a printout of directions is produced. For trip planning purposes, these systems can estimate minimum time, distance, or travel-related expenditures. Route-planning systems can also provide information on public transportation, including information on bus stop locations, schedules, and the location of subway and bus terminals.

Traffic information broadcasting systems provide information on traffic conditions, enabling drivers to alter their routes. With some systems, transmissions are received through car radios after drivers are alerted to turn the radio to a specific frequency. With other systems, special receivers must be installed. Existing examples of these systems include Highway Advisory Radio in the United States and the ARI (Autofahrer Rundfunk Information system in Europe. Various traffic information broadcasting systems are being considered for use in the United States.

In-vehicle navigation and location systems also provide information on video display terminals in the vehicle or use dashboard signals. More sophisticated systems, termed electronic route guidance systems, provide real-time information on traffic, road, and weather conditions and provide route guidance to the motorists that reflects real-time traffic conditions. These video display terminals show the highway network and the location of the traffic problems, allowing drivers to change routes and make more informed decisions.

There are a wide range of in-vehicle navigation systems and programs being developed in the United States and abroad. The following are brief descriptions of some of the systems and programs:

Pathfinder – is a cooperative project among the Federal Highway Administration (FHWA), the California Department of Transportation (Caltrans), and General Motors Corporation. Pathfinder, an in-vehicle navigation system, is an experimental project aimed at improving traffic flow. The project provides drivers of specially equipped vehicles with real-time traffic information about accidents, congestion, highway construction, and alternate routes. The Pathfinder system is being tested to see how drivers could benefit by receiving on-board information through a computerized mapping device on a monitor display. A control center manages the communication, detecting traffic density and vehicle speeds, and transmitting that information back to the equipped vehicles in the form of an electronic map shown on the display screen. The system helps motorists find the most efficient path of travel to their destination. The experiment will take place in an area known as the Smart Corridor, a 13-mile stretch along the Santa Monica Freeway between Santa Monica and Los Angeles. The corridor, one of the most heavily traveled areas in the country, includes the freeway service roads and five major parallel arterial roads. Following the installation and testing of the Pathfinder project, Caltrans will perform an evaluation of the experiment. The evaluation is scheduled to begin in April 1990.

ALI-SCOUT/LISB – developed in the Federal Republic of Germany by Bosch/Blaupunkt and Siemens, is a route guidance system that uses infrared transmitters and receivers to transfer navigation information between roadside beacons and on-board displays in appropriately equipped vehicles. Earlier versions of a route guidance system were tested along a 60-mile stretch of German autobahn. A more advanced ALI-SCOUT system (LISB) has been tested in Munich and is undergoing testing in West Berlin.

AUTOGUIDE – is the British version of the ALI-SCOUT system. A test of this technology is now underway in London, and in a corridor between London and Heathrow Airport. It is anticipated that roadside beacons will cover the London area, and then Great Britain, by the early 1990's.

AMTICS – sponsored by the National Police Agency, the Ministry of Posts and Telecommunications, the Japan Traffic Management and Technology Association, and 59 private companies. AMTICS is a relatively sophisticated traffic control system that transmits traffic congestion information from a traffic control center to an in-vehicle display. The AMTICS system has the capability to provide "static" and "dynamic" information. The basic design of the system was completed in October 1987. Pilot experiments, using 11 passenger cars and a bus in central Tokyo, began in April 1988 and were completed in June 1988. Twelve private companies developed pilot systems.

RACS – another Japanese program is the Road-Automotive Communication System (RACS). Using different communication technology, RACS is a parallel research project. RACS is sponsored by the Public Works Institute of the Ministry of Construction, the Highway Industry Development Organization, and 25 private companies. RACS consists of roadside communication beacons, on-board vehicle units, and a systems center. RACS collects and disseminates information between roadside beacons and vehicles. The system functions are classified into navigation, roadside information, and message systems. The first road test of RACS began in March 1987, and was carried out in an area of about 350 square kilometers in Tokyo and Yokohama. This test used 74 location beacons. The second road test began in March 1988. This test used 91 beacons and improved digital maps. Also, provision of real-time data and traffic data was tested. The third field test of RACS began in July 1989. This test included the total concept of RACS (i.e., navigation, traffic information, and individual communication).

PROMETHEUS – which is one of the two most important European IVHS programs contributing to ADIS, stands for PROgraMme for European Traffic with Highest Efficiency and Unprecedented safety. Primarily a private sector initiative, PROMETHEUS is aimed at developing a uniform European traffic system incorporating IVHS technology. To carry out this program, a consortium of European automobile companies, supplier companies, electronic firms, and university research institutes has been formed. The **PROMETHEUS** system is designed to be a European-wide traffic management and control system using three major levels of information transfer or communication – intelligent driver aids on-board the vehicle, communication networks between vehicles, and communication and information systems that link vehicles and roadside facilities. PROMETHEUS began in 1986 and is an 8-year, $800 million program.

DRIVE – is the other major European IVHS program. DRIVE Dedicated Road infrastructure for Vehicle Safety in Europe) is a European Community program of collaborative research and development to find ways to alleviate road transportation problems through the application of advanced information and telecommunications technology. The stated goal of DRIVE is to improve road safety, promote transport efficiency, and reduce environmental pollution. In 198.5, studies were conducted for the European Community on driver information systems. These studies confirmed the need for such a program, and the DRIVE program was initiated in June 1988. The DRIVE program focuses on the transmission of information between vehicles and the road. A major goal of the program is to develop standardized technology so that any products or services developed as a result of this program could be used throughout the European Community. Participants in the DRIVE program include representatives from the public sector, motor vehicle and supplier industries, and highway users. DRIVE has a total committed funding level of $132-150 million, over a 3-year period, of which one-half is from the public sector and one-half is from the private sector.

Table 1 lists some important attributes of the systems discussed above.

There are other driver information systems being developed which are external to the vehicle. The regional phone companies, IBM, Sears, AT&T, and many smaller companies are developing and implementing videotext systems and services for the home. These could be used to improve the transportation information base for individual mode and route choices.

Table 1. Examples of Advanced Driver Information Systems, Programs and Functions

Systems & Programs	Navigation	Route Guidance	Real-Time Traffic Congestion	General Traffic Info.	Trip Services	Pre-Trip Planning	Personal Communications	Emergency Communications
Systems Pathfinder	X		X					
AMTICS	X		X		X		X	X
RACS	X		X		X		X	
Auto-guide	X	X						
LISB	X	X						
Atlas				X		X		
CARMINAT	X							
CARIN	X				X			
HAR				X	X			
ARI				X				
RDS				X				
Programs PROMETHEUS & DRIVE	European research and development programs contributing to all components of ADIS							

STAGES OF DEVELOPMENT

We have found it convenient to divide the development of ADIS into three stages:

- Information Stage 1990-1995
- Advisory Stage 19952000
- Coordination Stage 2000-2010.

During the Information Stage, primary emphasis will ***be to provide each driver with information to improve individualplanning and decision making.*** Most of the capabilities will rely on the vehicle's own resources and will be independent of any infrastructure. Such features as dead-reckoning navigation systems, on-board information databases, and static route selection fall into this category. With limited support from the infrastructure, real-time traffic incident information could be made available to each driver to assist in personal route planning.

The Advisory Stage will supplement the static on-board information with dynamic traffic information collected and transmitted by the infrastructure. This will include traffic link times (the time to traverse various parts of the road network), incidents, weather, and other factors affecting traffic flow. This digital information will be received by the vehicle automatically and used to compute the current optimum routes, or filtered for relevance and only selected items presented to the driver. The vehicle will then guide the driver step-by-step over the optimum route providing critical information as needed.

The Coordination Stage will have been reached when the vehicles and the infrastructure automatically exchange information to optimize the flow and safety of traffic over the entire network. Vehicles will continually report on traffic conditions encountered. The infrastructure will combine this information with all its other sources of information using predictive data-fusion models to provide coordinated routing and traffic signal control. Individual vehicles requiring emergency assistance can summon the required service (police, medical, mechanical, etc.) which will be automatically routed to the scene.

The time periods shown for these stages are, of course, approximate and are meant to represent the time period covering from commercial introduction to penetration of approximately 10 percent of the new-car fleet. At any point in time there will be some localities and some vehicles operating in each of these stages.

The remainder of this report will describe our recommendations for the development of a North American ADIS system in terms of these three stages.

THE INFORMATION STAGE

During the Information Stage, primary emphasis will be to provide each driver with information to improve individual planning and decision making. Most of the capabilities will rely on the vehicle's own resources and will be independent of the infrastructure. Such features as dead-reckoning navigation systems, on-board information databases, and static route selection fall into this category. With limited support from the infrastructure, real-time traffic incident information could be made available to each driver to assist in personal route planning and to avoid known areas of congestion.

GOALS

The Information Stage establishes the technical and socio-political foundations critical to the future of ADIS. Of great importance during this stage is not only the designed performance of ADIS and the benefits derived from it, but also the cooperative nature of the public and private sector alliances that are formed to bring it about.

The Information Stage should achieve an economically viable basic navigation and receive-only traffic communications capability for private and commercial vehicles. These two features form the core capabilities which directly contribute to the congestion and safety benefits that ADIS can produce. A further goal of this stage is to achieve sufficiently stable standards for database formatting and access so that the investment to produce on-board map and information databases for vehicle navigation systems becomes commercially attractive for private enterprise.

This should be the testing period for ADIS. Systems of many different types and capabilities should be explored in field studies and demonstrations. The goals of these studies should be to evaluate the actual benefits the various features can provide in the hands of real drivers in real driving situations.

This is also the time to begin the much needed investment in human factors and behavioral studies relating to ADIS. These should include not only the obvious performance issues, such as color, size, and location of displays, but also the more basic issues of information intelligibility, cognitive performance in driving, and acceptability of various decision making and routing strategies.

SYSTEM DESCRIPTION

A typical ADIS system at the end of the Information Stage will have, on-board the vehicle, the features listed in the table below.

Table 2. ADIS Features — End of Information Stage

- Dead-reckoning map-matching navigation system;
- Digital traffic information receiver;
- Static mute-planning for minimum distance of travel;
- Color video display for maps, traffic information, and route guidance;
- Sysnthesized voice for traffic information and route guidance;
- Map database including turn restrictions and freeway signs;
- Business directory database integrated with map database;
- Electronic vehicle identification for toll debiting;
- Digital cellular telephone.

The infrastructure required to support these vehicles is listed below.

Table 3. Support Infrastructure Required

- **Traffic** Information Center to collect, format, and **transmit traffic information;**
- **Traffic information** transmitters;
- **Organization to prepare** and distribute map and business **directory** databases;
- **Agencies to inspect** and certify accuracy and currency of databases used for mute guidance;
- Toll stations equipped to read vehicle ID.

ALTERNATIVE CONFIGURATIONS

Alternative approaches exist for determining the position of the vehicle, providing route guidance, and communicating real-time traffic information to the vehicle.

The most likely approach to determining the position of the vehicle, with respect to the road network ("navigation"), is using dead-reckoning with map-matching. This is the approach pioneered in the U.S. by ETAK [9] that uses a magnetic compass, wheel speed sensors, and algorithms which match the vehicle's motion to the map network in such a way as to correct the build-up of position error inherent in any dead-reckoning system. There are several alternatives, however. LORAN [10] and GPS [11] are radio-based position finding systems, essentially triangulating on terrestrial or satellite-based transmitters. Similar triangulation can also be done using cellular telephone transceivers or other satellite-based receivers. Other approaches (AUTO-GUIDE [12], LISB [13], AMTICS [14]) correct errors in the dead-reckoning position when the vehicle passes electronic sign posts. Each of these approaches should be investigated for cost, accuracy, and practicality in a North American system.

On-board route guidance instructions could be communicated to the driver in a number of ways. AMTICS (Japan) has chosen to indicate the guidance route as a highlighted overlay on a CRT map display. AUTO-GUIDE (Great Britain) and LISB (West Germany) use a simplified display showing schematics of intersections with directional arrows indicating the next action for the driver to take. All of these systems can be augmented with synthesized voice, or voice can be used alone without a visual display. As head-up displays (HUD) [15] are developed having flexible format, they would be an obvious possible alternative.

Similarly, alternative approaches exist for communicating real-time traffic information to the vehicle. These can be as simple as an audio traffic message channel similar to the NOAA weather channel [16]. Approaches which offer the potential for growth into later stages of ADIS include exclusive-channel digital traffic transmitters (the option included in Table 2), digital messaging on the sub-carrier of commercial FM radio stations (Europe's Radio Data System's Traffic Message Channel [17]), and short-range rf or infrared transmitters on electronic signposts (AUTO-GUIDE).

POTENTIAL BENEFITS

Although full benefits of ADIS will not be realized until the later development stages, the Information Stage will provide significant benefits on its own. Estimates made by the Federal Highway Administration in 1985 show that approximately 6 percent of all driving in the United States is due to incorrect choice of route [18] An effective navigation system with static route selection, coupled with real-time traffic information, would go a long way to eliminating this unnecessary travel for ADIS-equipped vehicles. Reducing vehicles' exposure to congestion also reduces their exposure to accidents, further reducing congestion.

There are also definite psychological and safety benefits to "never getting lost" and always being able to determine an efficient route home or to an emergency facility.

The commercial vehicle sector will derive additional benefits from the Information Stage, such as lower transportation costs, more reliable just-in-time delivery, less delay at borders, weigh-stations and toll booths, and less stress on drivers.

Successful deployment of the Information Stage of ADIS builds a firm foundation for the succeeding stages with their additional benefits to individuals and society.

INTERFACES WITH OTHER ELEMENTS OF IVHS

During this stage, the primary interfaces to ADIS are with the Advanced Vehicle Control (AVC) sector, the Commercial Vehicle Operations (CVO) sector, and the Advanced Traffic Management (ATM) sector.

The Advanced Vehicle Control sector has responsibility for providing safety information to the driver. This may include collision warning, impaired driver warning, and similar notices which may require immediate driver response. It is likely that the driver interface for these functions will share many of the devices (video display, synthesized voice, etc.) used by ADIS. For this reason, a shared design philosophy must be developed between the two sectors. Joint systems analysis and human factors development and testing should take place to insure the proper prioritization of information and driver notification.

All of the features described in Table 2 will be of direct benefit to the commercial sector. In actuality, the commercial sector is leading in the applications of ADIS Information Stage features because they do reduce driving time and improve service, both of which contribute to profits. Federal Express [191 and United Parcel Service [20], among others, are making wide use of navigation and communications features now. Through cooperation with the Commercial Vehicle Operations sector, the ADIS electronic vehicle identification feature could be extended to permit weigh-in-motion [21]. Further development of the ADIS vehicle capabilities and infrastructure support should explicitly consider the needs of the commercial sector, both to improve overall transportation system performance and to increase the market for ADIS equipment, thus reducing its cost and making it more widely available. Several of the features of infrastructure support listed in Table 3 will become the direct responsibility of the Advanced Traffic Management sector. ATM must collect, format, and transmit the real-time information on incidents and congestion. This will include procurement and management of the traffic-transmitter network. ATM would also benefit by managing the infrastructure side of automatic toll debiting.

RESEARCH AND CEVELOPMENT REQUIRED

Since the Information Stage begins the development of an ADIS for North America, much of the research and systems analysis should be done during this stage. This will be a key to the successful, efficient development and deployment of ADIS.

Systems Analysis

Systems analysis should address the overall system design issues, benefits, studies, and tradeoffs among the different elements which constitute ADIS and its supporting infrastructure. This analysis should deal with the system at least at three levels: (1) the complete IVHS system design including technical, societal, and economics issues; (2) the complete ADIS system design, including users, vehicles, and infrastructure; and (3) individual subsystem designs for vehicles, stationary elements, and communication links. The results of these studies should be corroborated by the field demonstrations and experiments described in a later section of this report.

Research to support these analyses should include:

- Modelling and simulation of specific urban traffic networks to estimate level of benefit for the different stages of ADIS;
- Optimal allocation of tasks between vehicle and infrastructure;
- Channel capacity requirements for real-time traffic information;
- Communications architecture and technology;
- Methods of collection formatting and dissemination of real-time traffic information;
- How, where, and when real-time traffic information is provided;
- How to create predictive real-time traffic information;
- Cost-benefit analysis for various alternative system features (e.g., electronic maps, guidance displays, real-time traffic information, automatic toll debiting, etc.) and architectures (e.g., centralized or distributed dissemination of real-time traffic information);
- Content requirements for a national digital map database.

Human Factors Research

Human factors research for ADIS can be grouped into: (1) ergonomic and anthropometric issues, which we generally understand, and (2) cognitive, utilization, and acceptability issues, which we generally do not understand. Issues in the first category will require applied research to support specific de-signs, while those in the second category require some more basic research to ensure the ultimate efficiency and acceptability of ADIS. Recommended studies include:

- Driver Interface
  - Optimal Display Characteristics
  - Optimal Voice Characteristics
  - Sensory Channel Tradeoffs
  - Format and Wording for Traffic Information
  - Format and Symbology for Navigation Information
- Intelligibility – Cognitive Analysis
  - Cognitive Spatial Mapping
  - Cognitive Time Scaling
  - Sensory Mode Evaluation
  - Analysis of Cognitive Errors
- ADIS – Driving Performance Coupling
  - Vehicle Guidance Analysis
  - Vehicle Control Analysis
  - Sensory Mode Interactions
  - Information Capacity Analysis
- ADIS Utilization
  - Factors That Affect Perceived Benefits
  - Route Suitability Perception
  - Route Risk Analysis
  - Subjective Time Metrics
  - Use Prediction Model
- User Demographic Analysis
  - Cognitive Attributes
  - Performance Attributes
  - Preference and Attitude Attributes
  - Define User Clusters
  - Determine Specs, Utility, and Acceptability by Cluster

OPERATIONAL FIELD TESTS

Limited operational field tests and experiments to gather experience with the Information Stage of ADIS are already planned or underway. An example of these is the PATHFINDER [22] experiment to determine the benefits of route guidance and real-time traffic information in the Santa Monica Smart Corridor [23]. This experiment is described in more detail in the State-of-the-Art section of this report. PATHFINDER is a pioneering effort, but involves only 25 vehicles operating in a particular type of environment. It will be necessary to build on this base by conducting additional experiments and operational tests, using different approaches to ADIS in different roadway environments in different sections of the country. We recommend a series of operational field tests similar to the following:

Test 1 Test ADIS Information Stage features in rental-car fleets in representative cities across North America. This will provide human factors and preference information from a broad cross section of users in real driving situations, while giving the widest possible exposure to the public, government officials, and press of the potential benefits of ADIS.

Test 2 Extend Test 1 to include public service vehicles and commercial fleets, such as taxis and delivery trucks. This would permit assessment of productivity gains and mission time reductions, and allow the exploration of information exchange between commercial fleets and traffic information centers.

Test 3 Extend PATHFINDER to cover the major roadways in the Los Angeles basin while partially subsidizing the equipping of 100,000 private and commercial vehicles. Only with a large-scale test of this kind can we assess the real benefits to congestion and safety that an Information Stage ADIS can provide.

Test 4 Test a low-cost dissemination of available real-time traffic information using an FM-subcarrier or Highway Advisory Radio communications channel. This will evaluate the benefits that an absolutely minimal system can produce.

Test 5 Test the use of vehicles as traffic probes by equipping a percentage of the vehicles in Tests 1 and 2 to communicate traffic conditions automatically to a traffic information center. This would be used to test various communications technologies and to determine the fraction of vehicles which must be equipped to make the traffic probe concept viable.

Test 6 Test the value and technologies of on-board traffic signing by equipping electronic roadsigns and a fleet of vehicles able to receive their transmissions. This would be compared with alternatives such as an on-board sign database and direct reading, and on-board storage of sign information using image-processing technology.

Test 7 Test alternative vehicle-to-infrastructure communications architectures. Alternatives include digital cellular telephone, specialized mobile radio, FM-subcarrier (e.g., RDS), local area-radio and wide-area radio with dedicated frequency authorization, and ultra-short range rf or infrared electronic signposts. This could include joint participation by the Japanese AMTICS team, the British AUTO-GUIDE team, and the German LISB team.

Test 8 Demonstrate a pilot urban Traffic Management Center which has information and control for an entire metropolitan area, breaking down the political and institutional barriers that restrict the cooperation required to best manage congestion and incident response.

DEPLOYMENT ISSUES

Deployment of ADIS at the Information Stage depends largely on the value placed on the perceived benefits by the driving public and commercial interests, and how this compares with the cost of providing those benefits. Even at this. stage, some support infrastructure is required to provide real-time traffic information to the driver and more infrastructure is required to take advantage of other features such as automatic toll debiting and weigh-in-motion for commercial vehicles. The resources required to support this infrastructure must somehow be balanced against the number of users benefiting from ADIS. Successful deployment will require that a critical mass of users be attained quickly, or support for the infrastructure will fade. The most useful features of this stage require a vehicle navigation capability. This permits the vehicle to provide present location, to perform static route selection and guidance, and to filter the large volume of real-time traffic information to provide the driver only with that information that is relevant to the current driving situation. This requires that no matter where the vehicle is located, it must have a map database covering that area. That

continent-wide map database must be complete, accurate and up-to-date. Currently, there are at least two companies in the U.S. developing map databases for vehicle navigation purposes [24]. There will likely be more, and database standards dealing with format and content will be required.

OBSTACLES AND CONSTRAINTS

There are two primary obstacles to rapid deployment of ADIS at the Information Stage. The first of these is the often-discussed “chicken-and-egg” dilemma: Why should users buy ADIS equipment for their vehicles when there is no infrastructure to support it, and why should the infrastructure be put into place when there are no vehicles equipped to benefit from it? One solution to this is to subsidize the early users as proposed in field Test 3, described in the above section on Operational Field Tests.

The second obstacle is the wait-and-see attitude towards ADIS being taken by much of American industry. The uncertainty about the ultimate direction of IVHS creates a climate in which the investment to develop products to implement ADIS has an uncertain return and is very difficult to justify. A national consensus on the future of IVHS and ADIS, backed up with a specific development and implementation plan, could go a long way towards solving this.

THE ADVISORY STAGE

The Advisory Stage will supplement the static on-board information with dynamic traffic information collected and transmitted by the infrastructure. This will include traffic link times (the predicted time to traverse various parts of the road network), incidents, weather, and other factors affecting traffic flow. This digital information will be received by the vehicle automatically and used to compute currently optimum routes, or filtered for relevance and selected items presented to the driver. The vehicle will then guide the driver step-by-step over the optimum route by providing critical information as needed.

GOALS

During the Advisory Stage of ADIS, the in-vehicle system will begin to do more than just inform the driver of conditions; using knowledge from the infrastructure, it will also begin to advise of the best course of action. This advice must be credible. It must be perceived by the individual driver as being accurate and as providing personal advantage when followed; otherwise it will be ignored. Accuracy of both the navigation system and the real-time traffic information, therefore, becomes critical during this stage.

Specifically, a major goal of the Advisory Stage is to provide automatic minimum travel-time route selection and guidance using up-to-the-minute traffic information. This requires the traffic information centers to acquire traffic data from a wide variety of sources and synthesize predicted driving times for all major links in the road network. These link times are periodically transmitted to the vehicle where they are used by the route-planner to select the minimum time route.

Also during this stage, ADIS will provide for on-board display of road signs. These will include both permanent and temporary signs for freeway information, traffic control, and speed limits. The goal will be to have the sign information available when the driver needs it, not just when the physical sign is visible.

SYSTEM DESCRIPTION

A typical ADIS system at the end of the Advisory Stage will have evolved to include the features listed in the following table.

Table 4. ADIS Features — End of Advisory Stage

- Global positioning system receiver for correcting errors in the dead-reckoning map-matching navigation system;
- Digital receiver for traffic information and traffic network link times;
- Route planning for minimum travel time (and other selectable criteria) that takes into account current traffic conditions and traffic network link times;
- Color video display for maps, traffic information, route guidance, and in-vehicle display of road signs;
- Synthesized voice for traffic information and route guidance;
- Map database includmg nominal link times for the traffic network, turn restrictions, freeway signs, and general traffic signs;
- Business directory and travel information databases integrated with map database;
- Electronic vehicle identification for TOLL debiting;
- Digital cellular telephone;
- Semi-automatic MAYDAY using the cellular telephone for emergency assistance.

The infrastructure required to support these vehicles is listed in the table below.

Table 5. Support Infrastructure Required

- Traffic Information Center to collect, format, and transmit traffic information and current traffic network link times;
- Network of traffic information transmitters;
- Organization to prepare and distribute map, business directory, and travel information databases, including nominal link times for traffic network;
- Agencies to inspect and certify accuracy and currency of databases used for route guidance and in-vehicle signing;
- Toll stations equipped to read vehicle ID.

ALTERNATIVE CONFIGURATIONS

Additional approaches exist for minimum-time route selection and guidance. The system shown in Tables A3 and A4 assume that minimum-time route selection is done on-board the vehicle using current link-time information supplied by the Traffic Information Center. An alternative is to have route selection done on-board using static information with the TIC transmitting real-time alternate route information which the on-board ADIS automatically incorporates when approaching areas of congestion.

Alternatives exist for the occasional recalibration required by any dead-reckoning navigation system. The use of GPS periodically to obtain an absolute position fix seems to be a reasonable approach, provided the cost of the GPS receiver is low enough. Other possible approaches include LORAN, triangulation on the traffic information (or other) transmitters, and strategically placed very short-range electronic sign posts.

Traffic sign information could be carried in an on-board database updated by the traffic information transmitters as assumed above, or the information could be communicated directly to the vehicle from the signs themselves. This could be done in a passive mode (optical reading of sign text by the vehicle) or in a cooperative mode (magnetic coding, short-range transmitters on the signs, etc.).

Alternatives for the other features remain much as they were during the Information Stage.

POTENTIAL BENEFITS

At this point, the first stage of infrastructure to support ADIS will have begun to mature and the market penetration of ADIS features into the vehicle fleet will be large enough (5-10 percent) to begin to show results. During the Advisory Stage, congestion peaks will reduce as traffic gradually spreads out in time and space. More equal utilization of the road network in urban areas will have begun. The consequent benefits of fewer accidents, less fuel consumption, and improved air quality will become measurable. Commercial fleets using ADIS will realize noticeable savings in fuel and improved on-time delivery. Stress on individual drivers will be less, not only because of less congestion and reduced travel time, but also because of reduced uncertainty in travel time.

INTERFACES WITH OTHER ELEMENTS OF IVHS

Interfaces during the Advisory Stage continue to be primarily with the Advanced Vehicle Control (AVC) sector, the Commercial Vehicle Operations (CVO) sector,and the Advanced Traffic Management (ATM) sector.

Any attempt at minimum-time route selection in a congested urban area absolutely requires the collection of traffic data and the timely dissemination of predicted network link times. This requires a significant investment in equipment and operations for the Traffic Information Center and the traffic transmitter network. Without that investment, the benefits cannot be realized. Some of the alternative approaches to in-vehicle signing will require investment in infrastructure by the ATM sector. This may be as simple as patterns of magnetic nails imbedded in the roadway to convey sign information, or as complex as signs which transmit their messages using short-range rf or infrared signals.

RESEARCH AND DEVELOPMENT REQUIRED

Much of the systems analysis and human factors research described for the ADIS Information Stage should continue during the Advisory Stage with the emphasis gradually swinging more towards dealing with rapidly changing dynamic information and with decision making.

Systems Analysis

Systems analysis should address traffic data acquisition, data fusion, and

traffic network balancing issues. Specific projects should be carried out in

the following areas:

- Traffic data fusion for link time prediction;
- Development of link-time database and statistics;
- Development of origin-destination statistics for traffic management purposes;
- Congestion leveling strategies that can be achieved by modulating predicted link-times;
- Communications architecture and technology to support additional features of the Advisory Stage;
- Analysis of productivity and travel time savings;
- Information exchange between commercial fleets and traffic information center;

- Content and information priorities for in-vehicle signing;
- Tradeoffs between passive and cooperative approaches to in-vehicle signing;
- Efficient algorithms for rerouting vehicles when traffic link-times are continually changing;
- Concepts for increasing the availability of real-time traffic information and link-times to other potential users (people at home who may defer travel, public transit, etc.).

Human Factors Research

Many of the human factors research topics described for the Information Stage would continue during the Advisory Stage. Additional studies should include:

- Driver Interface

  Communication of in-vehicle sign information

  Communication of route guidance instructions

  Potential of head-up displays

  Treatment of recurrent congestion information

  Use of m-vehicle signing to increase the safety and mobility of special groups

- Behavioral Issues

  What types of routes do drivers prefer?

  Do drivers prefer complete routing or only routing around congested areas?

  What is the time-savings threshold for rerouting?

  What types of alternate routes will drivers accept?

OPERATIONAL FIELD TESTS

The operational field tests during the Advisory Stage should build on those conducted during the Information Stage. The infrastructure already developed should evolve in concert with the development of new features for vehicles to make use of it. Tests during this stage should include:

Test 9 Extension of Information Stage Systems to the 50 largest metropolitan areas in North America.

Test 10 Extension of Information Stage Systems to include real-time traffic network link times computed and transmitted to vehicles equipped for minimum-time route selection and guidance.

Test 11 Large-scale test of traffic-probe concept in which vehicles travelling through the traffic network communicate the link-times they experience to the traffic information center for use in its data fusion calculations. This test should make heavy use of commercial delivery vehicles and public service vehicles.

Test 12 Test comparing the long-term utility and performance of several hundred ADIS-equipped vehicles with and without GPS correction for dead-reckoning navigation systems.

Test 13 Test comparing various passive and cooperative approaches to in-vehicle signing with respect to cost, performance, durability, and benefits.

Test 14 Extend Test 10 to include cooperative route selection and traffic control management in the Santa Monica Smart Corridor, Chicago, Washington D.C., and western Long Island.

Test 1.5 Test integration of public ADIS with special commercial functionality packages, developing the interfaces required to support public and private communications, database, and other interrelated issues.

DEPLOYMENT ISSUES

Deployment of ADIS at the Advisory Stage requires little additional equipment on-board the vehicle. The only major new piece of hardware is the GPS receiver for absolute position fixes for occasional correction of the dead-reckoning navigation system, and possibly a device for “reading” cooperative road signs for in-vehicle signing. The bulk of the additional features are implemented in software.

The role of the infrastructure greatly increases in this stage, however. The Traffic Information Centers must develop networks of sensors, communications channels, and information sources to acquire traffic data for an entire metropolitan area. Data fusion and communications software must be developed to digest all of the data, produce incident notices and link-times, and transmit them to the ADIS-equipped vehicles in the network. In addition, the infrastructure must determine which traffic signs are to be available for in-vehicle signing and implement the passive or cooperative technology.

The use of GPS implies that the global positioning satellite network will be in place with 24-hour coverage of North America by this stage [25]. Current launch schedules make this likely.

With the volume of information being transmitted to the vehicles in the Advisory Stage, RDS-like systems become impractical. The most promising communications channel is UHF-FM radio. This will require the assignment of a set of frequencies for this purpose — certainly within North America and preferably world-wide.

Obstacles and Constraints

Assuming the obstacles discussed for the Information Stage have been overcome by this time, the major obstacles for this stage will be obtaining the necessary radio communications channels and obtaining the capital investment required for the Traffic Information Centers.

The technical problems associated with developing ADIS, while formidable, will continue to be implementation problems rather than lack of the basic technology. Developing reliable on-board ADIS features that can be sold to individuals at an attractive price will remain an engineering challenge. The continuing increase in the capability of electronics and its declining cost will, however, serve us well.

THE COORDINATION STAGE

The Coordination Stage will have been reached when the vehicles and the infrastructure automatically exchange information to optimize the flow and safety of traffic over the entire network. Vehicles will continually report on traffic conditions encountered. The infrastructure will combine this information with all its other sources of information using predictive data-fusion models to provide coordinated routing and traffic signal control. Individual vehicles requiring emergency assistance can summon the required service (police, medical, mechanical, etc.) which will be automatically routed to the scene.

GOALS

During the Coordination Stage, we should expect to realize the full benefits possible from ADIS. The Traffic Information Center of the previous stages will evolve into a true Traffic Management Center (TMC) with responsibility for optimizing traffic flow throughout the network. Vehicles will serve as traffic probes by automatically reporting to the TMC on traffic conditions and link times they encounter as they travel through the network. Minimum-time route selection by individual vehicles, using information supplied by the TMC, will account not only for current traffic conditions but also predicted traffic conditions and the routes of other vehicles in the network. Traffic controls will be coordinated with vehicle routing to ensure the maximum effective capacity of the traffic network.

At this stage the vehicle equipment and the infrastructure should support (without significant additional equipment) an automatic MAYDAY feature. This feature will provide the capability to summon emergency assistance and provide vehicle location when initiated by the driver, or automatically, in case of accident.

SYSTEM DESCRIPTION

A typical ADIS system at the end of the Coordination Stage will have evolved to include the features listed in the table below.

Table 6. ADIS Features — End of Coordination Stage

- Global positioning system receiver for correcting errors in the dead-reckoning map-matching navigation system;
- Digital transceiver for receiving traffic informationand traffic network link times, and for transmitting information on local traffic conditions to the traffic management center;
- Coordinated route planning for minimum travel time (and other selectable criteria) that takes into account current and predicted traffic conditions, current and predicted traffic network link times, and the actions of other vehicles in the network;
- Color video display for maps, traffic information, route guidance, and in-vehicle display of road signs;
- Synthesized voice for traffic information and route guidance;

- Map database including nominal link times for the traffic network, turn restrictions, freeway signs, and general traffic signs;
- Businessdirectory and travel information databases integrated with map database;
- Electronic vehicle identification for toll debiting;
- Digital cellular telephone;
- Automatic MAYDAY, vehicle location, and coordinated dispatch of emergency services using the traffic information transceiver.

The infrastructure required to support these vehicles is listed in the table below.

Table 7. Support Infrastructure Required

- Traffic Information Center to collect, format, and transmit trafftc information and current traffic network link times;
- Traffic Management Center to coordinate traffic controls (signal timing and split, ramp metering, etc.) with known movement of vehicle traffic
- Emergency service centers for coordinated management of emergency service vehicles;
- Network of traffic information transceivers;
- Organization to prepare and distribute map, business directory, and travel information databases, including nominal link times for traffic network;
- Agencies to inspect and certify accuracy and currency of databases used for route guidance;
- Toll stations equipped to read vehicle ID.

Alternative Configurations

Coordinated route planning can be accomplished in a number of ways. The system description shown in Tables A5 and A6 assumes the route computation is done on-board the vehicle using information about traffic conditions and statistical measures representing the movement of other traffic. It may be possible to perform route selection at the TMC and transmit routes to individual vehicles or groups of vehicles. This could be done on a waypoint basis where an optimal route is provided from the waypoint being passed to the next waypoint in the direction of the intended destination. This is essentially the method used by AUTOGUIDE.

The automatic MAYDAY feature is shown using the traffic information transceiver to transmit the emergency service request and vehicle location information. It may be preferable to use automatic dialing on a cellular telephone directly to the service equipped to deal with the digital message.

POTENTIAL BENEFITS

During the Coordination Stage, we should realize the full benefits of ADIS. The effective capacity of the traffic network will be greatly increased as traffic is spread over the entire network, flowing in complete coordination with traffic controls. Individual trip times will be low and predictable. Effective fuel economy of the urban fleet will be maximized and air quality will be further improved.

The elimination of congestion “hot spots,” combined with the coordinated flow of traffic, will lead to fewer accidents. In turn, fewer accidents will lead to further reductions in congestion and so on. Emergency vehicles will be dispatched over “green” routes with automatic coordination of intersecting traffic. Motorists in any kind of difficulty will be able to summon emergency assistance directly to their location, thus saving lives and providing for rapid clearance of incidents.

INTERFACES WITH OTHER ELEMENTS OF IVHS

In achieving the Coordination Stage of ADIS, the ADIS sector and the Advanced Traffic Management sector must achieve a high degree of inter-communication and agreed allocation of tasks. This is, of course, necessary in the planning phase, but it will remain so during the operations phase. The traffic management centers, the traffic network, and the vehicles operating over it will become individual elements of a single intelligent system. IVHS will be a reality.

RESEARCH AND DEVELOPMENT REQUIRED

The Coordination Stage of ADIS requires additional systems analysis in the following areas:

- Allocation of coordinated vehicle routing tasks between individual vehicles and the Traffic Management Center;
- Development of models, simulations, and algorithms to support coordinated routing and traffic control;

- Vehicle routing algorithms to provide near-minimum travel time to all vehicles in the network;
- Relationship between the proportion of fleet equipped with Coordination Stage ADIS and the level of efficiency achievable by the traffic network;
- Fusion of traffic probe reports, origin-destination data, and other traffic information to manage the complete urban traffic network;
- Potential for using the real-time traffic, origin-destination, and routing information of the Traffic Management Center for planning and managing a multi-modal urban transportation system;
- optimal architecture and protocols for two-way communications between vehicles and the Traffic Management Center;
- Potential benefits of having vehicles communicate directly with each other and evaluation of alternative architectures to do so.

OPERATIONAL FIELD TESTS

Operational field tests for this last stage of ADIS should be directed at bringing about the full-scale implementation of those ADIS features shown in earlier stages to have cost effective benefits. The need for additional field tests may develop to explore the potential of newly developed technologies and concepts, but we will leave their definition to the future.

DEPLOYMENT ISSUES

The Coordination Stage of ADIS assumes that individual vehicles become part of the traffic information network. As they move through the network they transmit to the Traffic Management Center data on the traffic conditions they encounter. This requires cooperation from the driving public, first in purchasing (or leasing, etc.) the necessary equipment for their vehicles, and second in allowing information on their travel to be transmitted to the Traffic Management Center. Ideally, this information would include origin, destination, and route, as well as link-times experienced during the trip. It may be difficult to convince vehicle owners to make the required investment and equally difficult to convince drivers that the data analysis can be done in a way that does not invade their rights to privacy.

When fully implemented, the ADIS Coordination Stage will entail massive communication between Traffic Management Centers and the vehicles in the network. This can mean communicating with, and, in at least a statistical sense, tracking tens of thousands of vehicles in an urban area. This will require a significant investment in communications systems, data processing equipment, software, and radio channels.

To support the automatic MAYDAY feature, either the Traffic Management Centers must become involved in emergency calls as dispatch centers, or the emergency services must each make an investment in the equipment to receive the digital message and location information from the vehicles in distress. This is true whether the digital communications takes place over the traffic message channels or over the cellular telephone network.

OBSTACLES AND CONSTRAINTS

Coordinated traffic management, including route planning and traffic control, for a major urban area will require traffic assignment and control models that simply do not exist at this time – particularly since they must run faster than real time. Combine this with the challenges of fusing traffic data from a large number of disparate sources, and providing for priority routing of emergency vehicles and the problem becomes a formidable one. Its solution will require a large investment in the development and operation of Traffic Management Centers, but one that must be made to maintain the viability of our urban areas.

It will be difficult to obtain the rf frequency spectrum required to support the Coordination Stage of ADIS. It may be necessary to use advanced communications technology such as spread-spectrum [26] with its additional complexity and cost. Alternatively, it may be necessary to move towards localized communications between vehicles and electronic sign posts using rf or infrared. Again, this solution would increase the complexity and cost of the communications system, since hundreds or thousands of such sign posts would be necessary to cover a city adequately.

Perhaps the most difficult obstacle to reaching this stage of ADIS will be convincing individual drivers that it is in their own interest to make an investment in ADIS communications equipment for their vehicles, and to be comfortable with the continual exchange of information between their vehicles and Traffic Management Centers.

STANDARDS

Since motor vehicles are by their very nature able to move from place to place, it is essential that there be North American-wide, perhaps world-wide, standards for ADIS. These standards should cover the interface between the system in an individual vehicle and the infrastructure which must support it. These should include communications standards, data collection standards, functionality standards, database standards, and human factors standards as listed below.

ADIS Standards

Type Standard	Time Frame
Communications	
Hardware/Transmission	1994-1998
Protocols	1990-1992
Message Format and Content	1992-1993
Data Collection	
Traffic Data	1992-1994
Business Services	1996-1998
Data Base Updates	1994-1996
Functionality	
Certification	1990-1999
Maintenance/Repair	1990-1999
Handicap	1990-1999
Database	
Interface Standards	1990-1992
Requirements for Data Contents	1992-1994
Data Description Rules	1992-1994
Accuracy Standards	1994-1998
Human Factors	
Information Priorities	1990-1999
Sign Data	1990-1999
Position/Legality	1990-1999
Controls	1990-1999
Command Vocabulary	1990-1999
Handicap	1990-1999

Further breakouts of the above activities, showing objectives, description, and scope of each activity, are listed below.

Activity:

IVHS Standards Steering Committee and Secretariat

Objective:

Coordinate and monitor all IVHS Standard committees

Description/Scope:

Establish individual committees

Approve draft standards

Interface with Europe and Japan

Coordinate with NHTSA re regulatory process

Start date: 1990

Duration: Ongoing

Communications

Activity:

1. Protocols – Digital Communications Standard 1990-1992
2. Message Format and Content 1992-1994
3. Hardware/Transmission 1994-1998

Objectives:

1. Determine protocol with all possible communications

   National Communication Standard technology/medium, namely: rf, infrared, satellite, microwave, etc.

2. Support each of the elements in the Interface Database Standard

3. Take results of experiments and apply to each situation, i.e., urban, rural communications specifications

Description and Scope:

See objectives

start:

See above

Duration:

See above

Data Collection

Activity:

1. Traffic Data Standards: ATMS1992-1994
2. Database update 1994-1996
3. Business Services Status Stds. 1996-1998

(parking, theater, tickets, hotels, etc.)

Objectives:

Define the standards for each area by the appropriate time

Description and Scope:

To support all communication services which will exist

Start Date:

See above

Duration:

See above

Functionality

Activity:

Certification standards with regard to ADIS level 1, 2, 3

Maintenance/Repair standards

Handicapped standards

Objectives:

Develop standards

Description and Scope:

Define minimum acceptable level for ADIS Level I, II, and III Systems

Start Date:

1990

Duration:

10 years

I DataBase — Vehicle DataBase (A)

Activity:

Interface changeability standards

Objectives:

Research and develop all data fields for next 20 years

Identify how and when likely to be used and establish timeframes

Description and Scope:

All type vehicles; Commercial, Public, and Private (Military)

Research literature for all functions in vehicle

Conceptualize future plans with industry and academia

Establish workshop

Start Date:

1990

Duration:

24 months

DataBase — Vehicle DataBase (B)

Activity:

Define content requirements

Objectives:

Content Standards of each field

Description and Scope:

Develop requirements to satisfy minimum standards

Start Date:

1992

Advanced Driver Information Systems

Duration:

24 months

DataBase — Vehicle DataBase (C)

Activity:

Data description and rules

Objectives:

Identify uniform methods of encoding data

Description and Scope:

Identify field length

Data element code

Geographic position description

Compilation of Data Element Dictionary

Start Date:

1992

I DataBase — Vehicle DataBase (D)

Activity:

Accuracy and completeness specification

Objectives:

Define levels of quality

Description and Scope

Level 1 standard - I - 1994-1995

Level 2 standard - A - 1995-1996

Level 3 standard - C - 1997-1998

Start Date:

See above

Duration:

See above

Human Factors

Human factors steering committee

Activity:

Information priorities

Sign content

Position/legibility independent

Controls subcommittees

Command vocabulary

Handicapped

Start Date:

Now

Duration:

Continuous (10 years)

Advanced Driver Information Systems

Table 8: Advanced Driver Information Systems Milestones

	INFORMATION STAGE	ADVISORY STAGE	COORDINATION STAGE	
19	90 19	95 20	00 20	05 2010
R&D				
System Analysis	xxxxxxxxx xxx	xxxxxxxx xxx	xxxxxxxxxxx	
Human Factors	xxxxxxxxxxxx	xxxxxxxxxxxx		
Driver Interface	xxxxxxxxxxxxxxxxxxxxx	xxxxxxxxxxxx	xxxxxxxxxxxx	
Cognitive Analysis	xxxxxxxx			
Utilization	xxxxxxxxx			
Field Operational Tests				
PATHFINDER	xxxxxxx			
Real-time ADIS	xxxxxxxxxxxxxx			
Low-cost ADIS	xxxxxxxxxx			
In-vehicle Signing	xxxxxxxxxx	xxxxxxxxxx		
Alternative Communication	xxxxxxxxxx	xxxxxxxxxx	xxxx	
Architecture		xxxxxxxxxxxx		
Experimental ADIS in 50 Cities				
Large-scale Traffic probes				
Cooperative route selection				
Deployment		xxxxxxx and		
100K L.A. Vehicle	xxxxx	continuing		
Real-time Traffic	xxxxxxxx	xxx and continuing		
Information	xxxxxxxx	xxx and continuing		
Automatic Tolls	xxxxxx and continuing	xxx and continuing	xxx and continuing	
OEM Navigation on U.S.	xxxxx	xxx and continuing	xxx and continuing	xxx and continuing
Vehicles		xxxx and continuing	xxxxx	
24-hour GPS Availability		xxxxxxxxx		
RF Spectrum Availability		xxxx		
ADIS in 50 cities				
Traffic Probes				
Traffic Transceiver Network				
Cooperative Route Selection				

ESTIMATED FUNDING SUMMARY

Table 9 presents a summary of the estimated funding required to achieve the goals under ADIS. It is estimated $1.134 billion will be required to perform the research and development and conduct the operational field trials necessary to ensure the deployment of ADIS over the next 20 years. This funding estimate includes both private and public investment. It should be pointed out that the research and development required for ADIS should also serve a portion of the generic needs of other elements in the IVHS program. For example, there are human factors issues concerning controls and displays for ADIS that are common to Advanced Vehicle Control Systems (AVCS).

' 'able 9. Estimated Funding Summary

	Research & Development	Operational Trials	Total
	Millions of Dollars		
Information Stage 1990 — 1995	$ 30	$ 160	$ 190
Advisory Stage 1995 — 2000	$71	$ 237	$ 308
Coordination Stage 200 — 2010	$ 119	$511	$ 630
Totals	$220	$908	$ 1,128

Advanced Driver Information Systems

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Intelligent Vehicle Highway Systems

Advanced Vehicle Control Systems

MOBILITY 2000

Dallas 1990

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EXECUTIVE SUMMARY

The reserve capacity of our roadways — particularly urban and intercity freeways — is quickly being used up. Adding more lanes to the existing system has become increasingly expensive, impractical, and unacceptable both politically and environmentally. Projected increases in demand will increase congestion dramatically from current levels — a five-fold increase in delay is predicted over the next two decades. Over this same period, the number of crashes, injuries, and fatalities will increase by 60 percent unless measures are taken to decrease the accident rate. The application of advanced technology to motor vehicles and highways provides the opportunity to significantly enhance highway safety and improve vehicle throughput.

Advanced Vehicle Control Systems (AVCS) are vehicle- and/or roadway-based electro-mechanical and communications devices that enhance the control of vehicles by facilitating and augmenting driver performance and, ultimately, relieving the driver of most tasks on designated, instrumented roadways. Automated roadways will require both vehicle and highway-based equipment and will utilize vehicle-to-vehicle and roadway-to-vehicle communication systems developed in other Intelligent Vehicle Highway System (IVHS) initiatives such as Advanced Driver Information Systems (ADIS) and Advanced Traffic Management Systems (ATMS). AVCS holds the promise of greatly increasing highway vehicle throughput, speed and safety without major construction of new lanes.

Roadway electrification is a related R&D initiative that is included in AVCS. Roadway electrification, or other clean vehicle propulsion systems, will be essential to ensuring that the increase in vehicle throughput will not be accompanied by an increase in pollution.

An intensive, systematic, multi-year program of research, development, and evaluation is required to bring the AVCS concept to fruition. A large number of alternative approaches will undergo system development and evaluation in the coming years and decades. Four critical requirements of AVCS system development are:

- Early identification and analysis of targets of opportunity to enable the establishment of system functional goals.
- A full accounting of the role of humans in the system; specifically of the "human operating characteristics" likely to affect system effectiveness.
- Rigorous evaluation at several key stages of system development to assess AVCS performance, reliability, benefits, and disbenefits.
- Coordinated government-industry effort with clearly established organizational roles within each system development effort (although the roles may vary across different AVCS developments .

Two R&D tools critical to the AVCS initiative are a research driving simulator and a dedicated AVCS roadway test facility. The application of simulation technology will permit highly controlled and safe evaluation of AVCS concepts and configurations focusing on driver performance in specific traffic or potential accident situations under baseline and AVCS conditions. The dedicated AVCS roadway test facility will allow test/evaluation of prototype systems before pilot testing on roadways open to the public.

Program Plan

Three levels of AVCS research, development, operational test, and deployment are envisioned:

- AVCS-I (Individual vehicle Control/Autonomous Driver-Vehicle Systems) includes only systems that are vehicle-based; i.e., that do not require the existence of roadway or roadside equipment.

  AVCS-I perceptual enhancement, warning, and collision avoidance systems will help drivers better sense impending danger, sense lapses in their judgment or skills, and eventually even compensate for some of their errors. The principal benefit of

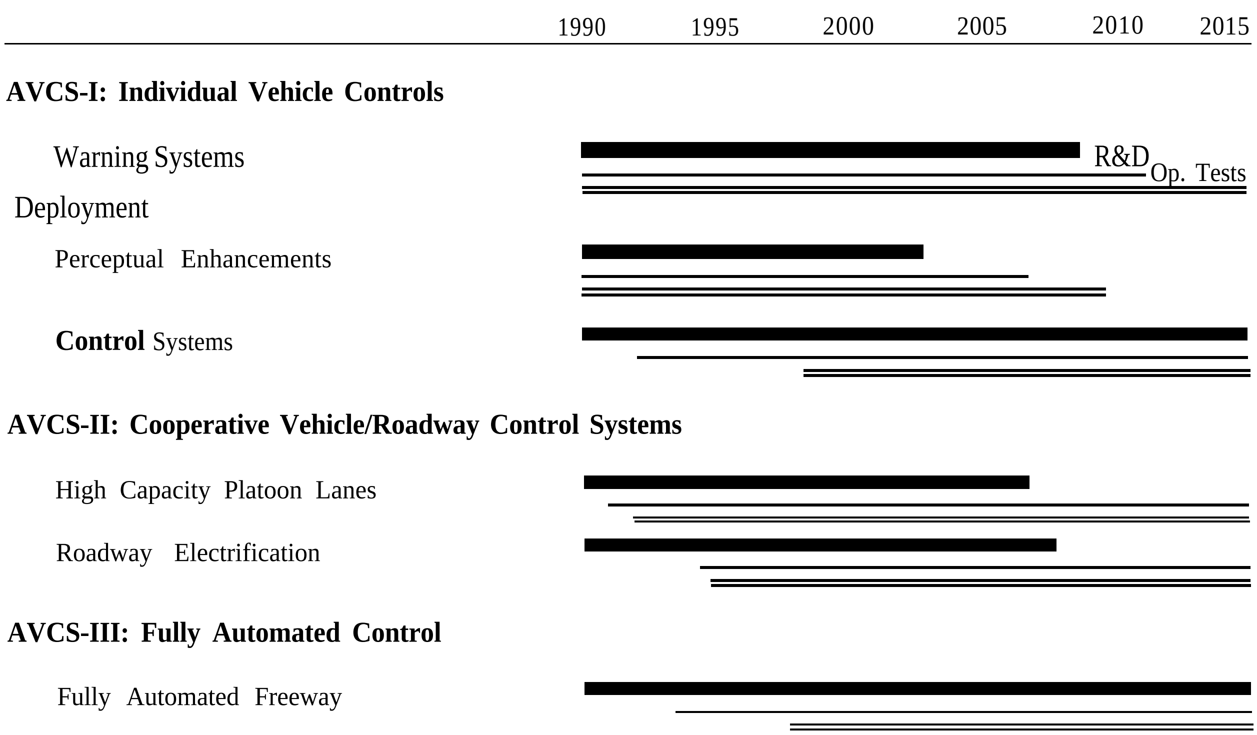
  AVCS-I will be enhanced safety.

- AVCS-II (Cooperative Driver-Vehicle-Highway Systems) begins implementation of a driver-vehicle-highway system whereby vehicle lateral and longitudinal position is controlled when suitably equipped vehicles are operated on dedicated instrumented lanes. Vehicles would enter and exit such lanes voluntarily and under manual control, but would be under full or partial system control while in the lanes. AVCS-II involves modifications to both vehicles and highways and roadway-to-vehicle and vehicle-to-vehicle communication systems. Platooning is the principal focus of current AVCS-II system development. In platooning, vehicles are electronically linked into “platoons” on one lane of a freeway. Platooning offers the primary benefit of a several-fold increase in lane capacity and the secondary benefit of enhanced safety.

- AVCS-III (Automated Vehicle-Highway Systems) represents the culmination of the AVCS initiative – complete automation of the driving function for suitably equipped vehicles operating on specially-equipped urban and intercity freeway facilities. It provides “automatic chauffeuring” of vehicles from arrival at the freeway on-ramp to departure from the freeway off-ramp. The benefits of AVCS-III will be the dramatic increase in freeway throughput and the enhanced safety associated with the elimination of the human factor in vehicle control.

Figure 1 provides an overview of AVCS research, development, and deployment over the coming decades. Note the considerable overlap among the AVCS-I, AVCS-II, and the AVCS-III initiatives.

Figure 1: Mobility 2000 – AVCS Program Plan



AVCS is the most complicated and far-reaching of the IVHS technologies. As such, it requires the largest investment over the longest period of time to reach fruition. The estimated cost (public plus private) of AVCS research, development, and field operational testing is $2.5 Billion. In addition, it is estimated that an additional one-fourth to one-half billion dollars will be required to construct and operate the needed specialized facilities to support AVCS development and evaluation over the next two decades.

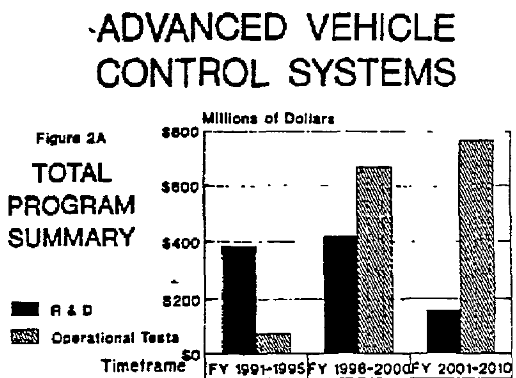
Figure 2 illustrates projected expenditures on AVCS-I, -II, and -III over the next two decades. The total expenditures will represent approximately 12 thousand person-years of R&D and field operational testing — an average of 600 person-years per year over the next 20 years.

Successful implementation of AVCS will require a national organization to steer AVCS development and implementation, and international cooperation — particularly in the areas of operational field studies and system architecture standards. It will require the development of technology transfer protocols that protect patent rights while supporting collaborative technology development efforts within the U.S. and internationally. Financial incentives for private sector investment in AVCS and other IVHS technologies will have to be increased. Along with an increase in incentives, there must be a decrease in the tort liability risk of AVCS developers, both public and private. While AVCS will greatly decrease accidents overall, it is inevitable that some accidents will occur. The harm suffered by a few cannot be allowed to prevent the benefits from being gained by the great majority.

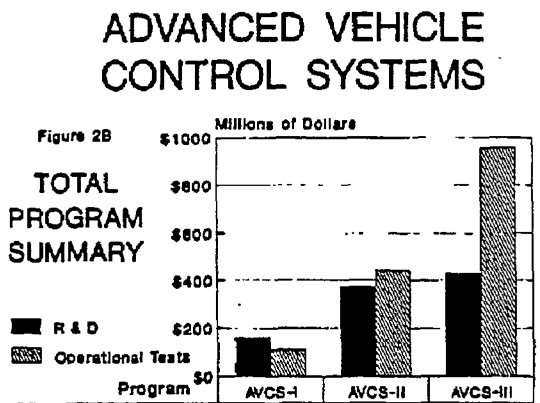
Public acceptance of AVCS will also be a principal concern. The costs of AVCS technology must be allocated in an equitable manner. Public education and marketing efforts must be undertaken to ensure that AVCS technology is not perceived as a threat to contemporary lifestyles, privacy, individual autonomy, or safety.

Some political opposition to AVCS should be anticipated. For example, highway builders and their suppliers may oppose the automation concept since there will be a deemphasis of "new concrete" construction. Organizational interests and concerns need to be addressed proactively to ensure that AVCS implementation is not unfairly damaging to any group, but that the development of AVCS concepts is not defeated by special interests to the detriment of the general public.

Figures 2A & 2B Total Program Summary



	FY 1991-1995	FY 1996-2000	FY 2001-2010
R & D	$385	$420	$160
Operational Tests	$75	$670	$765
Totals:	$460	$1,090	$925



	AVCS-I	AVCS-II	AVCS-III
R & D	$160	$375	$430
Operational Tests	$110	$440	$960
Totals:	$270	$815	$1390

Conclusions and Recommendations

AVCS technology has the potential to dramatically decrease traffic crashes and congestion, particularly on urban and intercity freeways. Achievement of these goals will require scientific, engineering, institutional, and socio-political initiatives that will be great in magnitude and scope, but small compared to the benefits.

The following recommended actions will ensure the full realization of AVCS benefits:

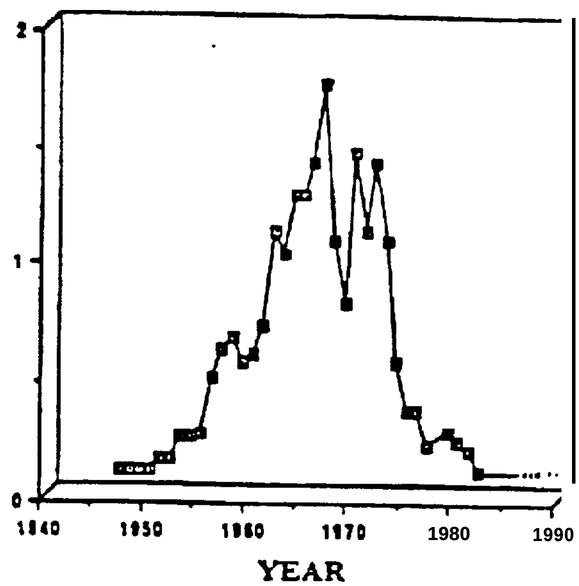
- Create a national organizational structure to oversee and coordinate public-private partnerships for AVCS research development, operational test, and deployment. An integral part of this partnership is the ability to pool funds.
- Provide sustained funding at levels sufficient to support a comprehensive, multi-faceted AVCS program. Critical R&D requirements include:
  - Definition of the ultimate AVCS architecture as soon as possible so that near-term systems will be upwardly compatible.
  - Development of system reliability and fault tolerance technologies and standards to ensure fail-safe systems.
  - Development of analysis tools such as driving simulators and AVCS test facilities.
  - Analysis of the human factors of driver-vehicle-highway interaction under baseline and AVCS conditions.
- Obtain legislation or implement policy to increase financial incentives and reduce liability risks for AVCS developers.

1.0 INTRODUCTION

1.1 THE PROMISE OF INTELLIGENT VEHICLE HIGHWAY SYSTEMS (IVHS)

The level of service on the principal road systems within most major U.S. cities has dropped to the lowest level on the scale for much of the day. With reserve capacity quickly being used up, additional demand will increase congestion dramatically even from current levels — a fivefold increase in delay is projected over the next two decades. Over this same time period, the number of crashes, fatalities, and injuries can be expected to increase 60 percent assuming that the current fatality risk per vehicle mile is expanded proportionate with the Federal Highway Administration (FHWA) medium estimate of VMT growth. Similar conditions existed after World War II when demand on the system took a quantum jump, and the highways simply did not have the capacity. What was needed then, and what is needed again, is a way to substantially increase the capacity and safety (since much of the delay is due to accidents) of the system. Doubling of the lane capacity and reducing the accident rate by 60 percent was accomplished **in** the 1950's and 60's by grade separating the intersections and by controlling access. The freeway was a marvelous improvement in level of service and safety. It greatly increased the competitive position of the U.S. private sector. It dramatically improved people's mobility and quality of life.

Figure l-l Freeway Construction in California



However, as the freeway system matured, problems began to appear with over demand, congestion, accidents, air quality deterioration, and foreign energy dependency. Freeway development followed the classic industrial decay curve cycle. Every new system must be augmented by, or replaced by, new systems to keep up with changing demands. As an example, the freeway development process in California peaked in the early 1960's (see Figure l-l). This would have been the logical time to start the development of automated vehicle features, thus continuing the improvement in system efficiency to match the increase in demand. Instead, we have waited until the early 1990's, resulting in two decades of worsening conditions on our systems.

Development of the next generation system holds the same or even more promise as its predecessor, the freeway. A doubling or tripling of lane capacity and a dramatic increase in safety is well within reach of the technology.

IVHS technologies - Advanced Driver Information Systems (ADIS), Advanced Traffic Management Systems (ATMS), and Advanced Vehicle Control Systems (AVCS) - can be deployed, in combination, within the same time frames and at no greater cost than the freeway. The 10-year development phase and 20-year deployment phase indicated for IVHS matches the 30-year freeway development phase (1955-1985).

IVHS can realize dramatic improvement in the productivity of private and public transportation and goods movement. It will improve efficiency on freeways, city streets, and in parking structures. The technology is robust and flexible, allowing capacity to match varying demand characteristics and land use patterns.

IVHS offers the only hope of really solving transportation problems instead of merely managing worsening conditions over time. What is called for is no more than what transportation professionals have already done twice in this century with paved roads and freeways — a major technological advance.

1.2 DEFINITION

Advanced vehicle control systems include individual vehicle controls, cooperative driver-vehicle-highway systems, and eventually full automation on certain roadways. Such systems are possible today because of the tremendous advancements that have been made in vehicle and roadway sensors, servo systems, image processors, computers, and communication systems. While the other components of IVHS make driving more efficient by providing the driver with better information about the macro-level conditions that affect his decision-making, the AVCS can provide information about highly localized and rapidly changing conditions in his or her immediate vicinity and can initiate actions based on those conditions. AVCS, therefore, can have more significant impacts on the productivity (capacity, speed) and safety of road travel. AVC systems can enable drivers to operate their vehicles closer together while maintaining a higher level of safety than at present, by enhancing drivers' ability to detect and avoid hazards and eventually by assuming responsibility for controlling the speed, steering, and braking of the vehicles. By compensating for the limitations of the human driver, AVCS makes it possible to achieve step function increases in road capacity and safety rather than just offering incremental percentage improvements.

1.3 BACKGROUND

Research on the technologies associated with automating highway operations started more than 30 years ago. These were mostly small private sector efforts. The support from the government for these efforts was late in coming and contained only token funds. Despite the great promise shown by these efforts, the transportation community was busy building highways and did not take the initiative to establish the well-funded, focused effort needed to advance the technologies to the stage where they could begin the long deployment process. The addition of new highway lanes has now become less practical. This, coupled with the availability of new electronic and communications technologies, has made high technology solutions more feasible and politically, economically, and environmentally attractive. Highway transportation research and development efforts are being refocused toward AVCS and other IVHS approaches to relieve congestion and improve safety.

1.4 SCOPE

Advanced vehicle control systems are one of the four major components of the IVHS program that were described by the Mobility 2000 group in San Antonio, February 1989. The other components are Advanced Traffic Management Systems, Advanced Driver Information Systems, and Commercial Vehicle Operations. The last category is not independent of the other components, but rather was created to signify that the needs of commercial vehicles are different in many cases from those of personal vehicles. AVCS will build upon the technologies developed and deployed during the other facets of the overall IVHS program to solve the nation's safety and congestion problems.

The technologies involved in advanced vehicle control systems are very extensive, but for the purposes of this report are generally limited to:

- Driver warning, vision enhancement, and assistance systems
- Automatic steering control or automatic headway control — platooning
- Obstacle avoidance or automatic braking
- Automatic trip routing and scheduling
- Control merging of streams of traffic
- Transitioning to and from automatic control

AVCS technology is broad-based, requires a multimodal approach, extends to both rural and urban needs, and involves the movement of both people and goods. The architecture of AVCS must also be flexible enough to accept higher levels of technology as they are produced.

1.5 GOALS AND OBJECTIVES

AVCS enhances the control of vehicles by facilitating and augmenting driver performance and, ultimately, relieving the driver of most tasks.

The major goals of programs to develop and deploy advanced vehicle control systems are the same as for the IVHS Program as a whole: congestion relief, improved safety, increased speed and trip-time reliability, travel convenience, and industrial competitiveness. AVCS differs from other IVHS work in that it goes beyond the efficient management of the existing limited system and has the potential to provide quantum improvements in throughput and safety.

More specifically, the AVCS program has set the following goals:

- Long-term Goals:
  - Solve the urban congestion problem
  - Develop an accident free ground transportation system
  - Reduce the negative environmental impacts of the transportation system levels.
  - Regain energy independence in the United states.
- l0-year Goals:
  - Deploy AVCS arterial systems and vehicle products which demonstrate the capability for 50 percent reduction in accident rates when used nation-wide.
  - Deploy freeway-based AVCS system which at least doubles lane capacity.
  - Design and demonstrate features of an AVCS-based, higher speed or higher productivity Post-Interstate Freeway Network.
  - Deploy freeway-based AVCS system with new features of modal and technology integration — e.g., roadway electrification; new transit operations; remote or automated parking; and goods movement.

1.6 REPORT OVERVIEW

This report is divided into five sections including this introductory section. Section 2 reviews critical AVCS program planning and system development considerations. The third section presents the program plan for the development and implementation of AVCS and brief scenarios illustrating the use of AVCS in the near, mid and long term highlighting in a qualitative sense the benefits to be expected from the implementation of such systems. It includes a schedule for the research, demonstration, and deployment of each of the components of advanced vehicle control systems. The fourth section describes the implementation issues associated with organization and funding of the program. Also addressed in Section 4 are institutional issues associated with the development of advanced vehicle control systems. Section 5 presents conclusions and recommendations resulting from the overall study of the AVCS technology.

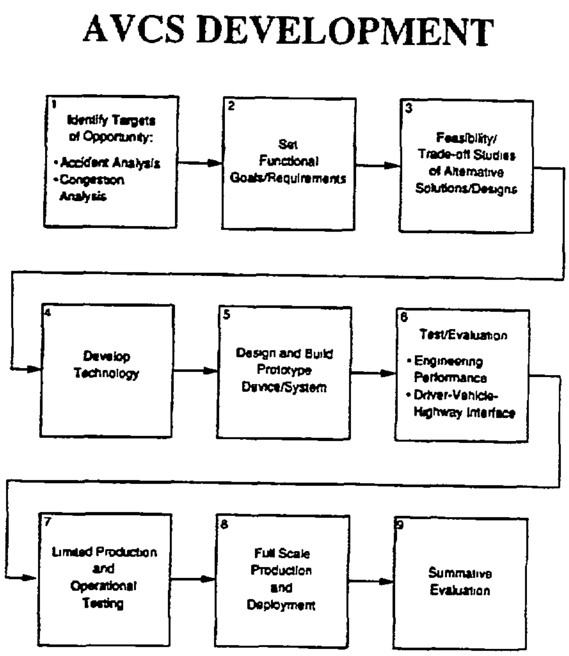
2.0 PROGRAM PLANNING AND DEVELOPMENT CONSIDERATIONS

2.1 Introduction and Overview

An intensive, systematic, multi-year program of research, development, demonstration, and evaluation is required to reach the goal of improving highway safety and reducing congestion through the application of AVCS concepts. It is envisioned that a large number of individual AVCS technologies will undergo system development in the coming years and decades. Although there will be many different specific initiatives proceeding somewhat independently, an overall program plan and common system development protocols are needed to ensure that the AVCS concept progresses systematically. This chapter overviews major AVCS development initiatives and discusses critical AVCS planning considerations. It addresses targets of opportunity and risks to be avoided in AVCS development. Three levels of AVCS technology are anticipated and planned:

- AVCS–I: Individual Vehicle Control (Autonomous Driver-Vehicle Systems)
- AVCS–II: Cooperative Driver-Vehicle-Highway Systems
- AVCS–III: Automated Vehicle-Highway Systems

Figure 2.1 Conceptual Phases in AVCS Development



This program plan outlines activities and milestones necessary for systematic research, development, demonstration, and evaluation of systems and concepts pertaining to AVCS–I, II, and III. A conceptual development model for AVCS applications, regardless of technological complexity, is shown in Figure 2-1. This model identifies nine conceptual phases in AVCS development from initial problem assessment through summative evaluation of system effectiveness. The system development model serves as a structure for addressing AVCS planning requirements and concerns.

2.2 Planning Considerations

The development of an AVC system involves transforming a target of opportunity into a set of requirements and then into an actual functioning system. Since AVC systems involve important human-machine interactions, the development of system requirements and specifications includes an analysis of human behavioral implications. AVC systems are to be viewed not merely as vehicle and/or highway systems, but rather as interventions that will have important influences on the dynamic performance of the total driver-vehicle-highway system.

There are a number of important considerations to be addressed to ensure that the development of an AVC system will result in a successful application of technology. Four critical requirements of AVC system development are:

- Early identification and analysis of targets of opportunity to enable the establishment of system functional goals.
- A full accounting of the role of humans in the system; specifically of the "human operating characteristics" that are likely to impact system effectiveness.
- Rigorous evaluation at several key stages of system development to assess AVCS performance, reliability, benefits, and disbenefits.
- Coordinated government-industry effort with clearly established organizational roles within each system development effort (although the roles may vary across different AVCS developments).

These critical considerations in system development, and recommended approaches to addressing them, are discussed below.

2.2.1 Identification of Targets of Opportunity and AVCS Requirements Definition

The initial phases of AVCS development (i.e., blocks 1 & 2 in Figure 2-1) assess the problem at hand and define the most important elements of the desired solution. Targets of opportunity are identified and system functional goals are set. This involves a process of prioritizing, whereby safety, congestion, and/or other problems to be solved (or opportunities to be exploited) are compared to determine where the needs, opportunities, and probabilities of success are likely to be greatest.

Identification of targets of opportunity relating to AVCS accident countermeasures involves the use of accident data to characterize relevant accident types in terms of patterns of occurrence, prevalence, and severity. Causal and contributory factors associated with relevant accident types are analyzed and used to define ways AVCS can reduce crashes and fatalities. The most important causal or contributory factor in most crashes is a failure of information processing by the driver in the seconds preceding the crash. An understanding of driver information processing in the context of the interactions of driver, vehicle, and highway environment permits the setting of functional goals for the AVCS.

Identification of targets of opportunities relating to congestion-related AVC systems follows a similar line of thought and research. Traffic congestion is analyzed in terms of the types of traffic tie ups that occur, their relative severity, and their causes and contributory factors. Problem assessment analyzes the causal relationships to identify specific targets of opportunity. For example, studies of platooning as a congestion countermeasure first assess the problem size and characteristics of highway congestion due to vehicle spacing, and then analyze related driver, vehicle, and highway factors. An understanding of vehicle spacing parameters and their relation to highway congestion permits the derivation of desired vehicle spacing under a platooning system. The specification of acceptable or desired spacing distances becomes a platooning system functional requirement.

2.2.2 Human Factors Issues

By definition, AVC systems will change the way that drivers perform the driving task. AVC systems will enhance perception, aid working memory, support driver decision-making, augment responses, or otherwise change ways that drivers perceive, make decisions, and respond. If the human factors impacts of a prospective AVCS are not folly understood and controlled, the benefits may be nullified or, even worse, unacceptable hazards or other negative side-effects may be crested. For this reason, human factors considerations permeate the AVCS development process.

Driving is a dynamic information processing activity. In-depth studies of accident causation have found that driver information processing errors are predominant as accident causes or contributory factors. Similarly, urban roadway congestion problems are related to driver information processing capabilities; for example, the capability of drivers to react quickly and appropriately to potential hazards. Human information processing models encompass mental or behavior activities such as sensation or perception, working memory, decision-making, response execution, and attention. Each of these subsystems of information processing has limitations in terms of speed, quantity of information, and types of information that can be handled reliably. And, there are limits on the total "mental energy" or mental resources available to support the information processing. Stressing any one subsystem of human information processing or the total system beyond its capacity may result in unreliable human performance.

Successful AVC systems will generally act by enhancing one or more element of human information processing. For example, lateral object detection devices (as might be employed to facilitate lane changing by heavy trucks) have the potential to enhance perception and decrease the workload on the driver, thus improving driver performance in general. However, an undesirable effect may be that the driver relies too heavily on the AVCS and thus fails to use side mirrors or other existing visual cues. Occasional system false positives or false negatives alter the driver's decision process in a detrimental way.

Apart from human information processing, there are a number of human factors issues to be addressed for each AVCS. These include:

- Driver education or training requirements. What specific knowledge, skills, and attitudes are required to operate the device, and do they need to be trained?
- Public acceptance. Individuals may react negatively to AVCS concepts due to perceived inconvenience, sense of loss of personal freedom, difficulty of device use, decrease in the enjoy-

ment of driving, incorrect assessment of risks (e.g., platooning may be judged by the public as being unsafe when it may actually be more safe). Each AVCS development should address how to maximize public acceptance through public education, system design, driver training, or other means.

- Impact of the AVCS on important subgroups of drivers; e.g., Alcohol or drug-impaired
  - Elderly drivers
  - Physically impaired or handicapped
  - Illiterate or low mental ability
  - Anthropometric extremes
  - High-risk groups (e.g., young males, long-haul commercial drivers)
- Failure mode human factors — how the human reacts to system failure (e.g., in the event of temporary failure of a platooning system, will drivers revert safely to normal highway spacing).

2.2.3 Evaluation Protocols

Several phases of AVCS development will involve the application of sophisticated evaluation protocols. Each AVCS development is likely to involve several different evaluation methods, with the selection of methodologies dependent on the phase of system development, specific evaluation questions to be answered, and information attainable from different approaches. Some of the more important of the evaluation protocols and methods to be employed in AVCS development include:

- Engineering test and evaluation to determine device reliability and performance parameters.
- Human engineering studies on the design of AVCS human-machine interfaces; includes evaluation of AVC systems in terms of existing human factors guidelines and/or new human factors research specific to AVCS concepts and individual AVCS devices.
- Driving simulation studies to permit safe and controlled experimentation, targeted toward a specific traffic or accident scenario, to determine the impact of AVC systems on driver behavior and on crashes and congestion.
- Instrumented vehicle tests to determine how AVC systems affect vehicle handling and control characteristics.
- Field operational tests before full-scale device deployment to demonstrate AVCS effectiveness.
- Post-deployment summative evaluations on a broad scale (e.g., national level) to document AVCS benefits and/or disbenefits.

The development of each AVCS concept will be subjected to rigorous evaluation using the above and other appropriate methodologies. More systematic research and evaluation protocols will be developed to apply to AVC systems. The driving simulator is particularly important as a research and evaluation tool for AVCS especially with regard to the human factors and safety aspects. The application of simulation technology to AVCS R&D will provide several distinct capabilities that cannot be achieved by other means:

- Highly controlled experimentation on specific traffic or accident scenarios.
- Economical testing of many different variations and modifications of AVCS configurations and characteristics.
- Testing of AVC concepts before the actual hardware exists.
- Safe laboratory testing of experimental devices when other evaluation methods would expose drivers to hazardous conditions.
- Collection of detailed, dynamic data on driver performance under both baseline and AVCS conditions.

2.2.4 AVCS Development: Participants and Roles

Joint government-industry effort is needed to optimize the success of each AVCS development and the overall AVCS initiative. There are several distinct groups of individuals, institutions, and organizations that will be involved in the AVCS program and specific system developments. Possible participant roles may include:

- The Federal Government will define functional requirements and set priorities for safety-related issues.

- Federal, state, and local governments will define functional requirements and set priorities for congestion-related issues.
- State and local governments will provide highway facilities for operational test projects.
- Research organizations and educational institutions with expertise in human factors, highway transportation systems, highway safety, computer systems, artificial intelligence, etc., will provide technical resources and facilities.
- Major U.S. automotive companies and their suppliers will provide expertise, concepts, and technical capabilities and facilities for the development and testing of devices, systems integration, and demonstration of advanced vehicle control capabilities.
- Individual inventors and small entrepreneurs will provide concepts and develop and perform preliminary tests of new technology.

Organizational roles will vary depending on the size and nature of the AVCS development effort. For example, AVCS-I developments will require little involvement of state and local governments since these devices will be vehicle-based and will require no infrastructure changes. At the other extreme, AVCS-III will involve large operational tests on highly instrumented highway facilities. Extensive state and local participation in system development is anticipated, particularly in relation to system demonstrations. Since organizational roles and responsibilities will vary across different AVCS developments, they will need to be clearly defined and communicated for each major development in order to facilitate and enhance the system development process.

3.0 PROGRAM PLAN

3.1 AVCSN-I: INDIVIDUAL VEHICLE CONTROL

3.1.1 Scenario

It's 6:30 a.m. John is leaving his suburban home to drive the 40 miles to his office just inside the city limits. The sun won't be up for 10 more minutes, it's dark and a morning fog reduces visibility even further. While backing out of his driveway, John hears the signal of his Near Field Proximity or Backup Warning System. He immediately applies the brakes. He leaves the car and finds that his son's bicycle was carelessly left behind the car. While moving the bike, John speculates on how much money the backup warning system has saved him this past year alone. As he cautiously proceeds towards the main arterial road, he switches on the Infrared Roadway Enhancer and is able to see the outline of a pedestrian crossing the street 100 feet ahead. He silently gives thanks to the engineers who came up with that handy gadget.

Before he leaves his neighborhood, John checks his Vehicle Diagnostic Status Panel and notices that he has enough gas for two more trips to work, but that his left rear tire is dangerously low on air. John stops at the next service station, fills the tire with air, the tank with gas, and then continues on to work.

John feels relaxed while driving to work knowing that his on-board computers are monitoring all vehicle systems and helping him drive safely under all conditions. As he leaves the local streets, John increases his speed towards 55 mph. Noting some heavy traffic in his lane ahead, he depresses his left turn signal. Immediately the Lane Occupancy Warning System informs him a vehicle is accelerating and moving to close a gap in the left lane. John decides to wait for a safer gap. Finding one a few minutes later, John effortlessly moves to the next lane, thinking the Enhanced High-speed Steering Assist option he purchased was worth the extra money.

Since the traffic is moving smoothly, John switches on his Adaptive Cruise Control and Lane Keeping Systems. These allow him to maintain a set speed in lane center while keeping a safe distance behind the car ahead. His Automatic Braking System and Antilock Brakes will also give John added protection in the event of sudden stops by the cars ahead. John relaxes, and begins to think about his first meeting of the morning. An alerting signal from the Driver Vigilance Monitor brings John's attention back to his driving task, and he silently reminds himself he is still in control, and must be alert to unforeseen dangers and watch for his exit.

A short time later, John exits the freeway, drives to the industrial park, and maneuvers over the patched-up roads in poor condition from the hard winter. John's car, equipped with an Active Suspension System, provides a comfortable ride and stable platform for his coffee mug. He turns into the company parking lot, finds and moves into an empty slot, where the car automatically slows, and stops inches from the car in front of him. The Automatic Braking System not only protects John on the highway but doubles as a parking aid. He can still remember the old days when parking involved kissing bumpers in parking lots in order to accommodate all the employee cars. Insurance rates are now lower because of the new safety devices and help offset their costs in his new car.

3.1.2 Overview

AVCS-I includes only those advanced vehicle control systems that are vehicle-based, i.e., they are totally self-contained within the vehicle and do not require the existence of any roadway and/or roadside equipment to satisfactorily perform their desired function(s). The principal benefits provided by the majority of the devices or systems envisioned to be included in this category will be significant reductions in the yearly toll of crashes, fatalities, injuries, and economic costs that result. The technology of the AVCS-I devices or systems will, in addition, serve as the basis for control systems envisioned to be included in AVCS-II and AVCS-III. AVCS-II and AVCS-III systems will further improve safety and significantly increase the throughput of **our nation's** highways (and thereby reduce congestion, especially in urban areas).

There exists significant potential for improvement in traffic safety through application of AVCS technology, initially by means of warning and collision avoidance systems and eventually through various stages of automatic control. In recent years, there have been dramatic advances in the development and application of high technology to motor vehicles and highways, including various vehicle and roadway sensors and servo systems, image processors, computers, and communication systems. Development of these technologies has focused on increasing vehicle performance, driving comfort, and convenience and more recently increasing safety and reducing traffic congestion. The possibility of greatly increased highway safety is clearly evident as one considers technology development trends and the potential for crash avoidance measures provided by these technologies through: (a) reduction of driver exposure to high risk environments, (b) reduction of the incidence of high risk driver behavior, (c) facilitation of earlier driver response to an imminent crash by providing additional seconds of warning and stopping time, and (d) improvement of the overall quickness and quality of driver-vehicle response in a likely crash scenario.

Studies have shown that 50 percent of all rear end and intersection-related collisions and 30 percent of collisions with oncoming traffic could have been avoided had the driver recognized the danger 1/2 second earlier and reacted correctly. Over 90 percent of these crashes could have been avoided had the drivers taken appropriate countermeasures 1 second earlier. The continuing development of innovative electronic, computer, information and communications technology by the engineering and scientific communities has the potential to provide these fractions of seconds to expand the driver's margins for safety in high-risk environments. AVCS-I systems can help drivers better sense impendmg danger, sense lapses in their judgement or skills, and eventually even compensate for some of their errors.

This is not a novel concept; indeed, it has been commonplace in aircraft design for years. Modem air transports are equipped with a wide array of devices that monitor the condition of the aircraft (e.g., fire detection or hatch closure monitoring systems), the environment in which it is being operated (e.g., weather radar), as well as the way it is being operated (e.g., stall warning indicators). Collectively these devices are intended to either warn pilots of potential dangers, aid them in performing the flying task, or, in some cases, compensate for errors. The program that is outlined herein would lay the groundwork for the introduction of that design philosophy and its associated technologies into the automotive arena.

A sober appraisal of the IVHS issue, however, reveals that significant safety risks may be imposed by systems that are ill-suited to the human operator. In particular, care must be taken to match m-vehicle displays and control systems to human capabilities so that drivers are not overloaded, distracted, or disoriented. Accordingly, while large safety benefits are possible, any national program in IVHS must be configured to also guard against the introduction of new safety hazards.

3.1.3 Identifying the "Safety" Targets of opportunity

Highway traffic safety problem assessment typically involves the use of accident data systems to characterize relevant accident types in terms of patterns of occurrence, prevalence, and severity. To set priorities and obtain the highest potential payoff, it is necessary to define workable crash problems and the functional requirements for countermeasures to address them, i.e., maximize potential safety improvement by appropriately applying those advanced technology developments which have the highest probability of payoff. To do this, analyses are needed to develop an understanding of the distributions of crashes, fatalities, and injury levels and the distributions of human, vehicle, and roadway or environmental factors resulting in the crashes.

A systematic approach to the identification of safety countermeasures is to proceed through an iterative three-step program to:

- Assess the prevalence and severity of classes of crashes,
- Identify the characteristics and relative contribution of causal and contributory factors, and
- Identify the functional requirements of countermeasure systems aimed at eliminating or reducing these contributions.

3.1.4 Technologies and Benefits

AVCS-I systems aid the driver through "perceptual enhancements," "warnings," or "control" actions. In performing their safety and mobility functions, all AVCS-I systems depend upon on-board sensors. These sensors provide signals containing information pertinent to the status of important aspects of the driver-vehicle-roadway system.

AVCS-I systems are distinguished herein (see Table 3.1.4) by the manner in which they aid the driver. For example, "perceptual enhancement" refers to systems that aid drivers by providing an enhanced "image" of the driving scene. The driver is expected to interpret the enhanced images and to control the vehicle in a manner that improves both safety and mobility under adverse environmental conditions. "Warnings" differ from "perceptual enhancements" in that warnings provide an interpretation of sensor signals. Warning systems send messages concerning hazards to the driver. Messages such as "no brake lights" or "erratic driver behavior" are examples of warnings to aid drivers in making prudent decisions. "Control enhancement" pertains to AVCS-I systems that alter control actions to supplement those provided by the driver. Control enhancements include antilock and/or automatic braking systems, cruise control, and lane-keeping technologies. These types of systems perform control functions that are difficult or tedious for the driver to do well.

The technologies associated with AVCS-I are in various stages of product development or definition. In Table 3.1.4, an attempt has been made to provide an indication of the development status of each of the technologies identified. The range represents a continuum: (1) no technology applied to a given problem (NA), (2) technology available to support demonstration of a concept (Demo Concept), (3) commercial products available on the aftermarket (Aftermarket), and (4) products integrated into production vehicles as either optional or standard equipment (Optional or Standard).

In those cases where technology is sufficiently developed to allow AVCS-I systems to be implemented in vehicles, the current applications of this technology might be regarded as "technology driven" in the sense that proof of concept studies have demonstrated feasible devices. Nevertheless, means for evaluating the performance of these systems need to be developed in terms of quantifiable performance signatures and measures. The anticipated benefits listed in table 3.1.4 provide an indication of the types of safety-related performance that would be assessed in analyses and simulations,

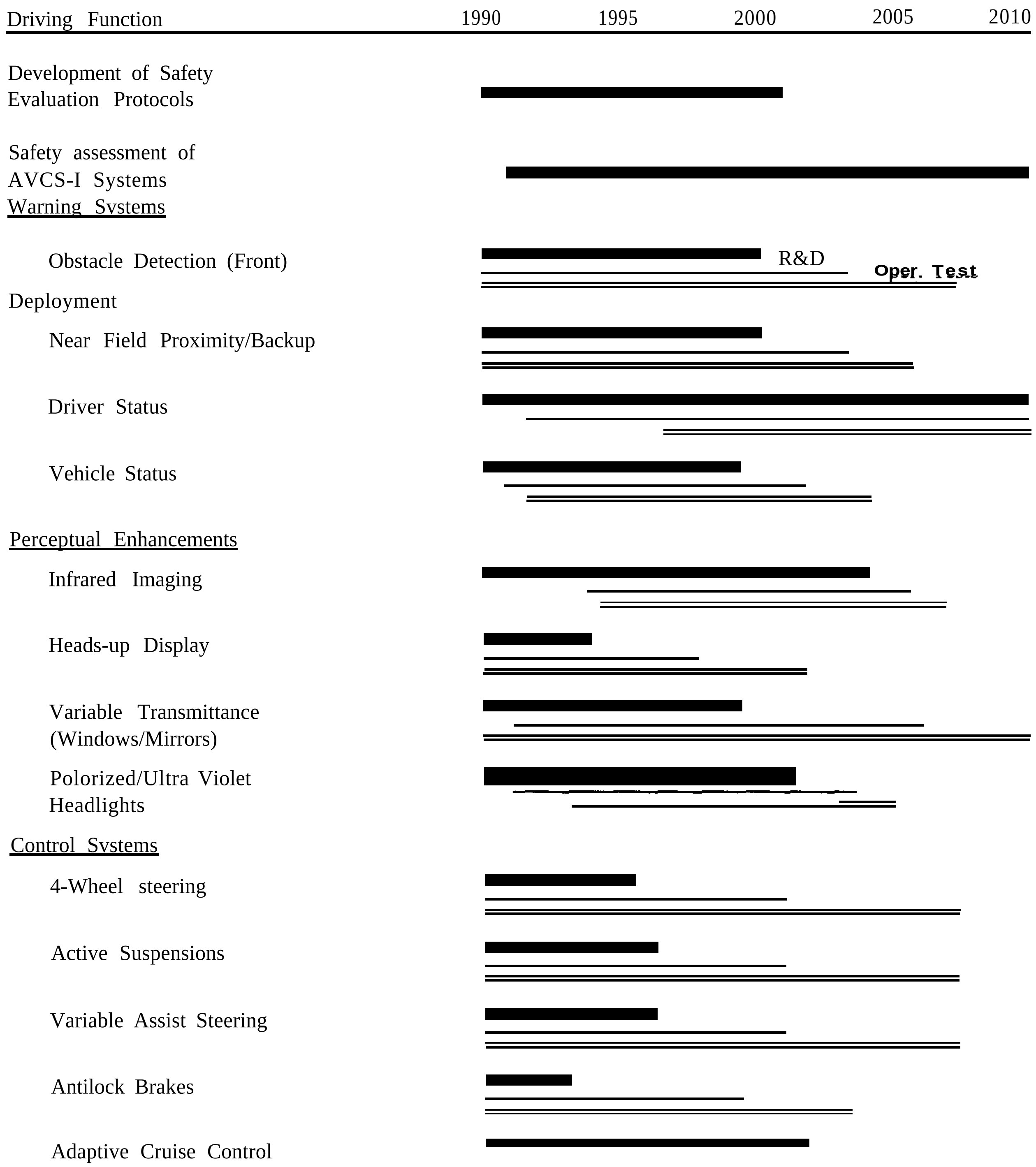
Table 3.1.4 Overview of AVCS-1 Technologies

Function	Technology	Benefit	status
1. WARNING SYSTEMS			
Provide Driver with a warning Indicating that braking or steering action should be taken to avoid hitting an obstacle	Obstacle Detector (for objects in front of vehicle)	Reduce frequency and/or severity of front-end crashes	Demo Concept - Cars
Provide driver with a warning if an intended vehicle action (e.g., lane change) will place the vehicle in the path of an adjacent object or vehicle or if an object is in the immediate path of a vehicle while backing up	Near Field Proximity (blind spot) Monitoring System/Backup Warning Indicator	Reduce frequency and/or severity of lane change, and blind spot related crashes, and crashes involving backing into pedestrians and fixed objects	Aftermarket - Heavy Vehicles Aftermarket - Cars
Provide driver with a warning if lapses in driver attention/vigilance are detected	Driver Vigilance Behavior and Status Monitoring System	Reduce frequency and/or severity of crashes involving falling asleep al the wheel, fatigue, drugs, alcohol, etc.	Demo Concept/NA
Provide driver with a warning if any of his vehicle components/systems are malfunctioning, operating with decreased performance or failed	Vehicle Status/ diagnostic System	Reduce frequency and/or severity of crashes and/or breakdowns resulting from vehicle component system failure	Standard/Optional
Provide driver with a warning that the vehicle is approaching its rollover threshold so that appropriate action can be taken to prevent rollover	Rollover Threshold Warning	Reduce frequency and/or severity of rollover crashes, particularly for trucks	Demo Concept
2. PERCEPTUAL ENHANCEMENT			
Provide driver with an enhanced image of the roadway ahead under adverse visibility conditions at night	Infrared Imaging	Reduce frequency and/or severity of crashes involving a lack of ability to see/detect objects ahead	Demo Concept
Provide a projection of vehicle information (e.g., speed) on the windshield with a virtual image located in front of vehicle	Head-Up Display	Reduce frequency and/or severity of crashes involving dashboard distraction and driver accommodation	Standard/Optional
Provide driver with the ability to vary the tint of the windshield and/or mirrors	Variable Window/Mirror Transmittance	Reduce frequency and/or severity of crashes involving reduced visibility and glare	Mirror - Standard/ Optional Window - Demo Concept
Improve visibility without increase in glare	Advanced Technology Headlighting (e.g., polarized. ultra-violet)	Reduce frequency and/or severity of crashes involving reduced visibility and glare	Demo Concept

Table 3.1.4 Overview of AVCS1 Technologies (can't)

Function	Technology	Benefit	Status
3. CONTROL ENHANCEMENT			
Provide driver with improved steering control at all speeds	4-Wheel Steering	Reduce frequency and/or severity of crashes involving crash avoidance maneuvers	Semi-Active - Standard Active - Optional
Provide driver with improved vehicle handling/control under harsh and non-level road conditions	Active/Semi-Active Suspensions	Reduce frequency and/or severity of crashes involving loss of vehicle control under poor road conditions	Standard/Optional
Provide driver with improved steering control at high speeds	Variable Assist Steering	Reduce frequency and/or severity of crashes involving excessive steering response by driver	Optional
Provide driver with improved vehicle control/stability while braking	Anti-lock Braking	Reduce frequency and/or severity of crashes involving braking on slippery surfaces or emergency braking	Standard/Optional
Supplement driver control with capability of automatically maintaining minimum headway while cruise control is operational	Adaptive Cruise Control	Reduce frequency and/or severity of crashes involving failure to disengage cruise control	Demo Concept
Supplement driver control with capability to automatically apply brakes if there is a potential for collision	Automatic Braking	Reduce frequency and/or severity of crashes involving failure to brake in time	Demo Concept
Supplement driver control with capability to automatically maintain lane position	Lane Keeping Control System	Reduce frequency and/or severity of crashes involving failure to maintain position in lane	Demo Concept

Figure 3.1.5 AVCS-I Development Plan



laboratory research, vehicle experiments, and vehicle-in-use field operational tests conducted to investigate the safety of deploying vehicles equipped with these systems.

3.1.5 Proposed Milestones

Figure 3.1.5 outlines the projected schedule for carrying out the R&D, operational testing, and deployment efforts required to bring AVCS-I products into widespread use by the motor vehicle fleet in the United States.

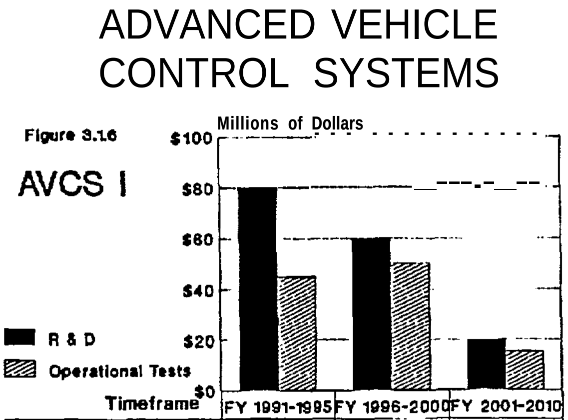
AVCS-I system development will be characterized by a number of distinct, but interrelated initiatives. The following points further explain the anticipated process and the assumptions on which the milestones or schedule are based:

- **The term** "operational test," as used here, means that the device or system has reached a stage of development that it can be incorporated into vehicles which can be operated in normal traffic conditions by typical drivers. Deployment implies that the product is being marketed with widespread use of the device or systems as the goal.
- All programs such as these are iterative in nature, at least until the final design is fixed for deployment. Thus, there is considerable overlap between R&D and operational testing.
- The deployment, validation, and utilization of evaluation protocols overlays the entire AVCS-I system development effort. This is why R&D is shown as still being necessary even when commercially available devices or systems have already been incorporated into motor vehicles.
- A prioritization process that includes systematic identification of targets of opportunity and feasibility studies of alternative solutions will determine the pace of development of AVCS-I technologies. Based on this prioritization process, specific AVCS-I initiatives may be accelerated, delayed, or even discontinued if they are shown not to be feasible or cost-beneficial.
- The milestone or schedule assumes that IVHS and AVCS are significant national goals, and, thus, that substantial funding will be available to accelerate the normal R&D process.
- **The milestone** or schedule assumes the existence of a research driver simulator by early 1995 to support R&D on driver performance under baseline and AVCS-I conditions.
- Because the ultimate success of AVCS-I technologies depends on the matching of devices or systems to the capabilities and limitations of the populations of drivers that will use the devices, human factors must be a significant focus of the R&D effort. In addition, ensuring highly reliable designs which fail "soft" is crucial, especially for those systems providing some level of vehicle control.

In addition to the above, a few words of explanation are needed regarding two specific technologies shown in Figure 3.1.5:

- *Autonomous lane keeping.* It would be difficult to develop a practical, vehicle-based lane keeping control system. For this reason, the time frames shown in the milestone chart are quite long. On the other hand, the development of such a system would be greatly simplified by the existence of a supporting roadway-based infrastructure. Thus, the AVCS-I lane-keeping control system should not be viewed as a technology that needs to be developed before. analogous AVCS-II and III lateral control systems can be developed.
- **Vehicle status**. Vehicle status systems have been available on motor vehicles for many years. In general, such systems alert the driver to the existence of a malfunction, but do not specifically diagnose the malfunction. Additional diagnostic information is also now available to mechanics who have the equipment needed to interrogate the onboard computer and could easily be provided to drivers. The question is what information do drivers need with regard to the status of their vehicle and how should this information be presented. It is anticipated that future systems will provide vehicle status information which will be specific, fault-diagnostic and prescriptive.

Figure 3.1.6 AVCS-I Funding Alternatives



	FY 1991-1995	FY 1996-2000	FY 2001-2010
R & D	$80	$60	$20
Operational Tests	$45	$50	$15
Totals:	$125	$110	$35

3.1.6 Funding Requirements

Figure 3.1.6 shows that $270 million will be needed to fund the research and development and field operational test programs that will ensure the deployment of AVCS-I technologies. This figure shows the expenditures for the years 1991-1995,1996-2000, and 2001-2010. Yearly breakdowns of the expenditures are provided in Section 3.4.

3.2 AVCSN-II COOPERATIVE DRIVER -VEHICLE HIGHWAY SYSTEMS

3.2.1 Scenario

The information and warning systems first introduced during the 1990's have become standard features on all new automobiles and trucks. Coupled with retrofits to older vehicles, over 75 percent of drivers can now benefit from the use of driver vigilance, behavior, and status monitoring systems. Sophisticated vehicle diagnostic units and journey data recorders have become the rule rather than the exception, and the widespread use of speed and distance sensing units has had a dramatic effect in reducing accidents.

The deployment of these systems since their initial introduction in the 1990's has undoubtedly had a major impact on traffic safety and driving comfort. More recently, however, further advanced technologies have been added which have begun to revolutionize society's whole perception of automobile travel. In particular, newly implemented systems have brought about significant and much-appreciated reductions in traffic congestion.

As Claire Parker departs from her home to make her way to the office, she remembers back to the time before these new systems had been introduced. Only a year ago, her 20-mile trip to work could take up to 2 hours at the height of the rush hour. The stresses of stop-and-go traffic, uncertainties over delays, and fears of an accident used to make Claire dread her trip to and from work every day. Since the new automated lanes opened on her route to work, however, she looks forward to an easy, predictable trip.

The recently implemented automated lanes are an outgrowth of High Occupancy Vehicle (HOV) lanes which were widely used throughout the 1980's and 1990's. They combine this exclusive right-of-way concept with the use of cooperative vehicle or roadway electronics for a new standard of transportation service.

More precisely, what the new system does is facilitate the grouping of cars into small linear strings, called platoons, which travel at a controlled speed of up to 65 mph. The system automatically takes into account adverse weather conditions and adjusts platoon speed accordingly. Each platoon can consist of up to 12 cars and each car in the platoon is electronically and precisely controlled to travel at a close distance from the car ahead of it. The result is a greatly increased highway capacity, with an automatically controlled travel speed and greatly reduced driving stress.

Claire approaches the facility as she would a normal freeway entrance. However, at the entrance ramp she pauses long enough to push an authorization button in her car. This button transmits information necessary to allow her to enter this restricted access roadway. The information transmitted includes the fact that she has a functioning in-vehicle unit installed on her car. It also includes basic status information on her car such as whether there is a sufficient level of fuel onboard and how long it's been since the car was last inspected. The response to her transmittal is almost immediate and Claire accelerates onto the right hand lane.

Once Claire's car reaches a speed of 55 mph, the new system assumes speed control and holds it at that speed. Claire immediately notices that platoons of cars in the left-hand lane are passing her. With their speed controlled to 65 mph, their passing speed is a comfortable 10 mph. The next passing platoon contains only six cars, meaning it has room for her car to join the string. As the last car in the platoon passes her, a signal light on her dashboard turns green, indicating that it is safe for her to merge into the left-hand lane and join the platoon. Claire turns into that lane and experiences the headway sensitive speed control system automatically accelerating her car to catch up to the remainder of the platoon. This is achieved in seconds. She then pushes a second button which activates her automatic steering system and Claire is able to take her hands off the steering wheel completely.

With Claire, and other drivers in the surrounding vehicles, now relaxed after the removal of the driving task, the platoon continues to make rapid, uniuterrupted progress. Claire can relax because fault tolerance built into the system assures her that even if her system malfunctions, she will be safely exited from the platoon.

Since the roadway will soon be electrified so that electric cars can pick up power as they travel, Claire and her fiance, Bob, have already been thinking about having one of their cars be an electric one after they are married. This will give their electric car as much range as they need to go anywhere in their metropolitan area. And the tax incentives to encourage clean air make it less costly to own than her gasoline-powered car.

To Claire, and others like her, the most obvious and important benefits of the AVCS-II technology are reduced congestion and improved convenience. These considerable benefits have already drawn in substantial numbers of private users. Many new vehicles are being fitted with the required onboard equipment as standard equipment and highway agencies are expanding the very low cost infrastructure to interurban routes.

3.2.2 Overview

AVCS-II requires both vehicle and highway-based equipment and utilizes the vehicle-to-vehicle and roadway-to-vehicle communications systems developed in ATMS and/or ADIS. AVCS-II begins implementation of a driver-vehicle-highway “system” whereby vehicle lateral and longitudinal position is controlled when the suitably-equipped vehicles are operated on dedicated instrumented lanes. Vehicles would enter and exit such lanes voluntarily and under manual control, but be under full or partial system control while in the lanes. It offers enhanced trip speed on designated instrumented lanes in congested corridors for specially-equipped vehicles. Conventional vehicles would not be permitted on the designated AVCS-II lanes. AVCS benefits will include increased travel speed and enhanced safety through bottleneck locations at a modest cost compared to gaining the same benefits by increasing the number of parallel lanes. AVCS-II is the logical stepping stone from the in-vehicle control systems of AVCS-I to the expanded control anticipated in AVCS-III.

Platooniug is the principal focus of current AVCS-II system development. In platooning, vehicles are electronically linked into “platoons” on one lane of a freeway. A car-to-car headway control system that can accurately and reliably maintain car spacing is the key element necessary for successful platooning. In addition, accurate vehicle speed control, platoon-to-platoon control, and automatic entrance diagnostics (at the interface between regular highways and designated instrumented lanes) are also needed. Each platoon would consist of a cadre of closely spaced vehicles. Optimal platoon parameters (e.g., travel speed, platoon size, headway distance, distance between platoons, types of vehicles permitted, degree of segregation of vehicle types) will be determined as part of platooning research and development.

This R&D will consider both technological and human factors relating to safety, efficiency, and economy. Platooning technology development choices are vitally dependent upon improved understanding of driver capabilities when in an “electronic assistance” mode. The role of the driver will be fundamentally changed. Extensive studies will be required to ascertain how drivers, with their wide variations in capability and performance, will adapt to an “electronic assist” mode. For example, can drivers with some additional sensor input, reliably merge into platoons, or must this function be fully automated? Can drivers learn to accept automated headway control at less than a car length spacing? Can they adapt to partial control situations (e.g., a merge or demerge situation where longitudinal control is automated but lateral control is manual)? As noted in Section 2.2.2, failure mode human factors is an important AVCS-II research concern. A critical AVCS-II R&D question is how drivers will respond to full or partial failure of the AVCS-II system. Other AVCS-II human factors issues include driver education or training requirements and public acceptance of the relinquishing of manual driver control of vehicles while operating on AVCS-II facilities. Work underway will allow the basic principles of platooning to be demonstrated in the next 2 years.

An additional need, particularly in large urban areas, is to significantly reduce pollution from today's levels in the face of dire forecasts of increasing traffic and much heavier congestion. Roadway electrification and the use of roadway powered electric vehicles is a promising approach which is closely tied to AVCS developments. Roadway electrification technology offers the advantages of electric propulsion while eliminating the range disadvantage. In a roadway powered electric vehicle system, power cables are buried beneath the roadway surface and passing vehicles are able to draw off power via an inductive pickup. This permits vehicles to recharge batteries while standing or moving on such a roadway.

Other AVCS-II system development initiatives include safety enhancing AVCS lanes (that vehicles can be "locked" into but with driver override), high-speed roadways or lanes, intelligent cruise control (involving instrumented highways), and improved safety equipment as a result of vehicle-to-vehicle and vehicle-roadside communications.

AVCS will require a greater R&D investment than AVCS-I. This is due to the communications and control functions (e.g., longitudinal and lateral control) that are required. These functions have stringent requirements in terms of reliability, safety, and related product liability concerns. The development, testing, and final selection of sensor and reference systems will be critical technology issues.

3.2.3 Targets of Opportunity

The first operating platooning facility will most likely consist of 20-25 miles of a two-lane freeway with a barrier separation from the remainder of the freeway lanes. The initial system could possibly be integrated into an existing High Occupancy Vehicle (HOV) facility to minimize costs. A realistic operation would involve 5,000 – 10,000 vehicles and drivers. Assuming adequate funding, detail design could be initiated in the mid-1990's with system operations beginning in the last few years of the century.

A short demonstration segment of electrified roadway has begun operations. This segment is being used to test a single bus operating at low speeds. Future demonstration work will include the addition of a variety of new vehicles, higher speeds, related off-roadway operations, and different fleet duty cycles over the next several years.

An initial deployment of a limited fleet of possibly 500 personal vehicles, some fleet van services and small van transit service, should be possible by 1995. This deployment will cover a restricted area, including some 10 or 20 miles of powered roadway. Such a system could easily be expanded to gradually cover a wider range, accommodating an ever growing fleet of private owners and both public and private services. A major breakthrough in range capability, and, therefore, attractiveness to the consumer, will occur with the first freeway deployment. This deployment step will be especially attractive when combined with the dedicated instrumented platoon lanes. Within the first decade of the next century, it is possible to foresee this combination becoming a major force in attacking congestion or pollution simultaneously.

Therefore, the principal beneficiaries will be users of these dedicated lanes located in high-volume major commuter corridors. There will be associated environmental, economic, and land use benefits through the alleviation of corridor capacity pressure. Since the benefits will be greatest for multi-passenger vehicles (i.e., in person-hours saved), AVCS-II will provide significant incentives for transit operators, their passengers, commuters in Vanpools, and other potential HOV facility users. Heavy commercial vehicles represent another potential user group, although safety concerns related to heavy truck use of AVCS-II facilities, together with smaller vehicles, will need to be addressed. Specific AVCS-II targets of opportunity include:

- States and localities planning new HOV facilities on new multi-lane freeways.
- States and localities considering adding HOV lanes to existing facilities.

- New state toll road authorities or private toll road developers.
- Developers of major new bridges or tunnels, where reduction in cross sectional areas could produce major cost savings.

3.2.4 Technologies and Benefits

Specific AVCS-II technological elements include the following:

- Automatic lateral control
- Automatic longitudinal control
- Vehicle-to-vehicle communications (e.g., for merge or demerge)
- System integration of AVCS-II technologies (e.g., platooning systems)
- Intersection hazard warning
- Electric propulsion

The first three of the preceding elements are component technologies that, when combined, enable the development of a true driver-vehicle-highway platoon system. Platooning offers the primary benefit of a several-fold increase in lane capacity and the secondary benefit of enhanced safety.

AVCS-II intersection hazard warning systems will entail vehicle-to-vehicle communication of intended travel path. Such devices would extend beyond the obstacle detectors developed under AVCS-I to detection or warning of a potential collision based on each vehicle's intended travel path. Intersection safety will be the primary benefit.

Electric propulsion enhances longitudinal control performance, which will probably enable shorter headways and, therefore, higher capacity. Electric propulsion has environmental benefits over gasoline propulsion that will make it easier to get approval for deployment in sensitive areas.

The following principal technological AVCS-II research and development issues will be addressed:

- Low-cost high-performance sensing of distance, velocity, acceleration, torque, rotation, etc.
- Low-cost high-performance computation
- Image processing and pattern recognition
- Reliability, safety, or fault tolerance
- Low-cost high-performance communication (vehicle-to-vehicle and highway-vehicle)
- Nonlinear and adaptive control
- Electric propulsion

One specific R&D need associated with AVCS-II is for AVCS roadway test facilities. Test facilities representing a range of conditions (speeds, curves, grades, weather) are needed. The eventual allocation of funds between R&D and operational tests will depend upon the extent to which test and evaluation work is carried out on such a facility (R&D) versus in the real world on actual highways (operational test). Following test and evaluation utilizing test facilities and other evaluation protocols, AVCS-II systems will be subjected to operational test applications on specially designated and instrumented freeway lanes.

Most AVCS-II technologies are in the early phases of system development, although the first demonstrations of roadway electrification and platooning will occur in the early 1990's. For example, experiments with longitudinal control are being conducted in the San Diego area on I-15 reversible HOV lanes (when these lanes are closed to the public) during 1990.

3.2.5 Proposed Milestones

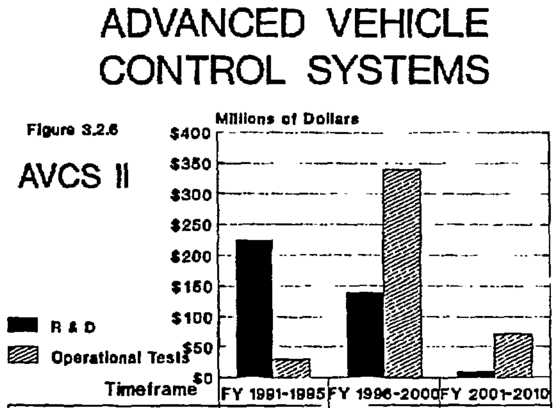
Figure 3.2.5 outlines the projected schedule for carrying out the research, development, and operational test efforts required to bring the AVCS-II systems into widespread applications on urban and intercity freeways.

This milestone or schedule chart assumes that IVHS and AVCS are significant national goals and, thus, substantial funding will be available to accelerate the program.

3.2.6 Funding Requirements

Figure 3.2.6 shows that $815 million will be needed to fund the research, development, and operational test programs that will ensure the deployment of AVCS-II technologies. This figure shows the expenditures for the years 1991-1995, 1996-2000, and 2001-2010. Yearly breakdowns of the expenditures are provided in Section 3.4.

Figure 3.2.6 AVCS–II Funding Alternatives



	FY 1991-1995	FY 1996-2000	FY 2001-2010
R & D	$225	$140	$10
Operational Tests	$30	$340	$70
Totals:	$255	$480	$80

3.3 AVCS-III: Automated Vehicle-Highway Systems

3.3.1 Scenario

For commuters living in the suburbs, the morning drive is now a realization of the many benefits of a state-of-the-art transportation system, not a mind numbing lesson in confusion and frustration. From the moment Norm turns the ignition key, he is aware of the advances in the transportation system. He pushes the "office" button on his destination selection console to indicate that he wants to head towards his office and the computer starts working out the fastest route to get there in this morning's traffic. The car completes its systems maintenance check and the journey begins with Norm driving towards the nearest freeway on-ramp. Norm controls the steering, but receives assistance from the "situation awareness" electronics equipment in the car which warns him of hazards ahead and to the side. Having avoided the neighborhood fender bender, he leaves his subdivision and pulls onto a major street.

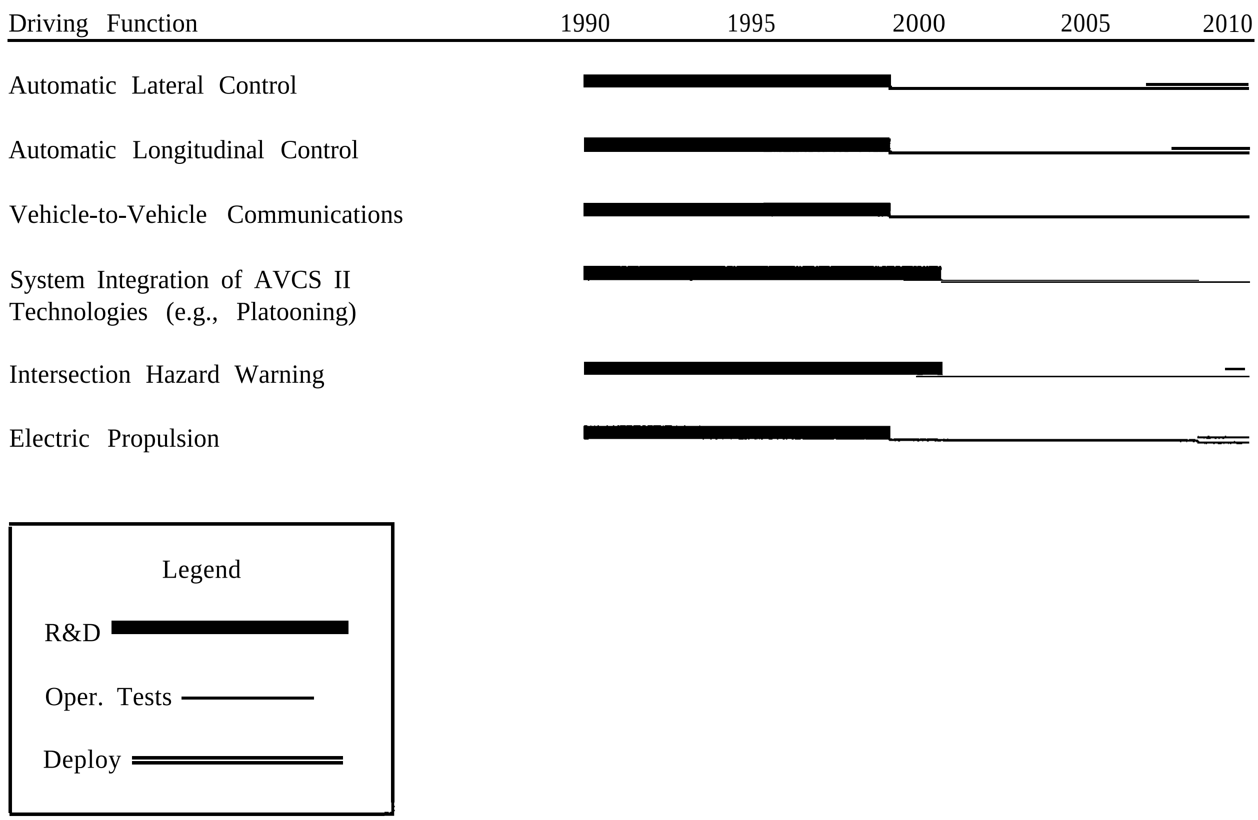
The dramatic improvements in freeway capacity and efficiency have eased the bottleneck that used to occur just a few blocks away from his home in the suburbs. Cars from the residential subdivision can move along the surrounding streets and toward the freeway on-ramps with greater ease now that freeway congestion has been drastically reduced. The driver information and warning systems do not indicate any problems this morning, so Norm knows he can proceed directly to the nearest freeway ramp.

At the freeway entrance ramp, Norm responds to the electronic signal and pushes the button on his dashboard that initiates automatic control of his ~~the normal R&D process. In addition, it assumes that a roadway test facility is available by 1993-1994 to permit test and evaluation of AVCS-II applications before initiation of field operational tests,~~ vehicle and directs his car to the off-ramp closest to his office. He can now take his hands off the wheel and his feet away from the pedals, since these no longer affect the movement of his car. He notices a brief slowdown of the car as the roadside diagnosis unit interrogates his car's diagnostics to ensure that the necessary on-board equipment is operational and that the vehicle condition is satisfactory to complete the trip. It was a good thing he had remembered to refill his tank last night so that he didn't have to repeat his experience of last week, when his car was directed into the reject lane and back to the local street because it didn't have enough fuel to complete the trip.

Once past the brief diagnosis period, the car accelerates smoothly and merges directly into a platoon of fast-moving cars. It's such a relief, not having to worry through the tricky merge maneuver the way he used to in the old days, when he never knew where he would be able to find a space in the heavy traffic stream and was always worried about getting rear-ended or sideswiped.

Norm pulls out his newspaper and catches up with the latest developments in the world, until he remembers the memo he forgot to write last night

Figure 3.2.5 AVCS-II Development Plan



in preparation for his morning meeting. He calmly retrieves his laptop computer from the back seat and types out the memo. When he finishes, he notices that he is not on Highway 580, where he normally travels, but is on 880 instead. His curiosity aroused, he turns on his map display unit and discovers that there is a resurfacing project underway on 580, which has taken a lane out of service, reducing its capacity. The central routing computer enabled him to avoid this by rerouting his trip onto the alternate route. Even though this would be a couple of miles longer, it would save some time this morning.

With the integration of electronic signposts, highway signs, and road markers, the cars in the platoon stay together for much of the journey to the city, with the faster moving platoons in the left lane and the slower platoons in the right lane. As Norm's car approaches its exit, the trip computer beeps to warn him that it is preparing to exit the freeway. Although Norm's car will remain in the fully automated mode until he has safely reached the exitramp, he is alerted prior to the exit so that he is prepared to resume control of the car. The detection of the road markers and the electronic signs prevent the car from running the signal at the bottom of the off-ramp. Norm punches in the right numerical code to assure the computer that he is awake and alert and ready to resume control of the car (just like one of those old sobriety check devices his boss had once told him about).

The traffic signals at the intersections near the freeway exits are integrated into the new transportation system to manage the flow of cars that have exited the freeways. The traffic signal integration system allows Norm and his fellow commuters to move away from the freeway and into the commercial and business district of the city with much greater ease and much less of the stop-and-go traffic patterns that were present before the new traffic signal system.

Although more commuters like Norm have chosen to drive to work, the traffic management capabilities of the advanced traffic network integrated with AVCS have kept the morning and afternoon commuting times to a minimum. Rush-hour commuters are not the only ones that have benefitted from the changes that have taken place. Sports and concert fans, along with theater patrons, and shopping center customers cherish the simplicity with which they drive to the stadium, theater, and mall. The horrendous traffic jams that used to occur with regularity have given way to a much more orderly exit from these places.

As cars leave the parking areas in the semiautomatic mode, they enter automatic merging lanes leading to the adjacent freeways. In the merging lanes, small groups of cars form platoons and accelerate and merge into the traffic flow as space permits. The newly formed platoons travel down major inner-city expressways, allowing the traffic to exit the parking areas with greater efficiency and speed than many had imagined. The parking lot that used to take a half hour to empty after the basketball game is now deserted within 10 minutes.

Elsewhere on the West side of town, the roadway electrification program has proven its usefulness with the postal service and the public transit authorities. For vehicles such as buses and trucks running along fairly consistent routes, the electricity available through the supplemental power supply in the streets has allowed the use of electric vehicles to be integrated into the city's transportation network. Electric vehicles, operating primarily on batteries, extend their range using these recharging facilities in the downtown area. The electric roadway program has helped the city keep its commercial vehicle pollution under control while providing a major reduction in the noise level in many downtown areas.

Commuters to and from nearby cities continue to enjoy the benefits brought about by the modernization of existing highways. With the complete integration of the automated vehicles and the advanced highways, businessmen and workers travel between cities in much less time than required just 20 years ago. Instead of travelling at average speeds of 30 - 40 mph, cars operating in the fully automatic mode now travel at the 75 mph speed limit for the entire trip. Tourists visiting Washington, D.C., can now routinely visit nearby cities like Baltimore and Annapolis as the difficulty of traveling on unfamiliar roads has been eliminated and the speed of automobile travel between these urban areas has increased.

This year, John's parents took their annual vacation to Florida as an overnight drive in their camper. After filling up their reserve tank with gasoline, they drove onto I-95 after dinner, punched in the exit number closest to their motel in Daytona Beach, then retired to the back of the camper, watched the evening news, and went to bed (just as the long distance truck drivers do it these days!). When they got up in the morning and saw how beautiful the sunrise was in Jacksonville, they decided to stop for a walk along the beach. They punched the "next exit" button on the trip computer and in the space of 2 minutes were out on the local streets, driving themselves to the beach. It was so nice to have the camper, with all of its comforts, and the freedom to go where they wanted to go, when they wanted to go. Just a few years before, they had despaired of being able to make a trip like this because neither one of them had the stamina or driving skill to drive such a long-distance, high-speed trip. Modem technology has its advantages after all!

3.3.2 Overview

AVCS-III includes complete automation of the driving function for vehicles operating on specially equipped freeway facilities. It builds on the developments in AVCS-I and II, incorporating elements in both the vehicles and the roadway, to provide "automatic chauffeuring" of vehicles from arrival at the freeway on-ramp to departure from the freeway off-ramp. It does not, however, go so far as to automate the trip all the way from the driver's origin to destination, because that introduces significantly greater complications.

Implementation of AVCS-III will require significant additions to the technologies developed for AVCS-1 and II. In addition to the basic lateral and longitudinal control functions, it will also require automation of lane changing and merging into and out of the traffic stream, as well as safe means for effecting the transitions between manual and automatic control, including checking the condition of both the driver and the vehicle. More significantly, it will require the development of the communications and data processing networks and algorithms to effect automatic routing and scheduling of vehicle trips from first freeway entrance to last freeway exit and the mtegration of the automated system with the pre-existing manual system of traffic management and control on local streets and arterials.

AVCS-III significantly expands the safety and productivity benefits gained from AVCS-I and II, and adds further benefits of convenience for drivers (enabling them to read or write, for example, while on the automated portion of a trip so that this time can be used productively). AVCS-III eliminates driver error as an accident cause for all trips on the automated facility, offering the potential for a significant safety benefit, and it also greatly reduces the delay-producing potential for any accidents or breakdowns that do occur by avoiding the "rubbernecking" of drivers slowing down to take a closer look. The vehicle condition checking that will be necessary upon entering the facility should also significantly reduce the incidence of mechanical breakdowns of poorly maintained vehicles on the freeways. The greatest benefit is likely to come from the dramatic increase in freeway capacity that AVCS-III makes possible, and from the resulting elimination of freeway congestion. AVCS-III should enable the vehicle to travel at full speed for virtually the entire freeway trip, regardless of the time of day, at the price of a small delay upon entrance to the system to enable the trip to be scheduled through the network. This should help reduce some of the pollution and energy waste that are presently attributable to urban traffic congestion. The routing and scheduling function of AVCS-III helps to ensure the most efficient distribution of vehicles throughout the network so that network capacity is fully utilized and incidents can be accommodated with minimum disruption to traffic. The coordination of the automated freeway operation with the local traffic management system ensures that the increased volume of freeway traffic remains compatible with the local streets and arterials, avoiding bottlenecks at the system entrances and exits.

3.3.3 Targets of Opportunity

The incremental benefits of AVCS-III technology over the two earlier stages of AVCS will be significant to all users of the road transportation system, in both urban and rural areas. Productivity, safety, and convenience enhancements are widely applicable, extending to both urban and rural highway users, including private, commercial, and transit vehicle operators. Commercial and transit vehicle operators, for whom high hourly operating costs make reductions in trip times particularly valuable, should see very high benefits from AVCS-III in congested urban areas. Similarly, private automobile drivers who waste much potential leisure time in traffic jams, would welcome the recapture of that time for more pleasurable uses. For intercity (rural) travel, the convenience of "driverless" operation could produce great economies for trucking operations and could make vacation travel more pleasant for private individuals and families. It could even ultimately enable the vacation traveler or long-distance trucker to sleep through an overnight journey of hundreds of miles, arriving refreshed the next day ready for a full day of activity.

These beneficiaries of AVCS-III help to categorize the targets of opportunity for development of the earliest systems. It seems that these would clearly be aimed at the most congested urban areas and at the intercity corridors with the heaviest commercial trucking traffic. It would also be easiest to phase in implementation of AVCS-III technologies in locations that are already planning new road construction and/or that have the space to construct new roads, because it is likely to be politically difficult to remove an existing facility from public use to equip it with the new technologies and then reserve it only for use by the suitably-equipped vehicles.

3.3.4 Technologies and Benefits

In AVCS-III, the benefits are generally enjoyed when all the technologies are applied together, to create a complete system. It is not really meaningful to assign separate benefits to the different constituent technologies, because all of the technologies are needed in order to create an automated freeway and the benefits are derived from the complete "package" of technologies in the system. The elements that must be included in an AVCS-III system include:

- Drive by wire
- Steer by wire
- Automatic on-board diagnostics (which must be interrogated and found to be acceptable before entry to AVCS-III facilities would be allowed)

- Automatic obstacle detection
- Automatic lateral control
- Automatic longitudinal control
- Vehicle-vehicle and vehicle-wayside communication for control
- Human interfaces for transitions to and from control
- Integration of automated roadway with arterials and local streets
- Automatic traffic merging control
- Automatic lane-changing control
- Automatic trip routing and scheduling
- Automatic obstacle detection and avoidance
- Reliability and safety enhancement features for all functions (real-time condition monitoring, fault detection, separate degraded performance and emergency operating modes, etc.).

It would also be very beneficial to have vehicles equipped with electric powertrains in order to provide AVCS-III functions, both for technical and environmental reasons.

In order to provide the above AVCS-III functions, it will be necessary to proceed through an orderly sequence leading from basic research to design, prototype development and testing, refinements, field operational testing, and deployment. The basic research foundation upon which the rest of the program must be built, should incorporate the following elements:

- Low-cost, high-performance sensing of: distance, velocity, acceleration, torque, rotations etc.
- Low-cost, high-performance computation
- Image processing and pattern recognition
- Reliability, safety, or fault tolerance
- Low-cost high-performance communication (vehicle-vehicle and vehicle-ground)
- Traffic engineering (traffic flow and control)
- Network modeling
- Optimal network routing and scheduling (algorithms)
- Nonlinear and adaptive control
- Electric propulsion (especially batteries)
- Man and machine interfaces.

The design and development stage will include component, subsystem, and system level design work to meet the requirements of each of the driving functions, based on the research outlined immediately above. This stage will also require extensive system engineering activity, both at the level of the individual driving functions and at the higher level of the complete integrated transportation system. Substantial test facilities will need to be developed so that all of the technologies can be tested thoroughly before they are first exposed to public scrutiny in field operational tests.

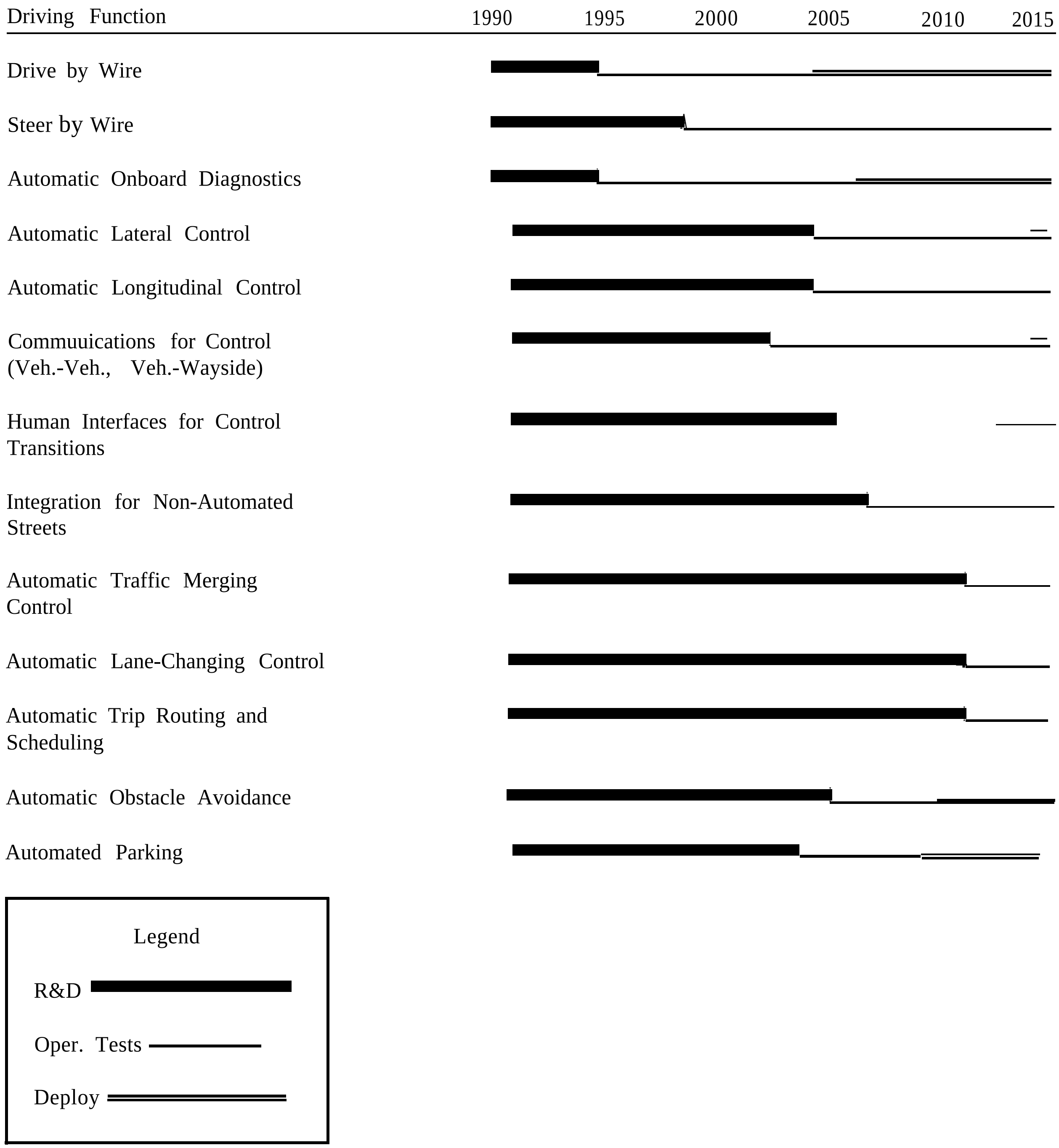
The only element of the AVCS-III technology that is commercially available today is drive by wire, which is available only on the top-of-the-line BMW model. Many of the technologies are in the basic research stage, with some progressing into the design and development stage as well. This means that some years of research and development activity will be needed on AVCS-III before operational tests would be considered.

3.3.5 Proposed Milestones

Figure 3.3.5 outlines the projected schedule for carrying out the research, development, and operational test efforts required to bring the AVCS-III systems into widespread application on urban and intercity freeways.

This milestone or schedule assumes that IVHS and AVCS are significant national goals and, thus, substantial funding will be available to accelerate the normal R&D process. In addition, it assumes that a roadway test facility is available by 1993-1994 to permit test and evaluation of AVCS-III applications before initiation of field operational tests.

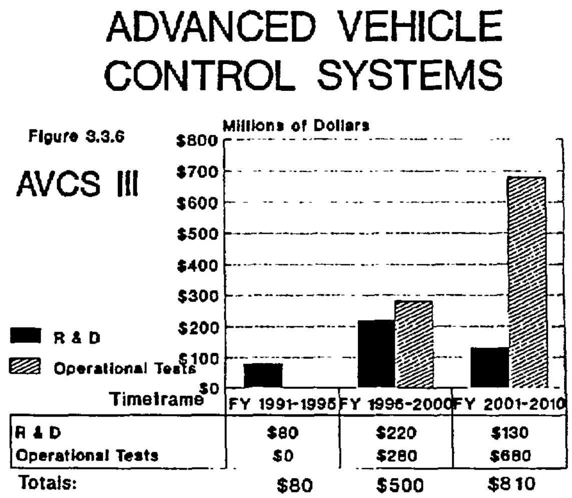
Figure 3.3.5 AVCS-III Development Plan



3.3.6 Funding Requirements

Figure 3.3.6 shows that $1,390 million will be needed to fund the research, development, and operational test programs that will ensure the deployment of AVCS–III technologies. This figure shows the expenditures for the years 1991-1995, 1996-2000, and 2001-2010. Yearly breakdowns of the expenditures are provided in Section 3.4.

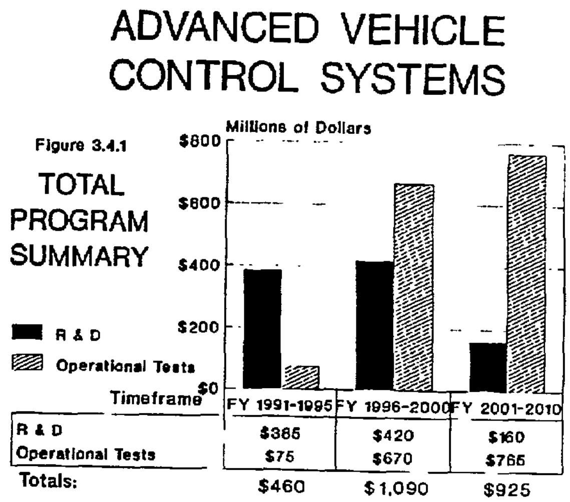
Figure 3.3.6 AVCS–III Funding Alternatives



3.4 Total AVCS Funding Summary

AVCS is the most complicated and longest-range of the IVHS technologies. As such, it needs the largest investment over the longest period of time to reach fruition. The attached figures (Figure 3.4.1 and 3.4.2) and table (Table 3.4.1) show basic estimates of the type of funding needed for the research and development and field operational testing of the three stages of AVCS over the next 20 years. The estimates do not include deployment costs, which are expected to be considerable, but which are indeterminate at this time. The funding estimate for R&D and operational tests includes both public and private investments, with the division between the two being left undefined at this time pending future policy decisions. Note that the funding for operational testing exceeds the R&D funding for AVCS–II and AVCS–III, simply because of the scale of the operational tests needed to show what the technologies can do. The funding for operational testing lags R&D by several years in each case because it is unwise to advance into operational testing before the technology has been thoroughly shaken out in the laboratory and on the test track.

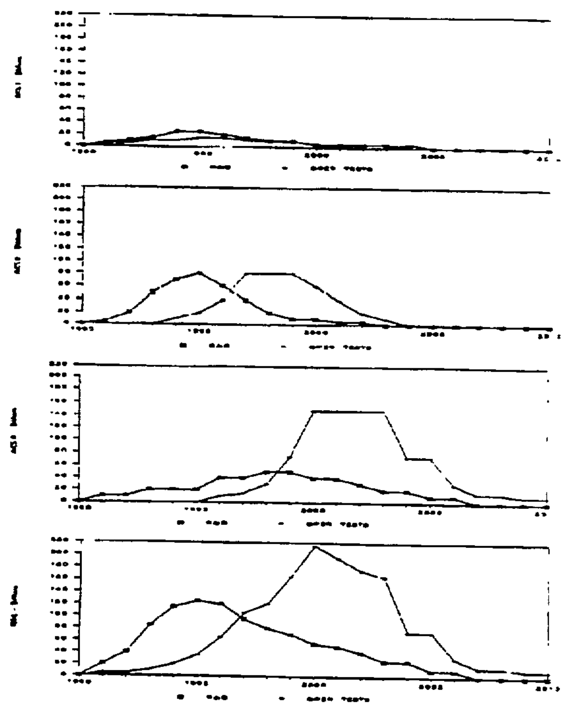
Figure 3.4.1 Total Program Summary



The resources for AVCS–I total $270 million, for AVCS–II $815 million, and for AVCS–III $1,390 million, reflecting the increasing complexity of the higher levels of functionality. In addition, it is estimated that an additional $250 to $500 million will be required to construct and operate the needed specialized facilities (e.g., research driving simulator and roadway test facility) to support AVCS development and evaluation. The annual funding peaks at $270 million in the year 2000 in this plan. Although this may seem like a great deal of funding, it is negligible compared to military weapons development programs and is even low compared to what DOT spent on the supersonic transport project 2 decades ago (where expenditures topped $300 million in the peak year, a figure which has not been escalated to current-year dollars).

Figure 3.4.2 Advanced Vehicle Control Systems: 1990-2010

(Millions of $ — Public & Private)



4.0 IMPLEMENTATION ISSUES

4.1 ORGANIZATIONAL STRUCTURE

4.1.1 Institutional Arrangement

It is of utmost importance that an organization be designated and put in place to steer the development and implementation of Advanced Vehicle Control Systems (AVCS). Ideally, such an organization would be composed of representatives from industry; universities; and state, local, and Federal Government.

A need for an organization overseeing the development of an Intelligent Vehicle Highway System (IVHS) was recognized by Mobility 2000 in April 1989. A special task force was established to determine the optimum organization model that would fulfill this need. The task force recommended that the U.S. Department of Transportation, Office of the Secretary of Transportation (OST), provide the leadership in organizing a national IVHS effort. The organization would be implemented as follows:

- The Secretary would form a joint high level IVHS Council to include major interests of government, industry, and academia, in charge of establishing:
  - Basic program goals
  - Priorities and program categorical allocations
  - Accelerated implementation and applications projects
  - Standards and protocols
  - Increased public information
  - Recommendations for incremental stages of development
  - Legislative initiatives
  - Policy
  - International cooperation
  - Industry cooperation and support
  - Identity of legal concerns
  - Involvement of major vehicular fleets
  - Professional staff development
- The Secretary would direct the modal Administrators (FHWA, NHTSA, UMTA), with FHWA as chair, to be an IVHS advisory committee to the Secretary and to:
  - Carry out programs specific to their modal responsibilities
  - Review and advise the Secretary on the IVHS Council recommendations
  - Provide budget oversight
  - Advise on needed legislation and interagency cooperation
  - Define IVHS administrative and technical elements within their respective organizations
  - Appoint a secretary to the IVHS Council
- The modal Administrators would carry on program administration using existing contract authority and through special arrangements for large scale demonstration projects.

Table 3.4.2 Advanced Vehicle Control Systems

(Millions of Dollars — Public and Private)

	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	Total
AVC–I																					
R&D	5	10	15	25	25	20	15	10	10	5	5	5	5	5							160
Oper. Tests	5	5	10	10	15	15	10	10	105	5	5	5	5								110
AVCS–II																					
R&D	5	20	50	70	80	60	40	20	10	10	5	5									375
Oper. Tests				10	20	40	80	80	80	60	40	20	10								440
AVCS–III																					
R&D	10	10	20	20	20	40	40	50	50	40	40	30	20	20	10	10					430
Oper. Tests						10	15	30	75	150	150	150	150	75	75	30	15	15	10	10	960
Subtotals																					
R&D	20	40	85	115	125	120	95	80	70	55	50	40	25	25	10	10					965
Oper. Tests	5	5	10	20	35	65	105	120	165	215	195	175	165	75	75	30	15	15	10	10	1,510
TOTALS	25	45	95	135	160	185	200	200	235	270	245	215	190	100	85	40	15	15	10	10	2,475
	460					1090					925										2,475
	1990-1995					1996-2000					2001-2010										

- Also, the Administrators may elect to appoint project level technical committees.

4.1.2 Technology Transfer Protocol

Work on AVCS research will be going on in numerous public and private sector laboratories. The technology transfer protocol must be worked out and agreed to in advance of the start of any national effort. The protocol must protect private sector proprietary technology, but at the same time allow all participants to learn from the work of the participants and reduce the tendency for each research group "to reinvent the wheel." Patent rights will have to be worked out for these technology development partnerships. The technology transfer arrangements should also include sharing of monitored foreign work on IVHS.

4.1.3 International Collaboration

The deployment of the best technology within the shortest time frames is a goal that makes sense against the backdrop of the pressing safety, congestion, and environmental issues facing many of the world's urban areas. International collaboration on transportation technology development is essential. However, can international competitiveness be preserved for each of the competitors? The answer is yes, if the collaboration is properly structured. Negotiations between the European, Japanese, and American groups could produce mutually beneficial results. Areas of joint effort could be:

- Development of control models
- Human factors research
- Computer simulation of alternative control schemes
- Compatible communications systems
- Electronic based system certification
- Development of test facilities
- Field experiments and test protocols
- International standards

4.2 FINANCE

The United States has fallen behind in the development of advanced technology for streets and highways. One of the reasons for this is that traffic safety and congestion problems occurred earlier and are more severe in other areas of the world than in the United States. However, an equally important barrier to progress is the division of interests between the private sector which develops the equipment and the public sector which is responsible for designing and constructing the roads and other elements of the transportation infrastructure. Industry finds it difficult to participate in these fields, largely because it can not see the opportunity for significant earnings.

U.S. industry has been accused of having too short a time horizon to commit to long range research, or to engage in the development of advanced products which do not have near-term payoffs. There are many reasons for this. Some, such as the relationship between the price of the company's stock and the last quarterly report, are well publicized. Other reasons are more subtle and less well understood by the public and most transportation professionals. The time value of money, for example, would deter prudent investors from committing to product programs with time horizons of more than 10 years, unless the survival of a company or major investment depends on it.

There are few, if any, financial incentives for the private sector to invest in new research on technology and product developments which have long time horizons. The investors would have to be confident of annual sales many times as large as would be justified for more traditional near-term markets. The risks to the investment include the development of new and superior technology, the ending of patent protection and the leakage of knowledge as key staff members change jobs, publish technical papers, or retire.

A related problem may occur when a new company or product has received support (from the government, a corporate sponsor, venture capitalists, or families) through the proof of principle stage and then needs capital to create the production capacity to meet projected market needs. At this point in the development, many start-up companies go to the public market for capital (so called initial public offerings). These stock issues limit their future options (and willingness to take risks) by placing emphasis on the need for quarterly earnings. In the recent environment, this may be complicated by concern over being acquired by unfriendly investors.

As a result, many potentially beneficial products and services are being neglected or lost. Some foreign countries, in particular, Japan, have different financial incentives and as a result it is not uncommon for Japanese investors to purchase start-up U.S. companies at this critical stage in their development. This will lead to a loss of social benefits, reduction in the quality of life and/or the loss of the market to a foreign producer.

The strategies which governments could employ to encourage investments in these developments do not appear to have been thoroughly explored. There is no consensus on what could be done. There has not been any significant recent public or private initiative on these problems.

The study of this important issue should examine candidate strategies in depth. These could include:

- Federal (or State) grants, how they would be awarded, size, recovery philosophies for the government, etc.
- Joint private-public companies, how they would be chartered, source of funds, earning requirements, etc.
- Trust funds, what would be taxed, how the money will be allocated etc.
- Changes in tax regulations to encourage long range investments.
- Modification of antitrust and liability laws and precedents to provide protection for new industries through the time at which initial research and development investments are recovered.

4.3 Deployment Barriers

No major technological breakthroughs will be needed to achieve the goals of advanced vehicle control. However, major cultural and institutional barriers to the deployment of the technologies need to be removed. These include social, safety, organizational, legal, political, and environmental considerations. They are addressed in the following sections.

4.3.1 Social

Public acceptance of AVCS will be a principal concern. Who will benefit from the technology and how will costs be allocated? Will costs be borne by the general public, or only by direct users of the technology? Will AVCS technology be perceived as a threat to contemporary lifestyles, privacy, or individual autonomy? What will be the education or training requirements for AVCS drivers, and will drivers be able and willing to attain the needed new skills? These social issues and concerns must be addressed in the planning and development of the AVCS concept.

4.3.2 Safety

AVCS technology introduces more significant safety issues than the other IVHS technologies because of the addition of control functions to the information exchange functions that predominate in the rest of IVHS. These safety issues represent both increased opportunities for improvement over present conditions and increased risks if systems do not work as intended.

Substantial research and engineering development efforts will need to be devoted to minimizing the probability of failures and then again to minimizing the consequences of those failures that do occur. The trade-offs between system cost and reliability will have to be confronted directly, in a process of dialogue between the technical and political communities. The general public and their elected and appointed officials will have to be satisfied that sufficient attention has been paid to safety before any AVCS technology can be implemented, even for demonstration purposes. This will require convincing experimental results and the publicizing of their significance in ways that can be comprehended by the public.

It is difficult to anticipate human responses to the sensations of utilizing an advanced vehicle highway system, particularly for the more advanced versions in which vehicles may be operating much closer together than they do today and in which the driver has less responsibility for control of the vehicle. Much attention will have to be paid to the public's emotional responses to this form of travel and their perceptions of its safety. Perhaps the experience will first have to be offered to the public in amusement parks, in the form of rides that can be experienced in complete safety, but do not necessarily *appear* to be as safe as people demand for their daily modes of transportation.

Education of the public about the relative safety of existing transportation systems will be a key element. If the causes of present-day accidents are understood better, it should become possible to appreciate the potential for improvements that AVCS technology offers, while at the same time recognizing that AVCS will not be perfect. Enhanced public awareness about transportation safety is vital so that appropriate public policy measures are taken. *The* public *perception* of the relative safety of different modes of travel must be brought as close to reality as possible.

4.3.3 Organizational

Financial and organizational interests which have developed over the years to build highways or provide services may feel threatened by advanced vehicle control concepts. For example, highway builders and their suppliers may, at first, oppose the automation concept since there would be a de-emphasis on new heavy construction. Studies to defme the rehabilitation and reconfiguration requirements of AVCS contractors and suppliers will be required. Public transportation providers may oppose AVCS development if it were perceived to provide greater benefits to private automobiles than to public transit. Truckers may oppose such systems aimed at automating traffic flow if they are excluded. The above organizational interests and concerns will need to be addressed pro-actively to ensure that AVCS implementation is not unfairly damaging to any group, but that the development of AVCS concepts is not defeated by special interests to the detriment of the general public.

Internally, transportation agencies that plan, design, and implement highway features will need to change their organizational structures and procedures to accommodate IVHS and AVCS approaches. Automated highway systems will require much higher levels of reliability and predictability than do current highway systems. Vehicle interaction, condition monitoring, diagnostics, failure analysis, and similar analytical approaches will need to be integrated into highway management procedures and strategies. Some highway engineers may initially feel threatened by advanced technology approaches since these will involve mechanical, electrical, and electronic control engineers along with traditional civil, structural, and traffic engineers to develop AVC systems. A more diverse mix of professional disciplines will be required to design, implement, and maintain the future vehicle highway systems.

4.3.4 Legal

A serious institutional barrier to development and deployment of IVHS and AVCS technology in the United States is its legal system. Court liability awards are reaching astronomical proportions, and the assessment of damage often bears little relation to responsibility. AVCS will greatly decrease accidents overall, but it is inevitable that some accidents will be caused by the system, whether these accidents are due to device malfunction, faulty system design, or human factors design deficiencies. Ways are needed to limit the liability risk of AVCS developers, both public and private. Possible approaches might involve stronger consideration of overall system benefits, narrower definitions of negligence, limitation of compensatory awards, limitations of punitive damage awards, limitations of joint liability, better training of juries, and elimination of contingent fee systems. Federally-subsidized liability insurance and/or Federal standards systems (where liability shifts to the government if products meet Federal standards) are other potential approaches to reducing liability risk.

Another legal issue of concern is antitrust. Collaboration among AVCS innovators, suppliers, and users will be particularly important. However, certain provisions of current antitrust laws restrain innovation by inhibiting collaboration among competitors. These provisions need to be reexamined in light of the need for collaboration among AVCS developers and between government and the private sector.

4.3.5 Political

Automated systems will require a much higher level of coordination across jurisdictions than do current highway transportation approaches. Regional transportation authorities or other transportation planning or management bodies that transcend jurisdictional boundaries will be needed. Internationally, ways will be needed to facilitate transportation technology trade agreements, international risk-sharing, and technology transfer. However, these arrangements must protect proprietary technology and international competitiveness.

4.3.6 Environmental

The environmental benefits from AVCS technology will result from reduced traffic congestion and the consequent decrease in air pollution. AVCS will also improve vehicle efficiency by automating functions to make driving smoother and more fuel efficient and will limit the "new concrete" approach to accommodating growth. However, the great increases in highway throughput resulting through AVCS technology will require concurrent dramatic advances in clean vehicle propulsion systems. The "more vehicles equal more pollution'* obstacle must be overcome.

4.4 Infrastructure Requirements

The existing network of highways that support and guide the transportation system is often referred to as the infrastructure. AVCS-II and AVCS-III will equip this infrastructure with technology that can permit communication with and physically guide the vehicles on it. The vehicles using the highway must also be fully equipped or "smart." By linking the smart highways to smart vehicles, the infrastructure will evolve and conform to accommodate the latest technology and efficiently provide the best transportation facility possible.

The fully controlled highway may be 20 years into the future, but its deployment will be associated with the following attributes:

- Considerable increase in traffic throughput
- Significant reduction in travel times
- Significant reduction in accident frequency and severity
- Improvement in air quality due to reduced congestion, improved vehicle efficiency, and cleaner propulsion systems
- Improved comfort and convenience of travel

While the cost to adapt the existing infrastructure to AVCS will be significant, it will be less than the cost of accomplishing similar enhancements in throughput by construction of additional capacity. Transition from the present infrastructure system to a fully automated system will require several years. It is important to plan and implement those AVCS improvements to the highway facility in concert with the longer-term evolution of the overall advanced transportation technologies. For example, existing freeways can be improved by implementing traffic management systems technologies that include advanced traffic signalization systems, driver information and warning systems, and special control applications such as ramp control systems. Infrastructure requirements for such technology may include the following:

- Maintenance and operation of the system,
- Lane widths and clearances,
- Grade and geometry, and
- Freeway location and traffic volumes.

Equipping the infrastructure for a higher level of automation, means that the following additional requirements be addressed:

- Start-up and diagnostic procedures,
- Communications link between the highway and the vehicle,
- Types of vehicle accepted on the highway,
- Mixture of controlled and non-controlled vehicles,
- Emergency breakdown procedures and facilities,
- Incident management, and
- Information on non-controlled sections.

Future implementation of advanced vehicle highway systems will heavily impact the existing infrastructure. Requirements for proper planning, design, and safety must be incorporated into the project scope for these projects. Critical requirements must be developed for merging automated and conventional systems. Proper and effective handling of the infrastructure is essential to the success of AVCS.

4.5 Marketing AND Public Relations

The success of the IVHS program, particularly AVCS, is highly dependent on public understanding and acceptance. Carefully designed strategies are needed to ensure highquality system development, to gain support from decision makers, and to receive acceptance by users. Critical elements in developing and marketing IVHS and AVCS include:

- Identify key decision makers. This includes upper management at the U.S. Department of

Transportation, Office of Management and Budget, members of Congress, user groups, and key state and local transportation officials. Provide comprehensive information describing IVHS and AVCS and its potential.

- Identify key users and user requirements. Identify users likely to attain the greatest benefits from AVCS and quantify those benefits. Analyze cost-benefits. Determine user willingness to pay for AVCS benefits.
- Define system requirements. Analyze current safety and congestion problems to determine the key elements of the needed solution. Specify AVCS functional requirements based on this analysis.
- Assess the available technology. Analyze key applications, underlying technologies, and key R&D issues relating to each.
- Develop an overall system architecture. Implement the AVCS phases and specific initiatives so that all are upwardly compatible with planned future systems.
- Assess organizational and political barriers to AVCS, e.g., special interests in opposition to elements of AVCS, public misgivings regarding 'loss of control, " or other AVCS aspects.
- Prioritize efforts. AVCS-I, AVCS-II, and AVCS-III represent three distinct phases of R&D and deployment. Within and between phases, prioritize R&D efforts based on needs and available technology.
- Define roles and responsibilities. Determine the appropriate nature and degree of involvement for various levels of government and private organizations.
- Develop a marketing strategy to promote the benefits to be gained from AVCS. The plan fosters positive public relations and education regarding AVCS concepts and benefits. Detailed milestones, schedules, and costs are outlined.
- Maintain rigorous controls and evaluation protocols. Establish facilities, procedures, roles, and milestones for evaluating AVCS development throughout the system development cycle.

5.0 CONCLUSIONS AND RECOMMENDATIONS

The specific goals and objectives of AVCS technology deployment are identical to those of the overall IVHS effort — enhanced safety, increased throughput (increased travel speed and improved trip time reliability), reduced environmental impacts and enhanced international competitiveness for U . S . industries. AVCS goes beyond the efficient management of the existing limited system and has the potential to provide quantum improvements in both throughput and safety.

The AVCS program has as its ultimate goal the virtual elimination of traffic crashes and traffic congestion. As a major IVHS element, it has far-reaching long-term potential, although it will take a concerted commitment to research, development, and demonstration to achieve the ultimate benefits. The autonomous in-vehicle systems (AVCS-I) will provide substantial safety enhancements for suitably equipped vehicles as soon as the technologies are commercially available. Beginning with AVCS-II, traffic throughput will increase significantly on those facilities where the infrastructure has been installed. AVCS-III will largely eliminate crashes and congestion where it is utilized. Universal elimination of crashes and congestion will require improved generations of AVCS to be applied to all vehicles, roads and streets.

Additional conclusions:

- Within the next two decades, AVCS technology will not be on every car. The purchase of the onboard equipment will be voluntary and only the most heavily travelled urban and intercity freeways will have the necessary infrasturcture to allow "hands-off' driving.
- A significant investment is needed to modify the infrastructure to accommodate the AVC systems envisioned. However, this investment will be small relative to the cost of new lane construction. Moreover, AVCS benefits will justify the needed investment.
- AVCS is initially a driver-vehicle system which evolves into a vehicle-highway system as more control is added. The ultimate success of this evolution hinges upon such major factors as

social acceptance, national commitment, and successful system integration and standardization.

- Careful attention to human factors is critical to the success of AVCS technologies. The issues to be addressed are very different in nature during the various stages of system evolution.
- Legal obstacles (e.g., liability risk) are a significant concern for AVCS technologies primarily because of the level of automatic control.
- A major part of the research and development funds must be dedicated to achieving a fault tolerant, reliable system at reasonable costs.
- Efforts need to be devoted to cleaner propulsion systems; otherwise, AVCS technology may never be implemented. The "more vehicles equals more pollution" obstacle must be overcome.

In order to fully realize the potential of AVCS deployment, we recommend the following:

- Create a national organizational structure to oversee and coordinate public-private partnerships for accomplishing research, development, field operational testing, and deployment of AVCS technologies. An integral part of this partnership would include the ability to pool funds.
- Provide sustained funding at levels sufficient to support a comprehensive, multi-faceted AVCS program. AVCS promises dramatic benefits, but research, development, field operational testing, and deployment costs will be significant.
- Obtain legislation to limit the liability risk of those who participate in the development and deployment of AVCS technologies.
- Define the long-term requirements of the ultimate AVCS architecture to the extent possible early so that these requirements can be considered in establishing the standards for the near-term systems.
- Allocate sufficient research and development funding earmarked specifically to address the critical "reliability" and "fault tolerant" requirements that such systems must embrace to be acceptable.
- On a priority basis, develop and validate measurement and analysis tools (such as a driving simulator and a dedicated automatic control test facility) and evaluation protocols for assessing the performance and/or efficacy of AVCS technologies.
- On a priority basis, stimulate the growth of available manpower and expertise in human factors as applied to highway transportation problems.

Intelligent Vehicle Highway Systems

Commercial Operations

MOBILITY 2000

Dallas 1990

Commercial Vehicle Operations

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Commercial Vehicle Operations

INTRODUCTION

The activities of Mobility 2000 with respect to IVHS technologies will ultimately involve all types of motor vehicles, regardless of ownership or use. The Commercial Vehicle Operations (CVO) Working Group is specifically concerned, however, about the application of these technologies to commercial vehicles. Commercial vehicles include large trucks, local delivery vans, buses, taxis, and emergency vehicles.

The application of IVHS technologies will improve the productivity, safety, and regulation of all commercial vehicle operations.

Productivity

Global competition is forcing U.S. companies to change the way they do business. Many of these changes, such as the use of overseas parts suppliers, the introduction of just-in-time manufacturing and distribution, and the increased emphasis on quality and consumer service, are having a direct impact on the way commercial carriers operate. Carriers are being asked to provide faster, more reliable, and more cost effective services. IVHS technologies are emerging as the key tools that carriers have to reduce costs and improve productivity. Automatic vehicle location, tracking and two-way communications, routing algorithms, in-vehicle text and map displays — all new IVHS technologies — are making possible faster dispatching, fuel-efficient routing, and more timely pick ups and deliveries. These productivity improvements have a direct impact on the quality and competitiveness of U.S. businesses and industries at both the national and international levels.

Safety

Over the last decades, we as a nation have invested in smaller passenger cars for fuel efficiency and in larger trucks for greater productivity. Today, we operate them together on very congested highways many of which were designed for fewer cars and smaller trucks. The mix has increased public anxiety about highway safety, adding to concerns about insurance costs, hazardous materials spills, drunk driving, and drug use. IVHS technologies offer a means of directly addressing the safety concerns of the public and commercial vehicle operators. Advanced vehicle control technologies, such as blind side and near obstacle detection systems, can make our nation's highways safer and more productive.

Regulation

The Federal government, each of the States, and many local governments regulate commercial vehicle operations — to administer taxes, ensure public safety, protect bridges, maintain economic competition, and promote fair business practices. The cost of regulation to government and commercial vehicle operators is substantial. The States spend over $100 million annually for truck weight enforcement alone. IVHS technologies, such as weigh-in-motion scales, automated vehicle identification transponders, and automated vehicle classification devices — some already deployed by the states — will reduce the time spent at weigh stations, reduce labor costs to states, and minimize the hassle of red tape for commercial vehicle operators.

The early application of IVHS technologies to commercial vehicle operations offers the U.S. a unique opportunity to fast track the development of IVHS systems.

- Commercial vehicle operators are the leading-edge users of currently available IVHS technologies (automatic vehicle location, tracking and two-way communications; routing algorithms for dispatch; in-vehicle text and map displays; etc.). While other potential users talk about someday adopting these technologies, over-the-road trucking companies, parcel delivery firms, taxi services, couriers, transit bus systems, and emergency vehicle operators are already investing in these technologies. These commercial users are making these investments in order to improve service to customers, increase productivity, reduce costs, and increase profit. They have already answered the perennial question about IVHS technologies, "Where's the demand?"
- Commercial vehicle operators are likely to be the first users of the next generation of IVHS technologies (e.g., real-time traffic information services and automatic vehicle identification technologies) — for the same market-driven reasons. Thus, CVO can serve as the logical testing ground for many additional IVHS technologies before they are made available to other motorists.

The IVHS program must address the unique needs of commercial vehicle operations.

- Heavy trucks, for example,cannot be operated on all roads for a variety of reasons such as restrictive geometry and substandard bridges. The operators of these vehicles must have accurate, detailed information about any proposed alternatives to the routes they normally travel. Vehicles carrying hazardous materials have similar kinds of unique information needs.
- While equipment and communications standards are important to all potential IVHS users, they are critical to CVO. Large vehicle fleets demand equipment standardization in order to reduce the training and maintenance costs associated with parts proliferation. Electronic vehicle equipment interface standards are essential if vehicle manufacturers are to be able to integrate add-on devices efficiently (a problem of particular concern to heavy truck manufacturers). Trucks that travel nationwide will need to be able to tune-in traffic information broadcasts everywhere without having to carry several different kinds of radio receivers. They will also require standardized electronic map databases capable of covering the entire nation.
- Governmental authorities are looking toward early use of IVHS technologies to monitor and regulate certain types of CVO. Weigh-in-motion (WIM) and automatic vehicle identification (AVI) technologies are already being tested as a means of streamlining heavy truck regulations. Other regulatory uses of IVHS technologies aimed at CVO are also under active consideration – long before they will be seriously considered for ordinary motorists.

The CVO section of this report has developed a series of scenarios to illustrate the future benefits to commercial vehicle operators, their customers, and public authorities from the application of a variety of IVHS technologies. These descriptions address interstate and local freight movements, transit bus service, and emergency vehicle operations. Appendix A also summarizes expected CVO benefits and beneficiaries.

Some of the CVO benefits from the adoption of IVHS technologies can be, and are already being, achieved solely through private actions. Some truckload motor carriers, for example, have already been able to reduce empty miles traveled by 10 to 20 percent through the use of vehicle tracking and two-way-communications systems. These systems, which can cost up to $4,000 per truck, can sometimes pay for themselves within a year. Their utility requires no public infrastructure investment. The same holds true for taxi tracking, commumcations, and dispatch systems that have cut the average time between incoming call and dispatching from about 3 minutes to 15 seconds.

Other benefits from these technologies hinge upon the willingness and ability of public authorities to invest in the appropriate supporting infrastructure. Real-time traffic information services, for example, are of enormous interest to many commercial vehicle operators in congested urban areas. This interest is market driven, i.e., traffic congestion costs taxis, bus operators and truckers money. Real-time traffic information services will require substantial infrastructure investment for traffic monitonng systems, control centers, and broadcast facilities. If these investments are not made, these additional benefits to CVO today, and to other road users tomorrow, will be lost.

The prospect of joint use of these technologies, however, by carriers and public agencies does raise several sensitive issues which must be dealt with in the course of policy and system evolution. These issues include driver and company privacy issues, communication and identification standards, and system operation/maintenance issues.

The research, operational testing and deployment, proposed for CVO activities, and discussed in this section primarily focus on interstate commercial operations. Similar aspects of other IVHS technologies and how they will address local commercial operation needs are discussed in the other sections of the IVHS report.

BACKGROUND

The term "commercial vehicle" has specific definitions for existing regulatory purposes. For this report, however, a commercial vehicle is defined to include any motor vehicle of public or private ownership, regularly used to carry freight or passengers, in commerce, or provide emergency response. It includes large trucks, buses, taxis, emergency and delivery vehicles. The term "heavy commercial vehicle" (HCV), within the context of the commercial vehicle definition of this report specifically refers to combination vehicles, large buses and fire trucks.

The primary technologies currently identified for special consideration in commercial vehicle operations, especially interstate include:

Advance Driver Information Systems	(AIDS)
Automation Vehicle Identification	(AVI)
Weigh-in-Motion	(WIM)
Automatic Vehicle Classification	(AVC)
Electronic Placarding/Bill of Lading	
Automatic Vehicle Location	(AVL)
On-board Computer	(OBC)
Two-way Real-time Communication	(TWC)
Automatic Clearance Sensing	(ACS)

GOALS

Current developments in advanced technologies and their application to commercial vehicles have three basic goals: (1) to improve productivity in the private sector portion of commercial operations, (2) to improve efficiency and effectiveness of traffic management and administration by transit agencies, State and local governments, and (3) to improve safety for commercial vehicle operations and others affected by them.

BENEFITS

Both individually and in combination, these technologies have the potential to provide significant benefits to carriers, State and local governments, and the public. The key technologies to improve local CVO are ADIS and TWC because of the increased productivity from real-time traffic routing and schedule information they will provide. These are discussed in the ADIS section of this report. The key applications to improve interstate operations are AVI and use of the OBC. They link government and carrier-oriented technologies and are critical to providing real-time, vehicle specific information which is important for fleet productivity, and optimizing traffic flow for all vehicles.

Assuming widespread deployment of technology by Federal, State, and local governments, voluntary participation by commercial operations, and financial support, significant benefits will accrue to all involved.

For commercial vehicle freight operations the key benefit is improved productivity due to:

- reduced operating costs through real-time, most direct routing and fewer required stops for both local and interstate operations,
- reduced paperwork burden for interstate operations through automated driver/vehicle record keeping and reporting, and
- improved safety performance.

For intercity bus operators, local transit agencies and taxi operators key benefits are:

- improved system operation, i.e., on-time performance, safety and capacity,
- improved passenger/driver security, and
- improved information and travel times for system users.

For State governments the key benefits are:

- improved pavement management, highway design and traffic management through more accurate traffic data collection,
- improved highway and vehicle safety, and
- more efficient administration of truck safety and weight programs due to technology that can monitor CVO while in motion.

For local governments, the key benefit is improved incident mitigation capability due to:

- the ability to provide detour routing information, and
- the ability to provide the appropriate emergency response, especially with regard to hazardous materials.

For the public the key benefits will derive from:

- environmental improvements due to increased efficiency in all commercial operations,
- better quality of travel due to the improved pavement management and incident mitigation,
- lower transportation costs because of increased commercial productivity, and
- an improved highway safety environment.

These are only a few examples of the areas in which tangible benefits will be realized. A more detailed list of benefits is provided in Appendix A. In order to begin to accrue these benefits, a partnership of industry, academia and government must perform research, field test technology applications, adopt uniform standards, and resolve institutional and privacy issues. Also, there must be widespread support demonstrated by systems deployment by States and local areas, and voluntary participation by commercial vehicle manufacturers and operators. The latter will depend on the development of standards and operating protocols as well as coordination both within and among States, urbanized areas, and the commercial vehicle industry.

THE FUTURE

The following six scenarios describe how the major technologies will significantly benefit commercial vehicle operations, State and local governments, and the public.

SCENARIO 1. INTERSTATE FREIGHT TRANSPORTATION – THE CARRIER

The carrier, BMK Hauling of Hartford, Connecticut, also has a mid-western terminal at Wichita, Kansas. Today, BMK's most experienced driver, Doug, will begin another trip between the two cities. Today's load consists largely of aircraft engine parts going from Connecticut to the aircraft assembly plant at Wichita.

Doug's vehicle is equipped with an automatic vehicle identification (AVI) transponder, an on-board computer (OBC), and automatic vehicle location (AVL) equipment with two-way communication (TWC) capability.

His on-board computer is an electronic system, including hardware and software, located in the vehicle which can monitor the other systems of the vehicle, and also function as an interface for communication both internally between a vehicle's systems and also between the vehicle and external sources.

As an interstate carrier, BMK regularly provides to its base State, Connecticut, standard fleet information which includes:

- The Commercial Driver License status of each driver;
- Data from the most recent safety inspection of each vehicle in its fleet, and
- Current fuel tax and registration data.

Connecticut is part of a multi-State network, which enables other States to access BMK's fleet information on a real-time basis. In addition, for any interstate trip, a BMK driver also enters his or her specific commercial driver license code into the vehicle's transponder through the OBC.

The national IVHS initiative has provided an ADIS in each urbanized area of 500,000 population or more. As an aid to HCV traffic, the ADIS gateway point is signed on each National Truck Network approach to an ADIS urbanized area. The ADIS gateway point is the location at which appropriately equipped vehicles can begin receiving real-time traffic information for the urbanized area. The sign indicates which broadcast radio frequency or OBC-satellite access code (for real-time map displays) to use to tap into the system. Doug routinely obtains ADIS information for every available area using the cab's FM radio band. In fact, before he even leaves the terminal he will query Hartford ADIS to help him leave town.

Several States have installed new, permanent WIM-AVC (weigh-in-motion/ automatic vehicle classification) locations which also include an AVI reader. When Doug passes these locations, the vehicle is weighed, classified, checked for bridge formula compliance, and identified. Within seconds, the State computer network will not only know the configuration of the vehicle and how much it weighs, but also whether the vehicle's operating systems are currently functioning properly, its base-State registration, who is driving and number of hours driven. All States have also begun to implement the State line beacon transmitter, another device which has greatly simplified some of the daily record keeping required of

BMK drivers. These beacons constantly emit a time of day and date signal. As appropriately equipped BMK vehicles, such as the one Doug is driving, cross a State line where a beacon has been installed, the vehicle's transponder picks up the beacon's signal and stores the time-date data in the OBC memory. Upon receiving a beacon signal, the OBC is programmed to read the cabs odometer and the wheel hub counters on the attached semi-trailer or trailer. These pieces of information, i.e., time-date, odometer reading and hub count are then permanently stored in the OBC memory for post-trip analysis. Beacons have now been installed at all Interstate System State line corssings and for driver's staying on the interstate, have eliminated the need to keep daily records of mileage traveled for interstate reporting purposes. In addition, State audit reviews of carriers for registration and fuel tax mileage data have been greatly simplified by the standardized reporting format of the beacon-odometer-hub-count record keeping system.

When the AVI uses were explained to BMK's drivers back in 1993, there were some eyebrows raised about Big Brother. However, Doug and the other drivers now realize that a clean, current vehicle/driver status allows them to proceed without ever having to stop at a scale, port of entry or safety inspection site along the way. Now Doug can travel more miles in the same amount of time and earn more money. In addition, the AVI feature allows Doug to traverse the three toll facilities along his route without handling money or receipts.

While traveling along I-70 near Cambridge, Ohio, the message light on the OBC in Doug's cab comes on. BMK drivers have standing instructions regarding the incoming message light. The urgency of the message is relayed by either a steady or flashing light. If it is a steady burning light a driver is to stop at the next practical or convenient location and use the OBC's function keys to display the message and acknowledge receipt back to the dispatcher. A flashing light indicates greater urgency, which means a driver is to stop at the next safe location, receive and acknowledge the message.

Doug's OBC is displaying a steady light. It is 15 miles to the I-70 rest area east of Zanesville, Ohio, soon enough to take the message. The BMK dispatcher is directing Doug to make a special parts pickup at the General Electric Appliance Park in suburban Louisville, Kentucky. The dispatcher also supplies Doug with a suggested route from his present location. These messages are displayed on the OBC's screen. Originally for this part of the trip, Doug planned to stay on I-70 to the Kansas City metropolitan area. The dispatcher's message suggests that Doug leave I-70 at Dayton and take I-75 to Cincinnati, then I-71 to Louisville. Doug is also reminded that all through-trucks must take the I-275 beltway at Cincinnati. Doug responds to the dispatcher with a question, "How about I-71 from Columbus to Cincinnati?*' The dispatcher replies that the Ohio Department of Transportation, in its seasonal construction bulletin, is advising that several pavement repair projects are underway along I-71 between US 35 and I-275. Only one lane is available and traffic will be completely stopped at times throughout the work area. Continuing with the route information, the dispatcher informs Doug that at Louisville he should follow I-265 and the signed truck access route to Appliance Park. On departure, from the Louisville area, the suggested route follows signed truck access to I-264 to I-64 west to the St. Louis area to rejoin I-70.

Fifteen minutes later, with the message stored in the OBC for recall as needed, Doug moves out from the rest area. He will follow the route suggested by the dispatcher supplemented by local ADIS information.

The AVL equipment on the truck automatically emits a location signal every 30 minutes to the dispatcher's office via satellite. Accordingly, Doug's actual location was updated to the dispatcher every 25 miles or so. This fact assisted the dispatcher in scheduling the special pick up and being able to inform Doug in a timely manner.

The one location at which Doug really feels that the WIM-AVC and AVI processes are a big plus to him is the weigh station along I-35 at Olathe, Kansas. Doug remembers sitting in queues of 20 and 30 trucks back in the 80's, waiting to be weighed one axle group at a time, and then possibly having to wait through a thorough, but seemingly slow safety inspection. It probably was not any slower than any other State's inspection procedure, but with only 150 miles to go on a 1500 mile trip, the drivers were anxious to arrive at the Wichita terminal.

Doug safely arrives in Wichita. This trip has involved an OBC, AVI, WIM, AVC, AVL and TWC technology applications, as well as ADIS installations in several metropolitan areas.

SCENARIO 2. INTERSTATE FREIGHT TRANSPORTATION THE STATE AGENCY

This is Bill's 20th year as a civilian employee of the Kansas Highway Patrol, the last 5 of which have been spent working the weigh station along I-35 near Olathe. Historically, this scale has been open 24 hours a day and in past years weighed, inspected and checked the paperwork of thousands of trucks each year. Last year, however, the weigh station joined the future. Oh sure, they still weigh and inspect some trucks here, but the number has dropped significantly. Why? Any truck which opts to join the State(s) electronic heavy vehicle program and is appropriately equipped (i.e., at least a transponder for AVI, an OBC, and TWC capability) will no longer be required to stop at every interstate weigh station, port of entry or vehicle inspection, unless there is a problem.

AVI transponder readers have been installed upstream from the low speed WIM scale adjacent to the new mainline WIM-AVC installation. As a participating truck passes the AVI reader, the vehicle is identified, its OBC polled through the transponder for mechanical system status, and the driver's status (valid commercial driver's license and compliance with hours-of-service regulations) and it is weighed, classified and checked for bridge formula compliance. Within 60 seconds, the State's computerized record center as well as the State's network have been polled and all current information on the vehicle is processed. If everything is okay, Bill' s computer console screen stays blank and the truck rolls on. If any information is not current or any weight threshold exceeded, the truck ID number and problems are displayed. Bill can review the information and if he believes there is a significant problem, he can send a message to the truck to pull in to the new truck weight/inspection area approximately 15 miles down I-35 at the Wellsville exit. At the same time the direct message is sent to the truck, it is also sent to the Wellsville State Patrol Station, so that officers there can expect a certain truck in approximately 10 to 15 minutes. The penalty for not stopping as directed will really compound the driver's problem. Meanwhile, the trucks that Bill weighs on the low-speed WIM scale are those which have not joined the State(s) heavy vehicle program. Of course, the trucks stopping at the scales also have the chance of being picked out for a safety inspection. Bill and his crew have a reputation for conducting thorough safety inspections. Drivers, however, often complain that the crew is awfully slow.

In this instance, AVI, WIM, AVC and TWC all combine to keep a legal truck on the move and keep high risk and overweight vehicles off the road. Simultaneously, the State is accumulating accurate data on traffic and axle weights, which will be used in planning and pavement management functions. In addition, safety is enhanced because a queue of trucks is no longer routinely backed onto the mainline from the Olathe weigh scales. The State's central record center has accumulated data for participating trucks from several sources including the Highway Patrol (inspections), and the Departments of Motor Vehicles (registration) and Revenue (fuel tax).

The record center is jointly funded and staffed by these agencies as well as the highway department. Data entry terminals are located at every port-of-entry, weigh station, highway patrol barracks, and Highway Department District Office in Kansas.

The Interstate Freight Transportation scenarios present some of the concepts, albeit simplistically, which if successfully implemented would provide many of the benefits stated at the beginning of this section.

What needs to be accomplished to bring these scenarios to life? Actions are necessary in a number of areas including; (1) applying technologies individually and in combination; (2) reduction of institutional barriers, both administrative and statutory; (3) development of communication and transponder standards; (4) resolution of driver privacy issues; (5) widespread deployment by States; and (6) widespread voluntary participation by carriers.

SCENARIO 3. LOCAL DELIVERY-THECARRIER

Acme Delivery is headquartered in Rosemont, Illinois, adjacent to O'Hare Field. They specialize in local delivery of time-sensitive items in the Chicagoland area. Each of Acme's 100 vehicles, which include cargo and step-vans, are equipped with transponders which uniquely identify each vehicle and an on-board computer with voice synthesizer, which can receive and send messages.

The transponder allows each Acme vehicle to use the special toll booth bypass lanes which the Illinois Tollway Authority has constructed at each mainline and ramp toll plaza. The readers adjacent to the special lanes allow vehicles with a transponder to pass through at highway speeds. Their passage is recorded and Acme's account at a local bank is electronically debited on Wednesday of each week.

The Chicago area ADIS continuously makes available an up-to-date list of highway segments on which operating speeds are significantly below posted speed limits. The dispatcher monitors this information and can forward updated route information on an area-wide basis or to individual vehicles as necessary. The on-board computer receives the signal and can display the information on the ADIS screen or use the voice synthesizer. Accordingly, Acme Delivery's dispatcher can easily contact the nearest driver for requests for package pickups that occur while the driver is in the vicinity. If the vehicle is equipped with an automatic navigation system, these additional stops can be downloaded to the vehicle system and entered as new segments on the driver's route display, and enunciated by the voice synthesizer at the appropriate route position.

Acme's productivity has increased significantly through the use of AVI and ADIS and customers are much happier with the prompt delivery. The technologies and derived benefits described in the "Local Delivery" scenario would also apply to the taxi and rental vehicle industries.

SCENARIO 4. Bus TRANSPORTATION-INTERCITY

A few years ago my parents traveled from Chicago to Boston on a Greyhound Bus in December to visit for the holidays. For many elderly people including my parents, the bus offered the best alternative from a cost and convenience standpoint for long distance travel. In previous years my parents would have driven their own car, as my father loved to drive. But health problems and the uncertainty of winter weather ruled out driving for this particular trip. They felt the train was too expensive, and neither one thought much of flying.

The bus they took was an "express" with scheduled stops only at major cities along the way. The bus route basically followed I-90 all the way, which itself has potential problems including: (1) in the winter is subject to "lake-effect" snow for almost one-half of its total distance, and (2) much of it is toll road with long distances between interchanges.

Afterwards I thought a little more about potential problems on the bus trip. What would have happened if while passing Ripley, New York, a passenger needed emergency medical treatment and there was a major snow storm? What would have happened if the bus developed a mechanical problem and had to pull into the shoulder and stop half way along the 28 miles between the Lee and Westfield interchanges of the Massachusetts Turnpike?

If a bus under these circumstances were equipped with an AVL system and TWC capability, a bus company dispatcher would know real-time bus location with a degree of accuracy sufficient for any practical reason. A driver would be able to signal the dispatcher in an emergency, who in turn could contact the proper authorities, as well as provide further advice to the driver. With an AVI transponder, all toll payments along the way could be handled automatically, relieving the driver of the need to handle cash or a credit card, at least for toll purposes, and keep track of receipts.

As in the Interstate Freight Transportation scenario, the AVI and OBC process would also give regulatory authorities the ability to monitor the bus and driver's status on a real-time basis.

SCENARIOS. Bus TRANSPORTATION - LOCAL TRANSIT

IVHS technology for local buses could also have a very positive impact on congestion and pollution problems. The following is a short scenario for local transit bus operations.

Five years ago, John regularly drove his car to and from work. Access to the city, however, became increasingly difficult as congestion grew on the freeway network. He was losing 2 hours a day in driving to work. Recent transit route changes brought on by the use of IVHS technologies in the metropolitan area, however, have created attractive bus service alternatives for John. Tuning into his television's cable station featuring local transportation information, John was surprised to see how convenient a new bus route serving his neighborhood would be for his regular commute. He tried it, and quickly became a bus regular.

The better knowledge of local travel patterns brought about by IVHS programs has, for example, permitted bus operators to optimize routings which now allow 85 percent of bus users to take only one bus to get to work. Previously, most bus users had to transfer at least once under the old routes and still travel slowly in congested traffic. Trips simply took too long timewise for many potential users. Direct bus service coupled with traffic engineering improvements such as dedicated bus lanes and optimized traffic signal control have greatly speeded bus travel.

While the transfer problem is often cited in local public opinion polls as the major reason for not using the bus system more often for work trips, another often cited non-use reason is personal security while traveling on the bus. Even here, however, IVHS technology has resulted in a one button alarm system which when activated by a driver for any reason, alerts a dispatcher of the need for police assistance and provides exact location. The dispatcher can then patch into police communications requesting help and providing location information for police response.

Implementation of IVHS programs has allowed the transit company to improve:

- real-time fleet monitoring leading to improved on-time performance,
- real-time information to the users,
- real-time location for emergency response, and
- preferential techniques favoring bus circulation (reserved lane, priority at traffic light, free parking lot at the extremity of the transit network).

These improvements have made the transit system more reliable and appealing. For John, it reduced travelling time significantly. In addition, travelling time can now be used productively even if that means to simply relax from a hard day of work before he reaches home. IVHS technology has permitted the town to reduce congestion and pollution by 20 percent without having to increase the number of freeway miles.

SCENARIO 6. EMERGENCY RESPONSE

Cargo information is extremely important especially since chemical and/or flammable products are constantly being moved via truck in both rural and metropolitan areas. The following is a scenario where exact cargo information becomes critical.

Eugene is carrying acid toward a metallurgical plant. Due to a sudden evasive maneuver, the vehicle rolls over and spills part of its content. Eugene loses consciousness. The roll-over device on his truck emits an emergency signal, giving the exact location of the vehicle, its identification number and cargo information from the electronic hazardous material placard. Public authorities are automatically alerted. From an existing database and the AVI, the properties of the cargo being carried by that truck are retrieved. Officials are then able to dispatch the closest relevant emergency vehicles by the best route using the local ADIS. In this case, the relevant emergency vehicles could be a police crew, an environmental crew, an ambulance, or a trailer carrying a neutralizing chemical product.

IVHS technologies allowed officials to respond quickly and with the proper countermeasures, because they immediately knew the when and where the incident occurred, and the type and properties of the substance(s) involved. This made a critical difference in response time, affecting in a positive manner the safety of all concerned.

PATH TO THE FUTURE

The normal sequence of steps to the successful implementation of a mature technology are research, operational tests and deployment. However, many of the individual CVO technologies have been researched and tested, making the next step for these technologies the field testing of their application on a system basis. Therefore, while research in areas which will directly affect CVO activities should be expanded and accelerated, the operational testing on a systems basis should also be initiated. The order of this discussion will follow the traditional sequence, but it should be understood that research and certain operational tests will proceed simultaneously.

STATE-OF-THE-ART

Application of individual technologies will produce a certain level of benefits for the user. For example, some carriers are already using AVL systems to improve customer service, and many States are expanding the use of WIM and AVC for travel data collection. All benefits, however, can be significantly increased if technologies are integrated and applied on a system basis. The key lies in the sharing of technology and data by CVO and the public sector. For example, both carriers and States will use AVI to identify and locate vehicles. Also, both interstate carriers and States need mileage for fuel tax and International Registration Plan (IRP) purposes. The cost is less for each if they share data collection using AVI, OBC, and AVI readers, thus, increasing both administrative efficiency and carrier productivity.

RESEARCH AND DEVELOPMENT NEEDS

As stated earlier, the research and initial testing of equipment has been completed for many of the technology applications mentioned earlier. However, there is also other simultaneous research needed to optimize the potential of the technology applications discussed in Appendix B and to resolve ongoing problem areas.

Research on the human factors aspect of information processing by commercial vehicle drivers must be expanded. While some research is underway, more is necessary to focus on the more complex on-board computer function capabilities which commercial vehicle operators will experience. It appears that technology is ultimately going to be providing all drivers the opportunity to obtain real-time highway and vehicular system information. The optimum way to display this information needs to be determined so that a commercial driver is not overloaded and can react in a safe, predictable manner.

Vehicle dynamics, especially for combination vehicles, is another research area where design changes and technology could directly effect highway safety by improving vehicle stability. HCV accidents involving trailer swing, vehicle roll-over and/or jackknifing are some of the most critical, in that they often cause complete blockage of a roadway for an extended period, and often involve fatalities and/or injuries. While the truck-tractor semi-trailer combination vehicle is likely to remain the backbone of HCV operations into the foreseeable future, it is also quite likely that there will be increased use of multiple trailer combination vehicles including Turnpike, Rocky Mountain and standard doubles as well as triple bottom units. Suspensions that instantly adjust, roll indicators, collision avoidance systems, and vehicle specific grade warning systems, for example, could improve vehicle dynamics, and prevent many of these incidents from occurring.

A summary of the proposed research necessary to fulfill the goals of the commercial vehicle operations section which should be initiated is listed below and briefly summarized in Appendix B.

- Human factors
  - "best" layout of cab equipment
  - "no hands" message receipt and transmission (head's up displays)
  - driver fatigue self detection and countermeasures
  - driver identification systems
  - driver trip pretest (real-time suitability to drive)

Note: It is recognized that any *items which involve unique driver identification raise extremely sensitive privacy issues and these need to be addressed in the research and demonstration phases.*

- Vehicle Performance
  - real-time vehicle systems monitoring (including status of brakes, other mechanical systems, vehicle dynamics, etc.)
  - improved designs with respect to the cargo's center of gravity
  - near-obstacle detection and warning systems
  - out-of-lane/run-off-the-road detection and warning systems
  - dynamic grade severity warning systems
  - dynamic ramp and sight distance warning systems
- Improvements to existing technology applications
  - bridge height clearance sensor

- two-way communication terminal receipt, i.e., screen, verbal, and transmission medium, i.e., satellite, radio, etc.
- unique vehicle identifiers with respect to combination vehicles

OPERATIONAL TESTS

As Appendix B indicates, operational tests of researched technologies are continuing or will begin in several areas including automatic toll collection, remote driver/vehicle inspections and safety warnings related to individual vehicles. In addition, however, there is already a major effort underway in which several technologies are to be tested on a system basis, i.e., the integration of individual technology applications. The Crescent Project demonstration of the Heavy Vehicle Electronic License Plate (HELP) program is designed to be an extensive integrated test under day-today operating conditions of WIM-AVC and AVI. This project is a cooperative effort of State governments and their counterparts in the interstate carrier industry. Initial implementation will begin in mid-1990 with additional segments phased into operation in 1991 and 1992. The "Crescent" name is derived from the project's corridor location, which is along I-10 and I-20 from east Texas, west through Texas, New Mexico, Arizona and California to the greater Los Angeles area, then north along I-5 through California, Oregon and Washington to the international border, continuing into British Columbia using portions of both the Trans+Canada and Alaska highways. Data will eventually be monitored at 35 locations.

The full Crescent Project 'will ultimately involve an estimated 4,000 heavy commercial combination vehicles for 1 year. An evaluation report of Crescent is due in 1993. As currently planned, Crescent will:

- Demonstrate a potential response to the motor carrier industry's desires to have one-stop shopping and transparent State borders to help reduce the number of required stops, and using the OBC reporting capability to replace manual record keeping insofar as registration, fuel tax, and driver's hours-of-service requirements are concerned.
- Show that the technology applications, i.e., WIM, AVC, AVI and OBC will work reliably from a system standpoint in the highway environment; and
- Demonstrate the potential for increased efficiency in governmental administration of selected motor carrier regulations, and highway planning. Specific areas include vehicle weight and tax reporting. The ability to count, classify and obtain vehicle weight information for highway planning, design and pavement management purposes will also be demonstrated. The latter information will be obtainable for all trucks in the Crescent corridor, not just those which will be equipped with AVI transponders.

Crescent presents an important, early opportunity with respect to the IVHS program to initiate the operational testing of concepts which are common to the other IVHS program areas. It is expected to show that technology applications can be successfully combined in a system, that institutional barriers can be minimized, and that both commercial operations and public agencies can successfully share in the collection and use of data.

OBSTACLES TO BE OVERCOME/CONSTRAINTS

There are three areas in which issues must be resolved in order to maximize the benefit potential of deploying IVHS technologies.

The first area concerns driver privacy. Deployment of the technologies discussed to this point will provide almost constant information on a commercial vehicle, and accordingly a driver's location and status. Situations will arise where the benefits to society in general will have to be weighed against the rights of an individual driver, in making a decision.

The second area involves development of AVI and on-board computer technology. The scope of what an OBC is intended to be, was previously described, and must be developed to the fullest practical extent as early as possible. For AVI, agreement by States and industry on transponder standards, particularly with respect to the identification of combination vehicles. The ability to uniquely identify a specific vehicle and its performance is key to both fleet management and State monitoring.

The third area concerns the Crescent project. It must be successful in terms of equipment, carrier benefits, and overcoming institutional problems. First, the hardware and software involved must be able to function almost flawlessly on a continuous basis and at a reasonable cost. Second, and perhaps more importantly, it must be demonstrated that direct tangible benefits can be derived by carriers which participate in a system of high technology applications. These benefits would primarily consist of reducing the paperwork/reporting burden associated with interstate drivers, and reducing the number and duration of required stops.

It must be remembered that during Crescent, it is possible that the actual achieved benefit per participating vehicle will be relatively small, since it is only an operational test. However, a successful Crescent project will demonstrate a benefit potential for all concerned parties and provide guidance and a strong incentive for further testing and deployment.

Third, the States must begin to examine the basis for the multi-agency involvement with CVO traffic which currently exists in most States. Whether administrative or statutory, each agency's role should be reviewed. If the need for an agency's involvement remains valid, perhaps some required record- keeping or reporting can be simplified, e.g., fuel tax information. If the original basis for involvement no longer exists or has greatly diminished, the withdrawal of reporting requirements might be appropriate.

Even a successful Crescent Project, however, will not completely convince all States and interstate carriers of the need for, and usefulness of system technology applications. Therefore, it is recommended to designate and fund additional cross-country or interregional corridors. These corridors would be viewed as continued operational tests. Carriers and States would begin to benefit in a significant manner because of greater participation, fewer delays and increasingly efficient collection and use of data.

DEPLOYMENT

A plan and milestones for the deployment of commercial vehicle advance technology applications is shown in Appendix B. As Appendix B indicates, widespread system deployment would occur in stages closely following successful corridor demonstrations. During 1993 and 1994, several major interstate carrier corridors would be equipped to reduce the paperwork burden on interstate drivers and the required number of stops. The corridors are anticiPATED to be along major National Truck Network routes. During 1995, large scale instrumentation in each State would begin and by the year 2000, all Interstate routes, and 50 percent of the non-Interstate routes on the National Truck Network would be equipped to expedite CVO traffic.

In addition, there will be direct benefits to local commercial vehicles resulting from AVI for automatic toll collection. This feature will be available on all toll facilities open to commercial vehicles by 1998. The IVHS technology which will provide the greatest benefit, however, for both local commercial and emergency response vehicles is ADIS, the details of which are discussed in the ADIS section of this report.

INTERFACE WITH OTHER IVHS SYSTEMS

Commercial vehicles will benefit not only from the technologies and applications discussed here, but also from the research, field tests, and deployment activities proposed by other IVHS efforts dealing with advanced driver information, traffic management and vehicles/highways. On the other hand, CVO will provide an early field test opportunity for the ADIS and ATMS applications.

Other IVHS efforts which involve the creation of databases for routing algorithms and traffic control must be cognizant of the special requirements of CVO, especially HCV, in developing alternative routing plans. Advanced traffic management systems must be aware of local transit and taxi operations, and perhaps consider these commercial operations for preferential treatment in the traffic stream.

ADIS, for example, is already evolving. As mentioned earlier, equipment is now available which allows two-way verbal and text communication between the truck driver and a home office. The ability for two-way communication automatically brings with it the opportunity to provide a driver with current traffic information and revised delivery scheduling.

The automated vehicle, on the other hand, is a concept which is just beginning to be developed as an IVHS component. As incremental developments in automated vehicle technology come on line, they will be considered for adoption by commercial operators. There is support for commercial driver assistance technology but some industry representative-s and drivers have expressed concern over technology which would take vehicle control totally away from the driver.

FUNDING/RESOURCES

The total public agency funding requirements for CVO are $837 million over 10 years, broken down as follows. IVHS funding would be sought for efforts which include:

Research, including:

Human factors, vehicle stability and other technological improvements

$17 million

Institutional barrier simplification, communications network development and marketing of research products

$15 million

Field Operational Tests, including:

Crescent project and additional corridors

$80 million

Deployment on Interstate mileage not previously covered and 50 percent of the non-Interstate National Truck Network.

$725 million

Total $837 million

Figure 1 shows the public funding requirements in 5 year intervals and that most of the IVHS funding would be for operational tests. Further, it shows that most of the integrated systems would be deployed and milestones in Appendix B achieved by the year 2000.

RECOMMENDATIONS

Advanced technology applications and the potential benefits have been discussed in the preceding pages. The following series of actions are needed to realize the full benefits.

1. Support the HELP-Crescent project. Review HELP-Crescent progress and make recommendations for the corridor demonstrations by the end of 1992. The FHWA should act as a catalyst to encourage Federal, State and industry participation in the HELP with the understanding that during all phases of the HELP, AVI technology will continue to be refined and alternative technologies recommended by the motor carrier industry will continue to be evaluated by the HELP's trucking industry representatives and associated State highway agencies.

2. Establish a clearinghouse with a separate staff and budget to collect, evaluate and circulate information about technology and research already underway in the commercial vehicle operations by the private sector and by various State and Federal government agencies.

3. Establish a national forum to coordinate the development and resolution of policy and technical issues with respect to CVO technology systems. The forum should be organized by the U.S. DOT in cooperation with Mobility 2000, commercial transportation operators and HELP, with a target for establishment by October 1990.

4. Have the U.S. DOT seek legislative action which:

   a. Establishes a mechanism whereby Federal funds can be made directly available in a timely manner for State and private IVHS-/CVO activities.

   b. Provides one time Federal funding on a 90-10 matching basis from a separate category to States and other qualified parties for the establishment of additional field operational tests of IVHS technologies of particular utility to commercial vehicle operators. These tests should commence in Federal FY 199 1 and should include corridor demonstrations; real-time traffic information systems tailored to the needs of CVO; AVI for toll collection; and support for fleet tests for both demonstration and research products. These field operational tests should be geographically dispersed so as to involve as many States and regions of the country as practicable. Estimated funding is $70 million. These costs include operating costs for 1 year.

   c. Gives the U.S. DOT Secretary the ability to remove for a period of time not to exceed 1 year Federal gross weight limits within

Crescent and demonstration corridors for HELP — type equipped vehicles, as long as Federal axle weight limits are not exceeded, the Federal bridge formula is adhered to, and participating carriers demonstrate that everything possible is being done to ensure safe operation of the specific vehicles being exempted.

PROGRAM MILESTONES

The interaction of Federal legislation, State cooperation and industry economic forces will, by the year 2005, provide deployment of the following system combinations of advanced technologies targeted at Commercial Motor Vehicle Operations, and interim benefits including:

By 1995,

- instrumentation to allow the application of Crescent Technology on 12,000 miles of major interstate truck corridors;
- weigh-m-motion technology in place on 50 percent of the Interstate System;
- concluded operational tests showing how the on-board computer can be used to satisfy various record keeping and reporting requirements; and
- the completion of research and beginning of field tests regarding advanced vehicle warning and safety systems.

BY 2000

- instrumentation to allow the application of Crescent technology on the entire Interstate System and 50 percent of the non-Interstate National Truck Network;
- automatic reporting for interstate carriers available in all States;
- automatic toll collection in place on all toll facilities open to commercial vehicles;
- electronic cargo tracking, driver/vehicle inspection and electronic permit recording available in all States; and
- widespread adoption and installation of dynamic safety warning systems.

By 2005,

- refinement of all previously listed systems and expansion where feasible
- to Canada and Mexico.

This deployment is, of course, predicated on the technological success, economic feasibility and poIitica1 acceptability of the concepts being discussed.

REMAINING ISSUES

Three areas of concern warrant special mention: (1) driver privacy, (2) operating standards (both for AVI and radio frequencies for data transmission), and (3) system operation and maintenance.

DRIVER PRIVACY

There is no question that implementation of the concepts described in this paper will allow, in addition to all of the facets previously described, closer surveillance of individual drivers. This fact by itself could provide a substantial obstacle to system evolvement and deployment without sensitivity and safeguards by both government agencies and carrier management.

The first stages of expanding surveillance have already been established through such actions as the single commercial driver's license and the various drug testing programs. Neither of these programs has been wholeheartedly embraced by all segments of the motor carrier industry and both exist today primarily due to the Federal legislation establishing the programs.

A growing amount of information will be available about truck and driver location and performance with an IVHS-CVO program. It may take both Federal legislation and carrier/driver education at the beginning to head off possible abuses of the available data by both public agencies and private companies.

OPERATING STANDARDS

Much of the IVHS-CVO potential is based on having the ability to uniquely identify each commercial vehicle. In order to realize this ability a national vehicle identification standard must be developed. At this time the International Standards Organization is already developing a unique identity system for containerized maritime shipping. Many times, however, containers are moved directly from a ship's cargo hold to a flatbed truck, instantly creating a truck tractor semi-trailer combination vehicle. Questions regarding the compatibility of the maritime system and what might evolve as a CVO system have yet to be resolved. A related standards issue involves the radio communication frequencies to be used for information and data exchange. As HCV's, for example, travel between metropolitan areas, standardization of communication channels is almost mandatory for the system concepts to work.

PUBLIC AGENCY SYSTEM OPERATION AND MAINTENANCE

As with any new system, operation and maintenance must be considered. Proper operation of any new system brings with it the requirement to tram and compensate operating personnel to the level necessary to maximize that systems potential.

APPENDIX A

PRINCIPAL CVO BENEFIT CATEGORIES AND THE PRIMARY RECIPIENT GROUPS.

COMMERCIAL VEHICLE OPERATORS

- Initially; broadcasts of real-time traffic, travel and weather information, later; real-time routing by combining on-board map and "electronic yellow pages" databases with radio broadcasts of real-time information.
  - Better trucking and parcel delivery services to shippers and receivers by avoiding delays caused by bad weather, road construction, and traffic congestion and, when combined with two-way communications, by providing more accurate ETA (estimated time of arrival) and shipment status reports.
  - Reduced operating costs from traffic delays.
  - Enhanced driver working conditions.
  - More efficient dispatch of emergency vehicles, trucks, couriers, transit buses, and taxis (especially when combined with two-way communications).
  - Ability to obtain current information about rest and truck stop locations and space availability.
- Automatic vehicle identification, with and without weight in motion (WIM).
  - Reduced delays at weigh stations and ports of entry.
  - Enhanced ability to recover stolen vehicles.
  - Reduced delays at toll booths through automatic toll collection.
  - Reduced paperwork, through electronic data interchange.
  - Automated record keeping for easier compliance with state tax laws.
  - Ability to gear safety messages to particular types of vehicles.
  - Ability to use roadside AVI to obtain fix on vehicle's current location.
- Advanced vehicle controls (driver impairment detection and warning, near obstacle detection and warning, automatic braking, machine vision, etc.).
  - Fewer traffic accidents and accompanying reductions in medical, insurance and repair costs.
  - Productivity gains from technologies that permit use of longer or heavier vehicles.
- Automatic "MAYDAY" device (combined AVI, AVL and communications link with dispatcher or public authorities).
  - Increased driver safety.
  - Increased cargo and vehicle security.
  - Enhanced incident management capability.

STATE GOVERNMENT

- Improved enforcement efficiency of motor carrier regulations.
  - driver licensing and physical examination records.
  - vehicle size, weight and inspection status.

    - driver log data.
    - taxation basis record keeping.
- Reduced enforcement costs on a unit basis
- Improved travel, vehicle classification and axle weight data.
    - for use in allocating current maintenance resources.
    - for use in making facility design projections.
- Stolen vehicle tracking ability.

LOCAL GOVERNMENT

- Improved incident mitigation ability.
    - real-time cargo information.
    - accurate emergency response.
    - ability to provide detours around incidents by vehicle type.

PUBLIC

- Environmental improvement (air quality).
- Ability to avoid incidents.
- Improved infrastructure condition.
- A lower or stabilized transportation cost aspect of consumer goods pricing.
- Increased safety of commercial vehicle operation.

APPENDIX B

PLAN AND MILESTONES FOR IVHS: COMMERCIAL VEHICLES

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2005
Crescent Project	Demo in 6 States AVI, WIM, AVC, OBC											
Corridor Instrumentation (Crescent Technology)				Demo 3 E/W 3N/S		Deployed on 50% of Interstate		Deployed on 50% of National Network				Deployed on 100% of National Network
Weigh in Motion	Deployed Selectively in all states			Deployed on 50% of Interstate							Deployed on 100% of Interstate	
Automatic Reporting for interstate Carriers		Demo integration OBC with Beacon AVI,AVC,AVL at Crescent sites	Demo multistate reporting in Crescent and Corridor States			Deployed in all states						Deployed in all border Canadian/ Mexican Provicences
Automatic Toll Collection		Demo at Dulles and TRANSCOM toll sites		Demo in 5 states and 5 urbanized areas		Deployed on all Tollroads State Tollroads and 50% of toll tunnels & bridges					Deployed at all major toll facilities open to trucks	
Remote Driver/ Vehicle Inspections		Research OBC/reader/ Out Service Criteria		Demo in 2 contiguous states & 1 other state		Deployed in 25% of states & 2 Canadian Provinces						Deployed in all states & Canada
Vehicle & Cargo Hazmat Tracking			Research Elec. bill of Lading/ Placard, Stolen Vehicle Tracking	Demo in 1 State	Feasibility for International HM	Deployed 10 states	Research non-HM cargo tracking					Deployed for HM tracking in all states & major HM shippers
Electronic Recording Oversize/Weight Permits			Regional Demo links states Electronically	Demo in 2 contiguous regions		Deployed in 50% of regions					Deployed in all regions	
CMV Driver In-Vehicle Displays		Research human factors	Demo in urbanized and interstate operation									
CMV Driver Fatigues/ self Monitoring			Research human factors & driver monitoring	Demo in 1 truck corridor		Disseminate Results						
Vehicle Dynamics		Research/test stability improvement		Deployment determined by market acceptance								
Proximity Warning Systems		Development by private sector		Deployment determined by market acceptance								
Dynamic Safety Warning Systems Vehicle and Site Specific Including Grade Severity, Ramp Speed, and Sight Distance			Research	Demo: Selected Locations		Disseminate Results						

Intelligent Vehicle Highway Systems

Operational Benefits

MOBILITY 2000

Dallas 1990

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EXECUTIVE SUMMARY

The "Benefits Group" of Mobility 2000 was charged with developing a first pass at *the benefits* that would accrue as a result of the deployment of IVHS technology and with developing a framework for analyzing and categorizing these benefits.

We recognize the projection of a comprehensive set of benefits for IVHS is a complex and difficult undertaking. Issue-s as market penetration, technology definition, time staging of technology availability, the public/private enterprise aspects, and distribution of benefits across groups make projection difficult. Nonetheless, we have no choice *but to do projections of IVHS benefits as best we can, and now*. Further, we need to recognize that estimation of benefits is a *process* over time. This is not something we do once and then forget about. Rather, we made first estimates of benefits at this time. Subsequently, we will refine these as various uncertainties are clarified.

After completing this first analysis, we assert that while benefits strongly depend on deployment and market penetration, reasonable assumptions lead us to conclude that SUBSTANTIAL AND BROAD-BASED BENEFITS ARE AVAILABLE THROUGH A DEPLOYMENT OF IVHS

Three major areas of benefits are:

Safety – under realistic sets of conditions, in the range of $4-$20 billion annual savings by the year 2010 are achievable through the implementation of IVHS technology.

Congestion – $100 billion are lost each year iu the U.S. due to traffic congestion. IVHS deployment can reduce this substantially. Some early experiments suggest 10-15 percent reduction in congestion are reasonable estimates. Some of these benefits can be achieved immediately upon implementation.

Fuel – Savings of in the range of two billion gallons by 2000 and six billion gallons by 2010 are reasonable estimates.

Clearly, other benefits are possible in areas such as air quality, mobility, infrastructure, and market development for auto and electronic companies.

A complete taxonomy of benefits is described in the full report.

To conclude:

1. There is a very broad set of benefits that can accrue as a result of deployment of IVHS, and these benefits are substantial.
2. The set of impacted groups is likewise very broad.
   - While urban America achieves significant benefits, there are important benefits for the rural population as well.
   - While the journey to work benefits are quite important, the recreational traveler will benefit as well.
   - While the auto traveling public will clearly be a major beneficiary of IVHS lmplementation, the transit industry and the transit user will benefit as well.
   - While the conventional auto driver will benefit, there are important benefits that accrue to fleet and commercial operations as well.
   - While IVHS will benefit travelers across all age groups, particular benefits will be provided to elderly drivers.

With this breadth of benefits, it is reasonable to expect that a broad base of support for IVHS can be developed.

We recommend that the estimates of benefits of IVHS deployment continue to be refined. However, benefits estimated thus far are such that the next steps in developing a national program for IVHS are appropriate.

INTRODUCTION AND APPROACH

INTRODUCTION

In considering the development and implementation of any transportation system, it is necessary to estimate the costs and benefits associated with it, so that proper decisions can be made. The "Benefits Group" of Mobility 2000 was charged with developing a first approximation of the *benefits* that would accrue as a result of the deployment of IVHS technology and with developing a framework for analyzing and categorizing these benefits.

We recognize at the outset that predictions of benefits for complex systems like IVHS are quite difficult. Further, the projection of a comprehensive set of benefits for IVHS specifically, is a particularly complex and difficult undertaking. The reasons for this are several fold, but include the following.

1. IVHS Technology is not fully defined. While we have a framework for IVHS technology, (ATMS, ADIS, etc.,) we do not yet have a well specified definition for IVHS. IVHS is envisioned *as* a *program,* not a project – but what the program is remains undefined.
2. Even assuming certain technologies as part of IVHS it is difficult to estimate:
   a) Market penetration,
   b) Time staging of technology availability.
3. IVHS is a joint public-private enterprise. That is, decision making on IVHS is not centralized. The phasing of "enabling" decisions by various parties is very difficult to project.
4. Distribution of benefits across groups is very complex and difficult to estimate.
5. Reactive decisions made by other actors (e.g., airlines, mag-lev entrepreneurs, construction industry, etc.) are difficult to project.

While difficulties abound in making projections of IVHS benefits, we have no choice *but to do so as best we can, and ROW.* However, we need to recognize that estimation of benefits is a *process* over time. This is not something we do once and then forget about. Rather, we will make gross estimates of benefits at this time and then eventually refine these as various uncertainties are clarified.

APPROACH

Our approach to estimating IVHS benefits in this report is as follows:

First, in Chapter 2, we present the idea of an M-IS benefits *taxonomy* intended to capture a broad range of benefits and impacted groups.

Second, in Chapter 3, we recognize that there are certain benefits that will likely account for a large fraction of total benefits. These so called focus *areas* are:

- Safety
- Congestion, Energy, and Air Quality
- Mobility and Infrastructure

Given their importance, each of these are discussed in detail, with specific quantitative estimates made where possible. These focus areas are in concert with major points raised in the DOT National Transportation Policy. This congruency is important in building support for IVHS.

In Chapter 4, we draw conclusions and make recommendations for further study.

Additional Material

When thinking about IVHS and projecting benefits for it, a parallel is the Interstate Highway System, implemented in the mid 1950's to the present day. This is a national transportation system of great scope. It is useful to review the history of this system and how benefits for it were estimated (and mis-estimated). For this history, *see Appendix A.*

Further, there have been several bodies of work on estimating benefits of systems of advanced highway technology. *Appendix B* summarizes these studies.

Finally, the classic cost-benefit approach and some thoughts on it relative to the task at hand are dis*cussed* in *Appendix C.*

THE TAXONOMY

In this chapter, we present a taxonomy of IVHS benefits intended to illustrate the range of benefits that accrue and the diverse groups which they impact.

A taxonomy is a useful way to categorize the complete set of IVHS benefits to groups in our society which share or participate in these benefits. The categories in the taxonomy partition the set of benefits. The taxonomy we envision has three dimensions – benefits, impacted groups, and technologies. Figure 1 presents a taxonomy of benefits for IVHS, showing benefit categories (as rows) and impacted groups (as columns). To simplify, we have not shown technologies in this representation. Four major

Operational Benefits

categories of benefits are envisioned (travel, economic, environmental, and information). Categories of impacted groups include users, the general population, and various organizations. In Appendix D, we give a more detailed listing of benefit categories and impacted groups.

We also expect IVHS to impact many diverse large and small groups in our society. The groups are not mutually exclusive. They include all of us, wearing different hats at different times, but all benefiting from IVHS To start with, we expect to benefit as users of IVHS, both directly, and as a result of others using IVHS to improve the operation of our transportation system. We also benefit as non-users when we enjoy economic growth and lower air pollution, etc. The organizations we work for and invest in, whether public or private, also benefit from improved productivity and efficiency, both as transportation operators, and as industries minimizing their transportation costs and increasing their international competitiveness.

Since transportation operators and planners are continually concerned with the costs and benefits of their actions, the need for benefits classification schemes is not new. The taxonomy idea builds on considerable previous work, and we do not expect it to be controversial.

Figure 1 Taxonomy of Benefits from IVHS

Categories of Benefit	Impacted Groups					
	Users (Groups) Urban, Rural, Elderly, Suburban Commuter	General Population		Organizations		
		Other Transportation System Users	Non-Users	Public Sector	Private Sector	
				Operators	Operators	Industry
<u>**Travel**</u> Safety, Mobility, rime, Costs, etc.)	X	X				
<u>Economic</u> Productivity, Growth, Competitive, etc.	X	X	X	X	X	X
<u>Environmental</u> (Pollution, Neighbor-iood Impacts)		X	X			
<u>Information</u> 'High Payoff, Construction,etc/	X	X		X	X	

What may be new to some is the need for, or usefulness of a taxonomy in the first place. Some people may feel that a simple list of the half-dozen or so most important benefits of IVHS (e.g., safety, mobility, etc.) will suffice for Mobility 2000. However, taxonomies may be used for many purposes:

- Their inclusiveness provides perspective and minimizes omission of important benefit categories and impacted groups; (i.e., protects against items "falling between the cracks");

- The way the categories are defined shows which benefits to which people are most important;
- The taxonomy highlights the distribution of benefits as much as their aggregate; and
- Keeping separate the major categories of benefits helps maximize the returns to society from public investments.

With regard to the last item, market forces help guard against routinely poor investment decisions in the private sector. However, in evaluating the benefits from public investments, market forces are often weak, and we must make a deliberate effort to insure that our transportation investments make a positive contribution to the many diverse areas of our economy, and groups in our society. More public investment can only result in net benefits if the right tools are available and actually used to forecast benefits.

Therefore, the first step in this process is to identify all the benefits and how they distribute themselves throughout our society. This is the purpose of the taxonomy.

As one scans this taxonomy, several important points become clear.

1. There are a very broad set of benefits that can accrue as a result of deployment of IVHS.

2. The set of impacted groups is likewise very broad.

While it would be naive to suggest that the M-IS benefits would be uniformly distributed across the population (after all, for what complex system is this true?), it is reasonable to suggest that there are benefits for many important groups, who can play a role in building a constituency for an IVHS For example:

- While urban America achieves significant benefits, there are important benefits for the rural population as well.
- While the journey to work benefits are quite important, the recreational traveler will benefit as well.
- While the auto traveling public will clearly be a major beneficiary of IVHS implementation, the transit industry and the transit user will benefit as well.
- While the conventional auto driver will benefit, there are important benefits that accrue to fleet and commercial operations as well.
- While IVHS will benefit travelers across all age groups, particular benefits will be provided to elderly drivers.

Later, in this Benefits Group report, we provide detailed descriptions of many benefits. We intend these descriptions to be informative of the size and range of benefits from IVHS, rather than totally inclusive of all benefits. It is the taxonomy itself that allows us to be totally inclusive, so the comprehensive benefits are not lost.

NON-OPERATIONAL BENEFITS OF IVHS

Many people, when they think of benefits of IVHS, think in terms of operational benefits (e.g., safety, improved travel times). While these are important (and indeed are expanded upon in Chapter 3), there are other benefits that do not relate to system operations per se. Limiting our perceptions to operations alone will underestimate the case for IVHS.

Among these non-operational benefits are the following:

1. *The Market Opportunity of IVHS for the Automobile and Electronic Industry*

IVHS could represent a significant business opportunity for automakers and the electronics industry. IVHS would add novel functionality to automobiles, and this increased functionality would increase the value of the automakers' product. This increase in product value translates into expansion in the overall automobile market and would bring with it new business opportunities for companies that serve that market. In short, IVHS gives producers an opportunity to sell a wide range of new and enhanced products.

In 1987, Daimler-Benz of Germany predicted that electronics will account for between 20 and 30 percent of total automobile production costs by the year 2000. That would be a whopping 50 percent increase over the 1987 levels, and it would take place in just 12 years. Obviously, this growth in the application of electronics is a tremendous market opportunity. Furthermore, the value of this market is even greater than might appear, since profit margins in vehicle electronics can be higher than margins for the vehicle as a whole.

This kind of market analysis led European automakers to join together in the PROMETHEUS research program. PROMETHEUS is a large-scale collaborative effort to develop the lVHS technologies that will be the driving force behind this rapid growth in vehicle electronics. Automakers in PROMETHEUS see IVHS as a determining factor on the medium-term evolution of vehicle transportation, and they intend to promote and benefit from IVHS technology. By investing in electronics they will hasten this evolution and develop the capabilities to be leaders in this new technology.

The commercial promise of IVHS can be judged by the large sums that these companies are investing in the technology; PROMETHEUS has a budget of $800 million over eight years. This makes PROMETHEUS the largest cooperative technology development program to date in Europe, and IVHS one of the most intensely pursued new technologies of the 1990's. Significantly, this initiative, together with the massive funding allocated to it, have come from private industry in the pursuit of new product markets. More than any marketing study, an industrial investment of $800 million is a strong argument that IVHS represents a potential major market.

In summary, IVHS is a real business opportunity for automakers. By adding new functionality to vehicles, IVHS will add value to automakers' products and lead to profitable new markets. Overseas manufacturers are already acting on positive market forecasts with an $800 million investment in IVHS technology development.

While we can envision a United States IVHS system purchased from overseas, clearly a major market opportunity would be missed if this were to occur.

2. Other Market Opportunities

In addition to the market opportunities outlined above, IVHS technology suggests a whole new set of business opportunities *in* the *information systems* area. Entrepreneurs will see many possibilities for providing information based services using the infrastructure and on-board devices developed as part of an IVHS system.

Further, the development of IVHS enhances the feasibility of private sector entry into the provision of transportation services that have been public sector dominated. The ability to track vehicles and bill for services enables a potential new set of entrants for highway transportation service.

3. Benefits to the Research and Educational Community

The last decade has seen both a diminution of research funds and concern for manpower needs in the transportation field. Special TRB reports have decried the former, and the latter has been highlighted as the critical problem in State DOT's and in the consulting community.

An extensive effort in IVHS can have a profound effect upon these problems. A major research program in an exciting area like IVHS, based on cutting edge technology, would send a signal to the young people of the United States that transportation is a field of the future. It would have the effect of raising the level of consciousness about transportation as a "high-tech" field in our undergraduate programs, leading to more interest in graduate programs in transportation. Research funds would be helpful in providing assistantships for the talented people we would attract. These people would then go on to make contributions to the transportation field throughout their professional lifetimes.

Thus, in addition to the transportation benefits of IVHS implementation, we foresee long-term benefits for the transportation profession and the education and research communities as well.

4. Spin-off Technologies

As with many major research programs, it is expected that there will be positive unplanned side effects. The U.S. Space Program led to the accelerated development of many consumer products, and there is reason to expect that an extensive research effort in IVHS will lead to the development of concepts, ideas, and products that cannot be foreseen at this time.

CONCLUSION

IVHS has the potential to change society in important and fundamental ways

For example:

- In the current environment of international competition and the need for productivity in U.S. industry, IVHS has the potential for having a major positive impact. changes in the way transportation is provided and the very structure of logistic systems can evolve from IVHS innovations. As business becomes global in scope, these changes will be of increasing importance.
- The structure of urban, suburban, and exurban land use brought on by IVHS could be profound. Changes in housing and land development patterns, in access to jobs, in lifestyle, and leisure time available can have important impact upon the fabric of our society.
- Accessibility to safer, less congested transportation services for a broad spectrum of our population will have a profound effect on the quality of life.

We have outlined a broad and comprehensive set of potential benefits that will accrue upon IVHS deployment. We recognize that a large fraction of IVHS benefits will fall in several major categories as follows:

- Safety
- Congestion, Energy, and Air Quality
- Mobility and Infrastructure

These benefits, which we deem of particular quantitative and political importance will be explained in detail in Chapter 3. Through this analysis, we can conclude that *substantial benefits are available through a deployment of IVHS*

SAFETY BENEFITS OF IVHS

INTRODUCTION

Since Intelligent Vehicle-Highway Systems bring new levels of information and control to the operation of motor vehicles, the concept promises major improvements in traffic safety. The basic premise is that the driver will obtain help from technological assists so as to reduce the probability of colliding with other vehicles or running off of the road.

In the development of a "safety technology" for highway transportation, the deployment of IVHS will represent a watershed. The issue is one of focus. The world-wide effort to improve traffic safety since the sixties has been based on the assumption that accidents will happen, but steps can be taken to lessen the consequences. Thus, we have adopted many useful measures that improve the crashworthiness, or so-called "secondary safety," of the vehicle and roadside. Having now "skimmed the cream" from our crashworthiness options, however, it is fair to say that safety improvements in the future must focus on the arena of accident prevention, or "primary safety."

Clearly, it is toward the prevention of accidents that many IVHS functions are directed. A premise of the European PROMETHEUS program, for example, is that 50% of all traffic accidents can be prevented if the driver is given another half-second of advanced warning. Accordingly, PROMETHEUS has been structured with a heavy emphasis on sensing and inter-vehicle communications so that the driver is warned automatically, with enough lead time to enable collision-evasive actions.

In this country, technologies for improving primary safety are an essential part of the envisioned IVHS program. Such systems will be of value to all road users over all geographical regions - no political constituency will fail to benefit from the safety impact of IVHS. The benefits in question are profound, providing much higher levels of protection for life, limb, and property. The long term prospect is that IVHS will take a large bite out of the current toll of approximately 47,000 fatalities, 150,000 permanent impairments, 1,650,OOO recoverable injuries, and $70 Billion in lost wages and direct costs. The FHWA has estimated that the direct economic burden is supplemented by another $20.3 billion, per the "willingness to pay" approach, when one considers the public's valuation of pain and suffering.

Within these totals, the rural community has the most to gain if the threat to life is reduced, since 57 % of all fatalities now occur on rural roads. Accidents incurred by the urban commuter are more numerous but less severe, causing tie-ups which account for half of all traffic congestion and thus burden the nation with reduced productivity.

Noting that these human and economic costs powerfully reduce the quality of American life, the question to be addressed here is, "what portion of these losses is likely to be eliminated by IVHS?" The reduction in accidents due to IVHS technologies has been estimated here through a scheme that is presented in section 2.

ESTIMATE OF SAFETY PAYOFF

An estimate of the likely magnitude of the safety benefits accruing from IVHS technologies is presented here, incorporating the following elements:

- *collision categories* by which we can link accident statistics to specific IVHS functions or technology groups,
- *an* estimated *rare of penetration of I*VHS products into the total vehicle population, according to the three defined phases of implementation,
- an estimate of the potential effectiveness of each IVHS function in terms of the likely reduction in accident rate for each of the corresponding collision types,
- the resultant *savings in the* human and economic costs.

COLLISION CATEGORIES LINKED TO IVHS FUNCTIONS

Accidents can be grouped into collision types, each of which poses certain requirements for effective prevention through technology. For the purposes of this discussion, the selected accident types are those seen as most amenable to prevention by IVHS technology, thus targeting a specific matrix of collision prevention problems for estimation of possible benefits. These accident categories represent 78% of all fatal accidents as reported through the 1987 Fatal Accident Reporting System (FARS), encompassing the following types:

- off-road accidents – involving rollover or collision with fixed objects (36 % of all fatalities)
- angle collision (18 %)
- angle collision (18 %)
- head-on collision (17%)
- rear-end collision (5%)
- sideswipe (2%)

Taking each category in turn, the prospect for reducing the accident rate through technological assists can be examined.

Off-Road Accidetns

Fixed objects are struck only when the vehicle departs from the travelled way. Similarly, most rollover accidents, which themselves account for 9 % of all fatalities, occur off the edge of the road. Thus, in order for a vehicle to strike a fixed object or roll over, it must take an excursion beyond lane boundaries and off of the shoulder. IVHS technologies offer to either (1) sense the location of lane boundaries, using an electronic imaging system plus, perhaps, cooperative lane-edge markings or (2) determine through a precision locating system the absolute position of the vehicle vis-a-vis the continuous lane boundaries. Then, upon deducing that an off-road excursion is imminent, a driver warning or automatic control intervention could be engaged. In Germany, the U.S., and Japan, automatic systems capable of lane-edge detection and, in some cases, path correction are already under development. In some cases, sensing systems for detecting lane edges are also able to detect vehicles and other obstacles in the near field of view. While much refinement is needed before these concepts will be implemented, progress already achieved shows that this largest of all categories, off-road accidents, is a prime candidate for reduction through IVHS technology.

Angle Collisions

The majority of collisions between vehicles approaching at oblique angles and from the side occur at intersections. In most of these cases, a patently erroneous decision is made by at least one party to proceed, in violation of another's right-of-way. In the common scenarios, people pull out from stop signs into the paths of others, they turn left across opposing traffic, and they violate signalized traffic controls. IVHS provides a special opportunity to assist the driver, in such circumstances, so that improper judgements and failure to perceive other vehicles is minimized. Especially since at least one of the parties should be stationary at an intersection, there is considerable time available for a warning to be provided and heeded. Accordingly, technology which automatically senses, or continually tracks the coordinates of, oncoming vehicles and otherwise knows the right-of-way status can directly advise the driver that it is unsafe to proceed. The warning can be visual or audible or both and a control intervention can be as simple as keeping a stopped vehicle stopped.

Head-on Collisions

On non-divided highways, head-on collisions are relatively rare but highly lethal per event. Thus, the head-on accident type shows up prominently in fatal accident data. Clearly, when one vehicle crosses abruptly over the highway centerline, the rapid rate of closure with oncoming traffic may leave little time for collision prevention. Nevertheless, a motion-detection system may be able to anticipate that cross-over of the other vehicle is pending, before the trespasser arrives, and warn the approaching innocent driver that evasion is needed. Conversely, a lane-edge detection and path-prediction technology could provide warning, if not control assist, to the trespassing vehicle so that the initial cross-over is avoided or its extent of penetration minimized. Systems of this type are seen as lying on the more challenging end of the spectrum of IVHS safety technologies.

Rear-end Collisions

Although rear-end collisions account for only 5 % of fatalities, they constitute on the order of 20% of all accidents, many of which are of low severity. Rear-end accidents are also the dominant type which delays traffic on congested expressways. Since the relational position between vehicles is simple in the rear-end case, this accident type is looked upon as readily treatable through an advanced sensing and control technology. Further, it is apparent that much of the hardware needed to deal with the rear-end accident problem also offers utility for dynamic headway-keeping. Thus, systems providing good protection against rear-end collision are expected to follow on the heels of headway-keeping systems which may be motivated by the desire for driver comfort and increased highway throughput.

Anti-lock brakes, an important enabler for systems to prevent rear-end collision, are rapidly penetrating the vehicle market and are expected to reach 70% of new vehicle sales, and 30% of the extant vehicle population, by the year 2000. The anti-lock development is significant because automatic braking for collision avoidance requires anti-lock, as well, to assure controllability. With the enablement provided by anti-lock technology, prevention of rear-end acctdents is seen as another prime candidate for relatively early benefits through IVHS technology.

Side-swipe Collisions

The side-swipe category includes many cases that could just as well have resulted in a head-on or rear-end type accident, had the vehicles moved further into an overlapping placement. Thus, comments made above relative to head-on and rear-end accident modes are pertinent here, as well. An additional consideration is that, for same-way traffic, it is not uncommon for one driver to change lanes into the path of an overtaking vehicle. This so-called "blind spot" problem is currently the subject of developments using ultrasonics, infrared, and radar-type sensing technologies. Since the relative approach speeds are typically low, the same-way sideswipe is thought to be reasonably treatable through IVHS technologies while, as in the head-on case, a side-swipe in opposing traffic is not.

Aggravating Environments

Common to all accident categories are certain aggravating aspects of the highway environment which influence accident risk and pose opportunities for treatment through IVHS technologies. Approximately 55% of all fatal accidents occur at night, for example, even though nighttime mileage accounts for only 25% of all travel. Two large elements of the nighttime safety problem involve alcohol impairment during leisure hours and poor visual acuity in the dark. Advanced technologies have been demonstrated for dealing with both of these factors. Approaches toward detecting and warning of unsafe driver impairments have employed, for example, artificial intelligence and an "interpretation" of the driver's steering behavior relative to an observed norm for the individual.

Major improvements in nighttime acuity have been achieved through infrared enhancement of the forward field of view out the windshield, contrasting the infrared "brightness" of people, animals, and vehicles relative to the cool, neutral background. The direct detection and warning systems described earlier can also aid in highlighting obstacles and lane edges at night and in fog or snow conditions. The visual acuity aids will be especially useful for the elderly, considering that the human ability to perceive nighttime images falls off in a wholesale manner with aging. Moreover, impairment detection and vision-enhancement technologies are not limited to the avoidance of specific accident types such as runoff-road, head-on, etc., but rather offer improved safety over all accident modes.

Benefits Due to Overall Improvement in Traffic Systems

While the collision-avoidance concepts discussed above deal with the mechanics and human aspects of accident production, there are also likely to be systems-level safety advantages accruing from other IVHS functions which lessen congestion, regularize flow, and reduce the frustration of drivers and their likelihood of getting lost. Such functions do not deal with the few seconds during which a collision may be imminent, but rather serve to condition traffic flow and the driving population at large so that, hour after hour, collision-precipitating conditions are reduced.

Research has shown, for example, that collision risk rises by 150% when vehicles in the same traffic stream have speeds differing by more than 10 mph. One technology that has dealt with a major aspect of this issue is ramp metering whereby the insertion of cars at on-ramps is regularized through automatic signals on the ramp. Ramp metering is a great success story, having reduced freeway accidents by 20 to 40%, where implemented, while substantially increasing throughput at the same time. Moreover, future use of headway-control technologies which regularize speeds and spacing within the traffic stream can be expected to normalize the very environment which tends to generate accidents on multi-lane roadways.

Some of the earliest IVHS deployments may serve to reduce accidents through a more subtle conditioning of the driving environment. For example, driver information, systems which provide immediate notice of accident blockages ahead may soften the "shock wave" which otherwise propagates back through traffic when brake lights constitute the only means of warning of a sudden disruption. If traffic is diverted away from an accident site with the aid of a motorist advisory system, a shorter queue will form, fewer vehicles will be caused to brake rapidly upon approaching the site, and the disturbance will clear more rapidly following clean-up.

In addition, the provision of automatic route guidance will result in fewer vehicle miles being driven in the confused and somewhat risky state that otherwise attends being lost. Recent research has concluded that such wasted miles, which may be largely eliminated through navigation aids, are on the order of 6 % of all VMT. Also, IVHS concepts which increase ride-sharing by providing special features only on HOV lanes of the highway, or which make transit services more accessible and attractive, stand to further reduce the net traffic demands on the road system. Traffic advisories displayed on large screens in shopping malls or other public buildings, or eventually even piped into home or office computer terminals will enable rational trip planning and the avoidance of inefficient travel.

Beyond the packaged technologies for accident avoidance and information-based services, the long-term prospect of automated highways offers a robust, integrated, means for controlling the steady separation of vehicles as well as the inter-vehicular movements within the stream. This is hands-off driving. As such, its safety benefit depends almost entirely upon the reliability of the hardware, itself. If a net safety improvement is to be made, the reliability of automated highways must exceed the already-high conventional level of approximately one million vehicle miles of safe travel for every injury accident. Nevertheless, as the reliability of automated highways approaches 100%, the safety benefits will approach the full magnitude of the current accident costs on conventional roads.

Estimates have been made of the benefit of collision-prevention technologies, recognizing that a certain technology might contribute to the treatment of more than one accident type. These estimates are employed in the next section as an example illustration of the net safety benefits of IVHS.

AN EXAMPLE COMPUTATION OF SAFETY BENEFITS, GIVEN A SPECIFIC EXPECTATION ON IVHS DEPLOYMENT

As each of the IVHS safety technologies comes into popular use, it will effect a reduction in certain types of accidents. This section lays out, by way of example, a numerical estimate of the accident reductions that would accrue if certain technologies came into usage according to a forecasted schedule of IVHS deployment.

Following the adopted schedule for a 3-phase implementation of IVHS, the rate of penetration of such technologies into the vehicle population has been projected over the next twenty years. The penetration projections are derived from the results of a study entitled, "The Future of Intelligent Vehicle-Highway Systems...a Delphi Forecast of Markets and Socio-technological Determinants." This survey, conducted by the University of Michigan during the summer of 1988, compiled the views of 32 panelists from U.S. government agencies and corporations on the likely deployment of IVHS, according to selected groupings of information and control technologies.

In the tabulation to follow, the previously discussed accident modes will be listed using the abbreviations shown below:

Abbrev .	Accident Type	% of fatal acct.
OR	Off-Road	36%
AN	Angle	18%
HO	Head-on	17%
RE	Rear-end	5%
SW	Sideswipe	2%

The effectiveness of a technology for preventing each of the given accident types has also been estimated. The effectiveness level expresses the percentage of current annual accidents of each type that would be eliminated if the technology achieved a 100% penetration in the vehicle population. It is assumed for this discussion that a linear reduction in accidents accrues as a function of the technology's penetration.

A "bottom line" net benefit for each technology is then computed by multiplying the percent penetration of the hardware into the vehicle population times the percent effectiveness in reducing a given type accident times the percentage of all fatal accidents that are of that type. For example, if a blind-spot warning system reaches a 10% penetration of the vehicle population and is thought to be 20% effective in preventing sideswipe accidents, which themselves constitute 2 % of all fatal accidents, then we compute a reduction in the annual total of all fatalities as: (0.10 X 0.20 X 0.02 = 0.0004, or expressed as a percentage = 0.04 % .) Where more than one technology has payoff for a given accident type, the listed percentages are considered additive.

Finally, the net reduction in the annual incidence of fatalities is listed in the tables, to follow, as a benefit attributable to a portfolio of IVHS safety technologies. The tables are presented here as an example of the benefit calculation, considering the optimistic implementation schedule (per the University of Michigan's forecasting methodology) which assumes that the federal government and American industry become strongly involved in a national IVHS program. Examination of all survey data from the University of Michigan survey reveals that rather wide variance exists in the projected penetrations and that the magnitude of the variance, itself, varies by a factor of two to three from one type of IVHS technology to the next. Thus, one should recognize that the illustrated estimates are based upon the median forecasts, only, and that they are offered here as a baseline example from which extensive sensitivity analyses could be performed.

The estimates of % effectiveness are simply judgements based upon knowledge of the widely-varying situations involved in real accidents. In estimations of the % effectiveness, the reader will note that the first IVHS technologies to be deployed are assumed to work well only in relatively simple collision modes while failing to prevent accidents in more

Operational Benefits

Phase 1 — to be achieved by 1995

Safety Technology Feature	Penetration	% Effectiveness per Accident type					% Reduction in Fatalities
		OR	AN	HO	RE	SW	
warning to apply brakes to avoid collision	1%	-	30	-	20	-	.065
Warning of vehicle in blind spot	1%	-	-	-	-	20	.005
driver impairment warning	1%	10	5	10	5	5	.065
nighttime vision enhancement	1%	5	5	-	5	-	.03
First Phase Total							.17

Phase 2 — to be achieved by 2000

Safety Technology Feature	Penetration	% Effectiveness per Accident type					% Reduction in Fatalities
		OR	AN	HO	RE	SW	
warning to apply brakes to avoid collision	10%	-	30	-	20	-	0.065
Warning of vehicle in blind spot	10%	-	-	-	-	20	0.05
driver impairment warning	5%	10	5	10	5	5	0.065
nighttime vision enhancement	5%	5	5	-	5	-	0.06
headway control, auto braking	1%	-	20	-	60	-	0.06
lane-edge tracking & warning	1%	40	-	10	-	-	0.15
Second Phase Total							1.7%

Operational Benefits

Phase 3 **– to be achieved by 2010**

Safety Technology Feature	Penetration	% Effectiveness per Accident type					% Reduction in Fatalities
		OR	AN	HO	RE	SW	
warning to apply brakes to avoid collision	50%	-	30	-	20	-	3.24
Warning of vehicle in blind spot	50%	-	-	-	-	20	0.25
driver impairment warning	50%	10	5	10	5	5	3.24
nighttime vision enhancement	50%	5	5	-	5	-	1.5
headway control, auto braking	25%	-	20	-	60	-	1.5
lane-edge tracking & warning	25%	40	-	10	-	5	3.7
robust collision prevention systems	10%	70	70	70	70	70	5.5%
automated highway	1%	90	90	90	90	90	0.01
Third Phase Total							18.9%

complex situations. Later, more robust systems are expected to appear which reflect the accumulated learning from earlier systems and which deliver much higher levels of collision protection. Insofar as the computed reduction in annual fatalities results from a multiplication of the penetration estimate times the % effectiveness estimate, the result is sensitive to a compounding of the variances in both estimates.

CONCLUSIONS

The results tabulated above represent rough estimates of potential reductions in the fatal accident rates, not including the benefit due to technologies that change the traffic environment, itself. The results are based upon only that 78% of all fatal accidents where the collision types appear most amenable to warning and control countermeasures.

There is also a large indirect benefit in reduced traffic delay due to prevented accidents in congested areas. If, as research suggests, rear-end accidents account for 70% of all accidents on congested freeways and if 50% of all such delay is due to accidents, the elimination of 3 1% of rear-end accidents by the year 2010 (obtained by multiplying the elements of the table, above) would, by itself, reduce total delay on freeways by 11 % .

The trend in results computed over the three phases reveal the classic progression that attends any new product or technique that must penetrate an existing population in order to render aggregate benefit. The exponential nature of the benefit accrual over time will, of course, eventually saturate as the penetration becomes complete. The rate of penetration is nsing so fast by the year 2010, for example, that in only another 10 years the reduction in fatalities would top 50%.

It is straightforward to convert the above percentage reductions into total savings by simple proportioning according to the current annual totals of fatalities, injuries, and direct economic costs (assuming the FHWA-adopted “willingness to pay” approach for converting risk of bodily harm to equivalent dollars. This approach assigns a cost of $1.5 M to a fatality and $11,000 as an average cost of an injury.) Further, in arriving at absolute savings, the numbers should reflect the anticipated rise in total accident volumes which would prevail if there were no IVHS improvements for the years, 1995, 2000, and 2010.

To reflect the rise in total accident volume, we have employed NHTSA’s projections of annual fatalities, which the agency has derived as a rather conservative linear projection from historical data. With 1988 as the base year, having 47,000 fatalities, the subsequent milestone dates have fatality projections (without IVHS) as follows:

Year	Total Fatalities w/o IVHS
1995	51,500
2000	54,500
2010	61,000

A bottom line of fatality reductions through IVHS technologies is then computed simply by multiplying the above fatality projections times the percent savings accruing at each milestone year cited above. Projected savings in injuries and total economic burden, as well, were obtained by simply pro-rating them, given the numbers of fatals, according to the same proportions as exist in the current accident statistics. Further, the economic costs are expressed in constant 1988 dollars. We thus obtain the following numerical values:

These benefits represent a yield that is estimated to accrue simply through accident prevention technologies if IVHS is developed vigorously, with the aid of a national program in the U.S. having strong federal funding and involvement of the automotive and electronics industries. By the year 2020, the annual savings are estimated to exceed 33,500 lives, 1.3 million injuries, and $64.5 billion in associated costs, respectively. These numbers do not include the additional benefits of overall reductions in accident risk due to smoother traffic flow, reduced miles travelled while the driver has lost the way, and reduced auto usage due to easier ridesharing, trip planning, and transit use, etc., as discussed earlier.

Also, it is generally recognized that the commercial application of IVHS will advance more rapidly than in other sectors. Thus, the more rapid decline in truck collisions (which are more lethal) would tend to bring about net accident savings that exceed those estimated on the basis of an equal rate of IVHS deployment across all vehicle types. Further, as mentioned earlier, the rural community would tend to derive the greater benefit in reduction of severe crashes, since crash severity is also strongly determined by vehicle speeds which are, of course, higher on the rural road network.

Baseline Estimate of IVHS Safety Benefits

Phase	Year	Lives Saved/Yr.	Injuries Saved/Yr.	$ Saved/Yr.
1	1995	88	3,060	$167,000,000
2	2000	927	35,500	$ 1,800,000,000
3	2010	11,529	442,000	$22,200,000,000

A Lower-Range Estimate

One example of the sensitivity of the benefit estimates to variation in the component figures is provided here, in the form of a lower-range estimate. The sensitivity illustration assumes that the penetration of IVHS technology into the vehicle population is *delayed* by 5 years relative to the Delphi estimates and that, when deployed, each technology is only *half as effective* in reducing accident risk as was estimated in the 3-phase tables presented above. The delay increment shows the price to be paid in deferred accident reduction if the deployment of IVHS is postponed, or conversely, shows the incentive for accelerating deployment. The simultaneous reduction in estimated effectiveness shows the incentive for development of highly effective technologies. By this combined scenario, the annual benefits due to collision prevention technologies would reduce in the three projected phases to the following:

Operational Benefits

Lower Range Estimate

(5-Year Delay in Deployment Schedule and 50% Lower)

Safety Effectiveness of all IVHS Technologies

Phase	Year	Lives Saved/Yr.	Injuries Saved/Y r.	$ SavedlYr.
1	1995	1	50	$2,,300,000
2	2000	46	1,780	$890,000,000
3	2010	2,200	84,000	$4,200,000,000

By the year 2020, benefits according to the lower range illustration would come to an annual total of 11,000 lives, 416,000 injuries, and $21 billion in associated costs. Obviously, the much lower savings of life, limb, and money relative to the baseline case, especially in Phases 1 & 2, are driven most strongly by the 5-year delay in deployment and only to a far lesser extent by the assumed 50% drop in effectiveness. Thus, while these figures roughly portray the sensitivity of the projected savings to the estimation accuracies, they also quantify the benefits to be lost if the U.S. delays in making an IVHS-enabling policy.

THE BENEFITS OF IVHS RELATIVE TO CONGESTION, FUEL CONSUMPTION. AND AIR QUALITY

REDUCED CONGESTION BENEFITS OF IVHS

The benefit most often visualized of IVHS is the role it will play in reducing congestion. Table 3 provides a list of measures related to the benefits of reducing congestion. For example, the primary function of Advanced Traffic Management Systems (ATMS) operating together with Advanced Traveler Information Systems (ATIS) is to provide for a smoother flow of traffic which will allow vehicles to reach their destinations with fewer stops and reduce the delays caused by current demand exceeding capacity. These systems are able to better utilize the capacity of the current system by shifting traffic from routes of inadequate capacity to routes with excess capacity. They can also eliminate excess driving brought about by inadequate knowledge of the system. One might think that most drivers know exactly the route they need to take, and thus no gain is to be made from ATIS. Certainly, the daily commuter knows well the route from his home to work, however, he does not know of impending congestion on the route, accident locations, road maintenance, and the like. Studies by Lindley and others have shown that over one-half of congestion is due to non-recurrent factors. Even the daily commuter could gain the knowledge to avoid that percentage of congestion on his daily drive to work.

Advanced Vehicle Control Systems (AVCS) are more concerned with improving safety than congestion, however, as pointed out above, a significant amount of current congestion is caused by non-daily events, including accidents. Thus a collision avoidance system that eliminates a rear end collision will also eliminate the congestion caused by the lane blockage as well as the traffic that slows in order to “rubber neck.” In fact improved safety and reduced congestion are invariably interrelated. Reducing congestion reduces stops and other speed changes which will reduce accidents, which in turn will further reduce congestion. The more advanced of the Vehicle Control Systems, such as the automated roadway, also offer the promise of increasing the capacity of the current roadway system.

The California PATH program anticipates increased freeway capacities of more than double resulting from automatic headway and lateral guidance. This by no means represents a theoretical upper limit of the possible capacity increase. If automated lateral control allows us to operate with 6 feet wide lanes instead of 12 feet wide lanes, and automated longitudinal (headway) control allows half second headways instead of two second headways an eight times increase in capacity is obtained.

Commercial and Fleet Management systems will benefit from congestion relief in two ways. First, their drivers will receive the same benefits that will accrue to drivers in general. Second, total trip times will be lower and of equal importance, trip times will be predictable. The customers will benefit by reduced costs, and dependable pick-up and delivery times. On-time supply is also becoming a world of on-time shipping. Not only is it less expensive for a business not to have an inventory of raw materials but it is equally or more important not to have an inventory of finished product. ATIS benefits commercial vehicle management as well. Not only does the commercial vehicle driver need to know his location and the location of his next stop, but management needs to know the location of the vehicles in order to respond to changing conditions. Thus the drivers question of, "Where am I?" has added to it, "Where are you?" Just as the commuters' best route and departure time to work may be changed by congestion and accidents, the commercial vehicle's optimum schedule and route can be changed by the same factors. In either case, volumes at accident sites are educed which reduces both accidents and congestion.

TABLE 3 Congestion Measures

A. Impact of reducing congestion for urban **and** suburban commuters and the general population.
   a. Reduced stops and delay **— reduced** travel time
   b. Reduced fuel consumption
   c. Reduced vehicle operating costs
   d. Reduced driver and passenger stress
   e. Reduced arrival time unpredictability
   f Reduced emissions
   g. Reduced emergency response time
   h. Reduced insurance costs
   i. Reduced reluctance of older drivers to venture onto system

B. Impact of reducing congestion for retailers and manufacturers
   a. Reduced shipping costs
   b. Reduced warehouse space
   c. Reduced production delay
   d. Reduced worker stress
   e. Reduced transportation equipment costs
   f. Reduced transportation employee costs
   g. Reduced customer impedance

C. Impact of reducing congestion for movers of goods and people and emergency vehicles
   a. Reduced operational costs
   b. Reduced vehicle fleet
   c. Reduced number of transportation workers
   d. Reduced rider apprehension, resistance to use transit
   e. Reduced response time

MEASURING AND QUANTIFYING IVHS CONGESTION RELIEF BENEFITS

Figure 6 shows a useful economic analysis framework for measuring IVHS congestion relief benefits. It consists of conventional supply and demand curves for travel in a typical area of the country. The demand curve, Do, and the supply curve, S,, are intended to represent current conditions without any IVHS system. Do shows the volume of travel which would occur at any given travel time or level of congestion. Do shows that as congestion is reduced, more travel will be consumed by the population of the area.

The supply curve, So shows the volume of travel which the existing transportation system can supply at any given level of congestion of travel time. As the volume of travel increases beyond a certain point, congestion sets in and travel times increase. Any transportation system has its zero-delay volume limits, beyond which travel time increases monotonically, normally at an increasing rate as volumes increase further.

A very important goal of IVHS and all other transportation improvements is to provide transportation at a lower cost. We represent that cost by travel time in Figure 6. In reality, travel costs include all the mobility related costs that individuals value when making their travel decisions (and that society values more than the sum of the individual travel utility values since so many of the costs of travel (e.g., air pollution) are not "internalized" by the traveler).

The point at which the demand and supply curves intersect represents the "equilibrium" *volume* of travel consumed, and the "price" or *travel time* at which the travel is supplied. This intersection of Do and So in Figure 6 is at to travel time and Vo volume of travel. This represents in the aggregate the total travel time and volume on the existing transportation system (without IVHS).

Supply curves for three types of IVHS systems are shown in Figure 6. Also shown are supply curves for two levels of investment and technological advancement for AVCS (Advanced Vehicle Control Systems). The supply curve nearest So represents ATMS (Advanced Traffic Management Systems). These systems increase the capacity of the roadway system through better signalization and ramp metering which directly controls the use of roadway space at any given moment. ATIS (Advanced Traveler Information Systems) can increase the capacity of the system still further by better routing of vehicles through the network. This routing can be driver optimized by furnishing real time system status information, or it can be system optimized by furnishing centrally computed route guidance information. ATIS also can provide information on more than just route choice. In fact, its most significant benefits ultimately are likely to result from the pre-trip information it provides on the entire trip and possible alternative travel choices (time of day, mode, destination, residence location, etc.). This point is discussed later.

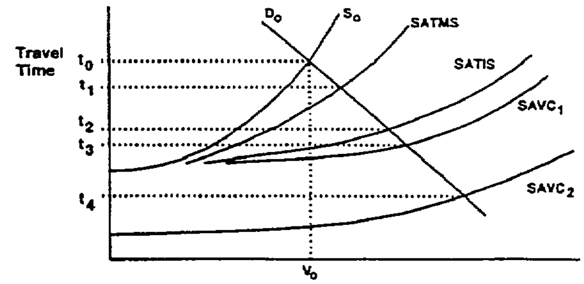
For the two AVCS system supply curves shown on Figure 6, $AVCS_1$, represents headway monitoring and control schemes that are vehicle-based as discussed in the AVCS report. These systems provide somewhat more capacity on a given lane. $AVCS_3$ as described also in the AVCS report, provides higher speed and automated control which would reduce travel times from those experienced today, even at low volumes.

The congestion reducing benefits from each of the IVHS systems can be represented by the lowered travel times at the intersections of the (constant) demand curve and each of the supply curves in Figure 6. This means t_o minus t_1, represents ATMS benefits; t_o minus t_2 represents ATIS acting together with ATMS; t_o minus t_3 represents ATMS, ATIS, and AVCS, acting together, and so on. (Figure 6 is not drawn to scale, so the reader should not scale off these travel time changes on the figure.) The actual total congestion benefit from each system or combination of systems is the change in travel time multiplied by the total volume under the demand curve.

For example, the benefit from an ATMS installation would be V_o (t_o minus t_1) plus (V_1 minus V_o) * (t_o minus t_1)/2. The latter term is the benefit to new travelers and is the area under the triangle between t_o minus t_1, on the Y axis, and V_o minus V_1 on the X axis.

Figure 6 Analysis Framework for Measuring IVHS Benefits

It is important to understand that new travel *will* result from IVHS improvements. Since IVHS improvements lower the cost at which a given volume



of travel is supplied, and since demand curves monotonically slope downwards, the new larger equilibrium volume of travel will take place at a lower cost. This provides travel time/cost benefits for both existing travelers and for new travelers "at the margin" who are induced to travel (or travel farther) by the lower costs at which travel is supplied by IVHS.

It is also possible that in the long run, travel times on a transportation system with IVHS improvements will actually be the same as they were without the IVHS improvements. Aside simply from growths in population or income, this can result from longer trip distances due to changes in the land use distribution (settlement pattern) caused by the IVHS improvements. People may choose to keep their total travel *time* constant and increase the *lengths* of their trips to work, shopping, recreation, etc.

Nevertheless, it is important to understand that there are significant benefits from IVHS related to congestion relief, *regardless* of how much induced or additional travel results from the IVHS improvement. We can measure these benefits using the analysis framework in Figure 6. Indeed, the importance of the analysis framework in Figure 6 is that the travel time/cost benefits it measures are valid regardless of how much additional travel is induced by IVHS. This framework is *the only* way to measure the congestion reducing benefits from transportation system improvements. This results from the widely accepted transportation planning assumption that the benefits from trip length increases resulting from higher valued resident locations and other activities at the tip ends, are equal ("at the margin"), to the added travel time/cost of these longer trips.

Therefore, we can avoid making value judgements on the worth of different land use distributions, and allow individual choice behavior (represented by the demand curve, Do) to determine the numbers of trips made with each length and mode. We then value those trips at the values used by the individuals in making their travel decisions. This means that the travel time differences in Figure 6 (e.g., t2 minus t1 can be valued at the travel time versus out of pocket travel cost "utility" values of travelers. These utility function values of time are fairly well researched in travel demand forecasting. For example, for daily trips to work, travel time is valued on average at approximately 40% of the wage rate.

The big remaining question, therefore, is what are the sizes of the to minus t1's we can expect from

Table 4 Travel Time of Adults in the United States, 1976

(minutes per day)

Activity	Weekday		Saturday		Sunday	
	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.
Work	**24.0**	**30.4**	**7.7**	**22.0**	**4.6**	**17.6**
Childcare	**4.2**	**11.0**	**1.7**	**8.7**	**2.1**	**10.6**
Shopping	**17.9**	**23.6**	**21.6**	**36.4**	**8.5**	**21.6**
Personal	**14.9**	**27.8**	**19.3**	**50.4**	**18.6**	**46.4**
Education	**2.3**	**10.4**	**0.4**	**4.3**	**0.2**	**3.1**
Organizations	**3.4**	**9.8**	**2.7**	**12.2**	**12.1**	**37.6**
Events, Social	**8.9**	**16.2**	**19.6**	**43.4**	**18.0**	**34.5**
Leisure						
Active	3.3	14.8	8.5	48.7	8.2	38.1
Passive	5.4	5.4	1.3	6.8	1.7	9.9
Total	80.2		82.8		74.2	

IVHS. First, of course, this depends on the total cost of the delay we experience in congested traffic today in the U.S. There is no lack of estimates. A 1986 study estimated the cost of passenger vehicle delays at 47 billion dollars per year in the U.S.

We can arrive at a 50 billion dollar per year estimate for passenger vehicle delay very easily by multiplying out the following reasonable assumptions.

The average person spends 1/2 hour per day in congested traffic, Delays equal (only) 25% of that travel time, Multiply this delay by the U.S. population, times 40% of the current average wage rate.

This calculation of delay per person is 25% of 30 minutes or 7.5 minutes per person per day. This is less than ten percent of the daily average travel time of adults in the U.S. in 1976 shown in Table 4. An estimate of current total delay per person equal to ten percent of 1976 average travel time is likely to be a minimum value.

In addition truck delays have been estimated to have the same 50 billion dollar value per year. The two together total $100 billion per year. Lindley in a recent ITE Journal article also predicts increases in urban freeway travel of about 50 % by 2005, and delay increases of 500 % or more if we don't improve our current highway system. This means we're on the steep part of the supply curve, So in Figure 6. The values of automobile and truck delays in the future may therefore be a multiple of the current 100 billion dollars per year. This doesn't include fuel and other operating costs, accident costs, and the lost productivity and economic growth due to this congestion.

The Texas Transportation Institute at Texas A&M University has published a study of congestion in 39 cities in the U.S., which documents over $41 billion in total congestion costs in these cities alone based on 1987 data. In this study, total congestion costs include delays on both freeways and principal arterial streets, fuel costs consumed while traffic is delayed, and the differences between insurance costs in the cities and statewide insurance costs exclusive of the cities. A striking aspect of the study is that congestion is not uniformly distributed among urban areas. Los Angeles has the greatest cost of congestion at almost $8 billion, and Corpus Christi, Texas the least with $20 million per year lost. Cities with over one billion dollars annually in total congestion costs includes: Los Angeles, New York City, Chicago, San Francisco-Oakland, Washington, D.C. Philadelphia, Detroit, Houston, Miami, Atlanta, Boston, and Dallas. These twelve cities, have seventy-seven percent of the $41 billion annual congestion costs in all 39 cities.

How MUCH CAN BE SAVED BY REDUCING CONGESTION?

How much can IVHS reduce congestion? Referring to Figure 6, how big are the to minus t1, S multiplied by the travel volume? The first estimates for the Los Angeles Smart Corridor Project (e.g., ATMS) are that delays will he reduced by 20 % , travel time by 11-15 %, and number of stops at intersections by 35 %. It's important to recognize that the Smart Corridor uses Changeable Message Signs (CMS) and Highway Advisory Radio (HAR) external to the vehicle – not ATIS m-vehicle information on system status and individualize information *on* route guidance for the vehicle.

Initial simulation results presented at the 1990 TRB Annual Meeting in January by Hani Mahmassani of the University of Texas at Austin indicated a 10% reduction in delay by providing users (only) with system status information. This result depended strongly on volume conditions and is very preliminary. However, we can expect ATIS routes guidance information to have more benefit in making better use of network capacity since it allows routing vehicles in the network according to system optimum, rather than individual user optimums.

Even more revealing were the results reported by the same group, that with peak *spreading* – users changing their time of travel – delays were reduced by up to 50%. Again, this result depended on initial volume conditions and is very preliminary. However, it is an important illustration that there are sizeable benefits from ATIS systems. It suggests that the big benefits from IVHS in general, and ATIS in particular, will come from changing people's behavior not just with respect to path choice, but for all the other travel choices as well. These choices include:

- time of day, destination, mode,
- foregoing certain travel, and
- working at home, etc.

Quantifying how much IVHS technologies can reduce congestion in urban areas depends on several factors not the least of which is the extent of IVHS penetration into the cities. Since realized benefits depend on penetration, estimates must also be made of the rate at which IVHS will be deployed. For convenience, four time periods will be used beginning with the current time through 1995, from 1995 through 2000, and from 2000 through 2010. The fourth period begins at 2010 and ends with the complete deployment of IVHS.

Now Through 1995

During the period prior to 1995 it is likely that IVHS technologies will not be fully depIoyed in any city in the U.S. There will, however, be several demonstrations of some parts of IVHS. Advanced Traffic Management Systems and some forms of Advanced

Driver Information Systems will be demonstrated in several cities in the U.S. None of these will be complete in the sense that they will cover an entire city, but several corridors will have traffic management. These early deployments will not achieve all of the benefits of the technologies because they will not be available throughout any city. The driver information systems will not he integrated into the traffic management systems so that all information is fully available to a large number of drivers. Examples of these early demonstrations are the Smart Corridor and Pathfinder projects in Los Angeles and the information demonstration in Florida. Pathfinder will have only twenty-eight equipped vehicles and communication will be by a polling cellular telephone instead of real time communication. In Florida there will only be 100 vehicles with navigation systems.

Using the costs of the Smart Corridor project in Los Angeles as an example, the costs of traffic management may be estimated. The project is estimated to cost $40 million for twelve miles of ten lane freeway and the five major arterials that approximately parallel the freeway. This is about $335,000 per freeway lane mile including the arterial streets within the corridor. The total costs of installing such a system throughout Los Angeles, which has 4,750 miles of freeway lane miles would be $1.55 billion. The total cost of congestion in Los Angeles is $7.94 billion per year. It would be unreasonable for a traffic management system to eliminate all congestion. Conservatively, we could estimate that congestion would be reduced by fifteen percent. The savings per year would be $1.19 billion. A reasonable assumption would be a 20 year life time and 10 percent maintenance costs each year. The benefit to cost ratio would be 4.1. Performing the same calculations for a few selected cities the benefit to cost ratios are 2.75 for Chicago, 2.61 for Houston, and 1.53 for Dallas. Dallas has congestion costs just over $1 billion per year.

As has been pointed out before traffic management cannot be fully installed in any city prior to the year 1995. If we assume that there are $1 billion of traffic management demonstrations installed in cities averaging a benefit to cost ratio of 3.1, then the nation would be saving $580,600,000 of congestion cost per year. During this same time period there would be demonstrations of early stages of vehicle navigation systems. Since these would not be integrated with the traffic management demonstrations we will not calculate a congestion reduction to these early systems.

1995 through 2000

During this period there may be a few cities that will have traffic management systems fully deployed. In the previous section we found that the benefit to cost ratio of these systems, assuming a 15 percent reduction in congestion, would average about 3.1 for cities with congestion costs exceeding $1 billion per year. The 12 cities with congestion costs this high have a total congestion cost per year of $31.8 billion per year. If half of the cities could have systems installed, the total amount of congestion saved per year would be over $2.3 billion. However, during this period the interrelationships between Advanced Traffic Management and Advanced Driver Information will be realized. Conservatively, we could estimate that the two combined will reduce congestion by over 25 percent. In that case, the congestion saved during this time period would be about $4 billion per year.

The remaining areas of IVHS that we have not discussed are Advanced Vehicle Control Systems and Commercial Vehicle Operations. There is no question but that commercial operators will be the first to implement many of the IVHS technologies. Some companies are paying large amounts for vehicle location systems today. The new traffic management systems may reduce the costs of vehicle location systems making them even more attractive to commercial operators. It is difficult at this time to estimate the added value of ATMS and ADIS implementations to commercial operators. We can assume that the major implementations of Advanced Vehicle Control Systems prior to 2000 will be in the safety area and not in congenstion reduction.

2000 through 2010

The combined impact of ATMS and ADIS during this time period may be so that they can combine to reduce congestion by 40 percent or more. King and Mast have estimated that the total annual cost of navigational waste in private vehicles exceeds $45 billion per year. In fact, if accident costs are excluded from their calculations, navigational waste is equal to $41.3 billion per year. Almost equal to the congestion costs of the 39 cities in the TTI study. Accident reduction benefits are treated in another section of this report.

All cities with $1 billion of congestion cost per year will have systems installed. Los Angeles will be saving almost $4 billion per year and the 12 cities will be saving as much as $12 billion per year. At this time the benefit to cost ratios for the 12 cities will be over 8, and for the 39 cities in the TTI study the ratio will exceed 6. It should be noted that all of these calculations are based on 1987 congestion costs. We know that congestion is growing in all cities so the actual amount of congestion saved by these installations will be much higher than those indicated.

However, costs will also increase although congestion costs will increase much faster than simple inflation. In addition most of the costs of ATIS systems are expected to be private and not public investment costs. Therefore, the benefits stated in 1987 terms are a conservative indication of the relative amounts of benefits that will be derived. The important point is that the benefit to cost ratio is already over 2 assuming a 15 percent reduction in congestion. If we assume higher rates of reductions due to the interaction between ATMS and ATIS we will find that the average benefit to cost ratio will rise.

If we find that the actual reduction in congestion is 25 percent the benefit to cost ratio is *3.3*, for 30 percent it is 4.0, and for 40 percent it is 5.3. Of course all of these ratios are much larger for Los Angeles since its ratio at 15 percent is 3.2, at 25 percent it is 5.3, at 30 percent it is 6.4 and at 40 percent it is 8.6.

Beyond 2010

With full implementation of ATMS and ATIS systems, the combined benefits from congestion relief are likely to be very high. Since we have not implemented these systems and observed and evaluated carefully their impacts, we are not in a position to make hard estimates. We can only hypothesize congestion relief related benefits of 30 to 50 percent, as discussed above, even with the added travel that these systems will likely induce.

Indeed there are likely to be real benefits from ATMS and ATIS systems in ways we can’t imagine. Just as paving roads in the 1920’s got us out of the mud, and changed the face of pre-war America. And just as the limited access highway allowed us a way to control access onto highway links and not throw our highway capacity away by allowing traffic friction from abutters. Now with IVHS systems, we may be able to control and guide access onto and within the transportation system in a non coercive manner so we don’t replace moving traffic on highways, with stopped traffic on these same highways.

Beyond 2010 there will also be big reductions in congestion as Advanced Vehicle Control Systems become advanced sufficiently so that vehicles can be controlled on freeways, both in terms of headway and lateral clearance. When these “automated highways” come into existence profound reductions in congestion will be possible.

In summary, the congestion reducing benefits from IVHS, the to's minus t1's could be enormous. We have mentioned current congestion costs in the U.S. alone of $100 billion a year -- not including the contribution of this congestion to accidents, fuel and other operating costs, and lost productivity. Considerable research is needed to get more accurate percentage delay reductions than the ATMS delay reduction and the 15% ATMS delay reduction and the additional 10% to 50% ATIS delay reduction reported above. But whether congestlon 1s ultimately reduced by 10% or 50% from IVHS systems, the benefits are certainly more than enough to justify moving work in this area forward, when considered in a benefit cost framework.

POTENTIAL FUEL SAVINGS BENEFITS OF IVHS

In addition to the benefit of time savings as a result of IVHS, there is also the potential for savings in fuel consumption for equipped vehicles on systems with supporting infrastructure. The benefits will be available with the implementation of the Advanced Traffic Management Systems (ATMS) and the Advanced Driver Information Systems (ADIS) capability in the vehicles. With these portions of the system in place, drivers will be informed of optimal route selection and will be travelling at nearly a constant rate.

This offers the potential for fuel savings from three perspectives:

- Savings from reduced travel times and delay

Operational Benefits

- Savings as a result of fewer starts and stops
- Savings from following the shortest effective route

Although no specific studies have be-en done here to evaluate these potential benefits of IVHS, some estimates can be made and later verified by demonstration.

The concept of Advanced Traffic Management includes both the capability to update equipped vehicles of the current traffic network conditions for the selected or desired route on a real time basis, and the capability for predicting the network impact of diverting some portion of the demand to alternative portions of the network. This capability will provide balanced vehicle densities and maximum utilization of the infrastructure. The Advanced Driver Information System in the vehicle will receive this data from the ATMS and calculate the best route. When ATMS is implemented throughout the network, the vehicles should travel with minimal starts and stops and at nearly a constant speed. If we use the current EPA Fuel Economy Label values as a starting point to quantify these benefits, it is clear that the closer the IVHS allows vehicles to perform in the "Highway" mode, the higher the benefits, The difference between the city versus highway fuel economy as determined in this manner is dependent on several factors such as vehicle weight, engine size, and options such as air conditioning. As seen in table 5, for a typical small engine (less than 2.0 L) equipped subcompact vehicle the potential savings is 10%. This can increase to as much as 50 % as the engine size increases to 5.0 L. Based on published data it appears that the correlation follows engine size such that vehicles equipped with a 2.0-3.0 L engine has a 20-30% difference in fuel economy in the two modes.

Table 5 Fuel Economy Estimates

Class	Powertrain	City MPG	Highway MPG	Difference
Subcompact	<2.0 L	25-38	29-40	5-16%
Subcompact	2.0-5.0 L	18-25	27-30	20-50 %
Compact	1.5-2.5 L	18-33	23-40	21-27%
Compact	2.6-5.0 L	18-21	25-27	28-38 %
Midsize	2.5-3.8 L	18-23	23-32	28-39 %
Large	3.5-5.0 L	17	24	41%

Another means of assessing the potential benefits would be to determine the degradation in fuel economy using a duty cycle analysis.

Assume a 10 mile trip at a constant 40 miles per hour. This trip would take 15 minutes. The calculated degradation in fuel economy using this calculation is shown in table 6.

Based on either analysis, the savings are substantial.

For the target years the following estimates are reasonable based on the reductions in congestion stated earlier and projections reported in a recent ITE Journal citing FHWA estimates of existing urban freeway congestion accounting for 2.2 billion gallons of wasted fuel yearly. This was projected to rise to 11.6 billion gallons of wasted fuel by 2005. A rough approximation of fuel savings is estimated through a linear projection since the shape of the curve is not well defined. For this analysis let us assume that IVHS initiatives are encouraged nationwide and not just in a few of the worst urban areas

Operational Benefits

Table 6 Trip Characteristics

Based on a 10 mile trip

Time Stopped	0 minutes	1 minute	3 minutes	5 minutes
Speed underway	40 mph	42.8 mph	50 mph	60 mph
Driving consumption	0.4 gal	0.408 gal	0.448 gal	0.5128 gal
Idling consumption	0	0.0088 gal	0.0265 gal	0.044 gal
Total fuel consumed	0.4 gal	0.4168 gal	0.4749 gal	0.5569 gal
Fuel mileage	25 mph	24 mpg	21 mpg	17.96 mpg
Fuel economy	100%	96%	84%	71.8%

with optimistic but plausible penetration percentages.

	% Penetration	Fuel Saved
1995	15	1.0 billion gallons
2000	25	2.2 billion gallons
2010	50	6.5 billion gallons

In addition one billion gallons of fuel per year could be saved through surface street signal optimization and coordination based on today's congestion.

The other potential for fuel savings resulting from the implementation of IVHS is the minimization of inefficient route selection. In a FHWA study (FHWA/RD-86/029) conducted in 1986, it was shown that major improvements in distance travelled and time spent travelling could be achieved with navigational aids.

Excess travel was attributed to any of the following factors or combinations of the factors:

- Use of route selection criteria set which does not emphasize route optimization.
- Failure to consider an adequate number of alternative routes.
- Inadequate skills to identify optimum routes
- Unavailability, inadequacy or inaccuracy of information necessary for route selection.
- Failure to follow a planned route due to deficiencies in the highway information system.
- Failure to follow a planned route due to lack of adequate skills or of required prior knowledge.
- Failure to follow a planned route due to deficiencies in route description or storage.
- Incorrect evaluation of real time route choice alternatives.
- Voluntary diversion from a planned route.
- Forced diversion from a planned route.

Clearly the goals of IVHS address the improvement of the majority of these causes.

The referenced study cited previous studies done in various places around the world and concluded that for non-work, non-CBD trips, excess travel in every study amounted to more than ten percent of optimum. In actual empirical investigations undertaken as part of the study, it was found that navigational failures were responsible for approximately 20 percent of all miles driven and approximately 40 percent of all time spent driving. Further results of the study show that an extremely high proportion of subjects attempting to plan local trips in unfamiliar areas using maps developed unfeasible routes due to street discontinuities, turn restrictions, of one-way regulations. In cases where feasible routes were established, those routes averaged 11.1 percent excess distance.

Based on the studied data and assuming steady state conditions in the infrastructure, the study estimated that the excess travel for non-commercial vehicles in the United States amounts to 83.5 billion miles per year. The excess time due to recoverable navigational waste is estimated to be 914,000 years. The combined cost due to the excess time and distance was estimated to be $45.7 billion annually.

This study did not consider the additional savings that could result from route planning that includes the dynamic infrastructure conditions. The planned IVHS research will include providing real time data to optimize route planning based on actual traffic, highway, and climatological conditions. These incremental savings will be assessed as part of the planned demonstrations.

The study concluded that there appears to be a lack of appreciation, on the part of the general public, of the magnitude and associated costs of the excess travel problem. This should be a prime focus of the IVHS education process to raise the public awareness of the cost/benefit potential of these systems.

AIR QUALITY

The March, 1989, U. S. Environmental Protection Agency report entitled "National Air Qualify and Emissions Trends Report, 1987" stated that emissions from transportation sources accounted for 43% of total emissions of nitrogen oxides, 3 1% of hydrocarbons, and 66 % of carbon monoxide. The urban area contribution is much greater. For example, in Los Angeles, mobile sources accounted for 59% of the nitrogen oxides, 46 % of the hydrocarbons, and 87 % of the carbon monoxide.

The future of air quality in North America is one of good news and bad news scenarios. The good news is that emissions of carbon monoxide, hydrocarbons and nitrous oxides from light duty vehicles have been declining for the past two decades due to various emission control strategies. The bad news is that many areas of the country still have intolerable levels of pollution and by the middle of this decade increases in VMT and resultant congestion will overtake the benefits that emission controls have created.

The trend lines shown in figures 3-5 provided by Mr. Gary Hawthorn, Special Assistant for Transportation Policies of the EPA, graphically demonstrate these trends. Please note the assumptions listed on the page following the trends. To reduce the impending negative impact on air quality that already is blamed for many fatalities in some areas, several strategies are proposed. Among them are alternative fuels, reliance on mass transit, demand management, and IVHS initiatives to reduce congestion, provide optimum routing, and avoid wasted trips or excess mileage through improved traffic management, advanced driver information and other strategies.

For most carbon monoxide and ozone non-attainment areas states must submit implementation plans (SIP'S). Included in these plans are reasonably available control measures for stationary and mobile sources. Many experts believe that VMT growth will become the key determinant of air quality problems instead of tailpipe or evaporative emission rates. The disproportionate increases due to congestion loom as the single most important contributions to degradation of air quality in the future.

IVHS strategies offer the greatest hope for the future because impacts will be virtually immediate depending on implementation rate and such strategies are complementary to other air quality initiatives. For example, much discussion currently centers on alternative fuels especially in Los Angeles where one ambitious penetration scheme called for 400,000 vehicles by 1996. Most alternative fuels have side effects including emissions of other pollutants such as the increased tailpipe emissions of formaldehyde with methanol. IVHS strategies will reduce emissions, regardless of the fuel. Any clean fuels program will not begin yielding significant emission reductions until the late 1990's.

IVHS initiatives also complement efforts in promotion of mass transit. Improved driver information may cause a diversion from auto trips to mass transit. Traffic management strategies will impact

Insert Figure 3 Trends in Light Duty Vehicle Emissions

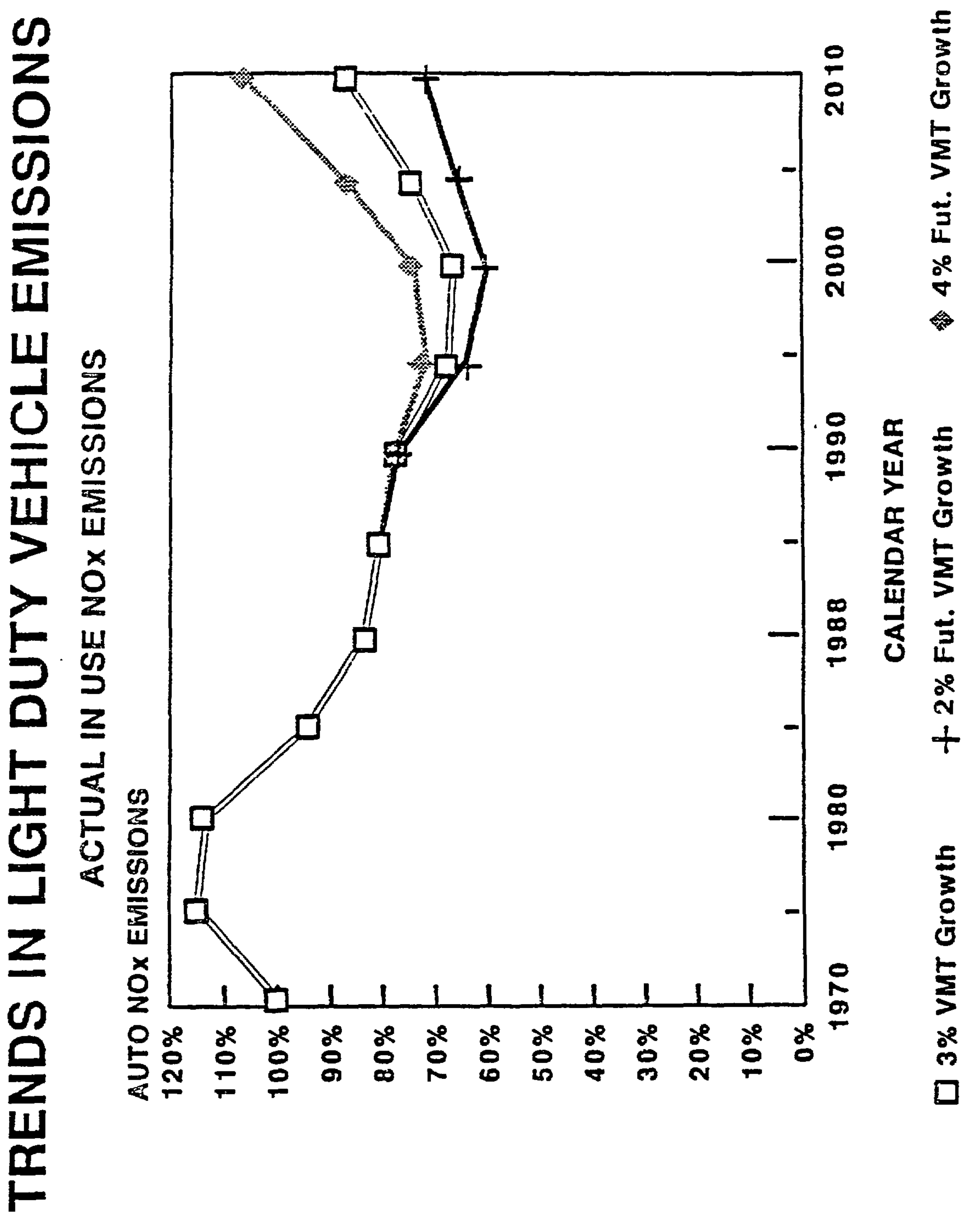


Figure 3

Insert Figure 4 Trends in Light Duty Vehicle Emissions

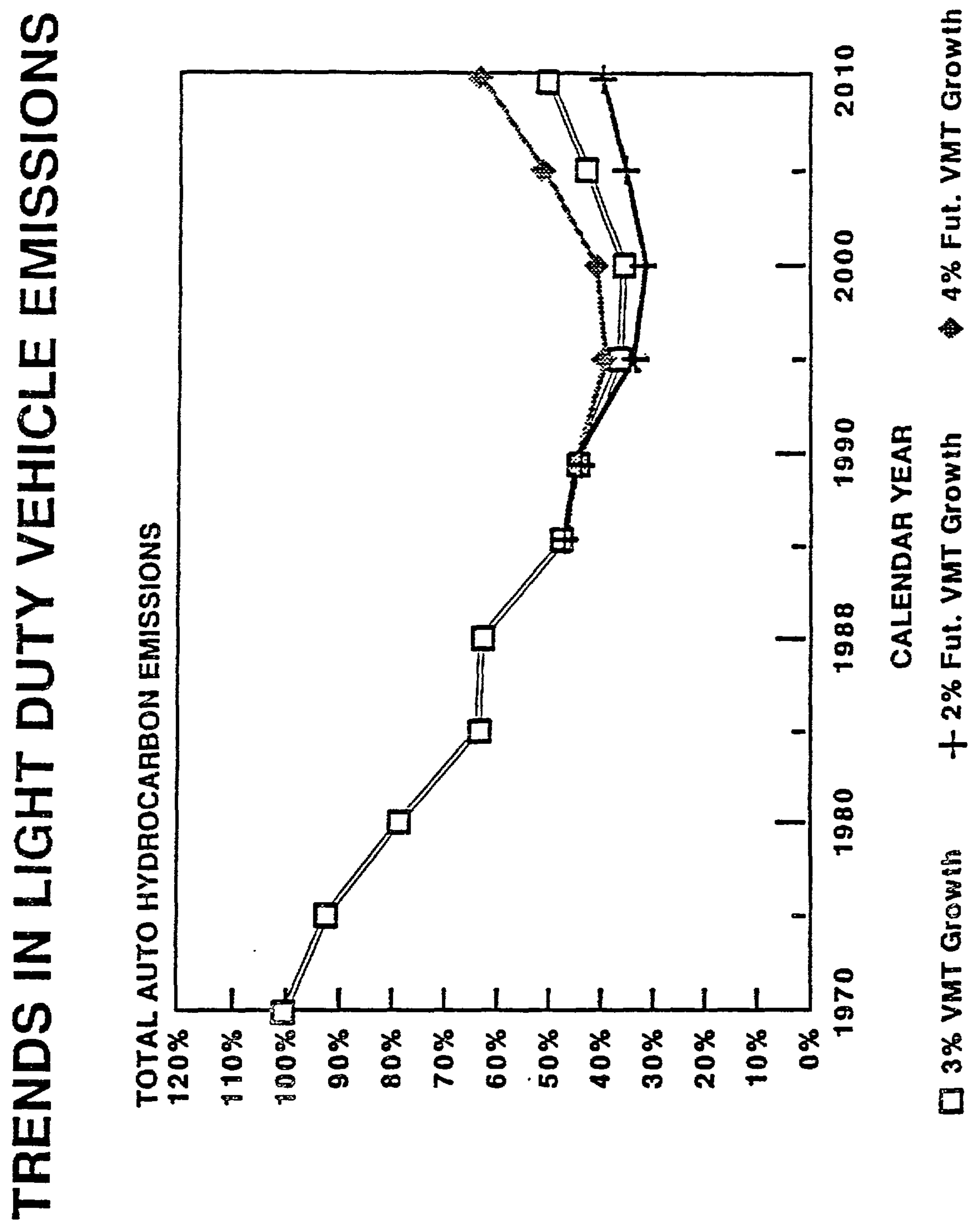


Figure 4

Insert Figure 5 Trends in Light Duty Vehicle Emissions

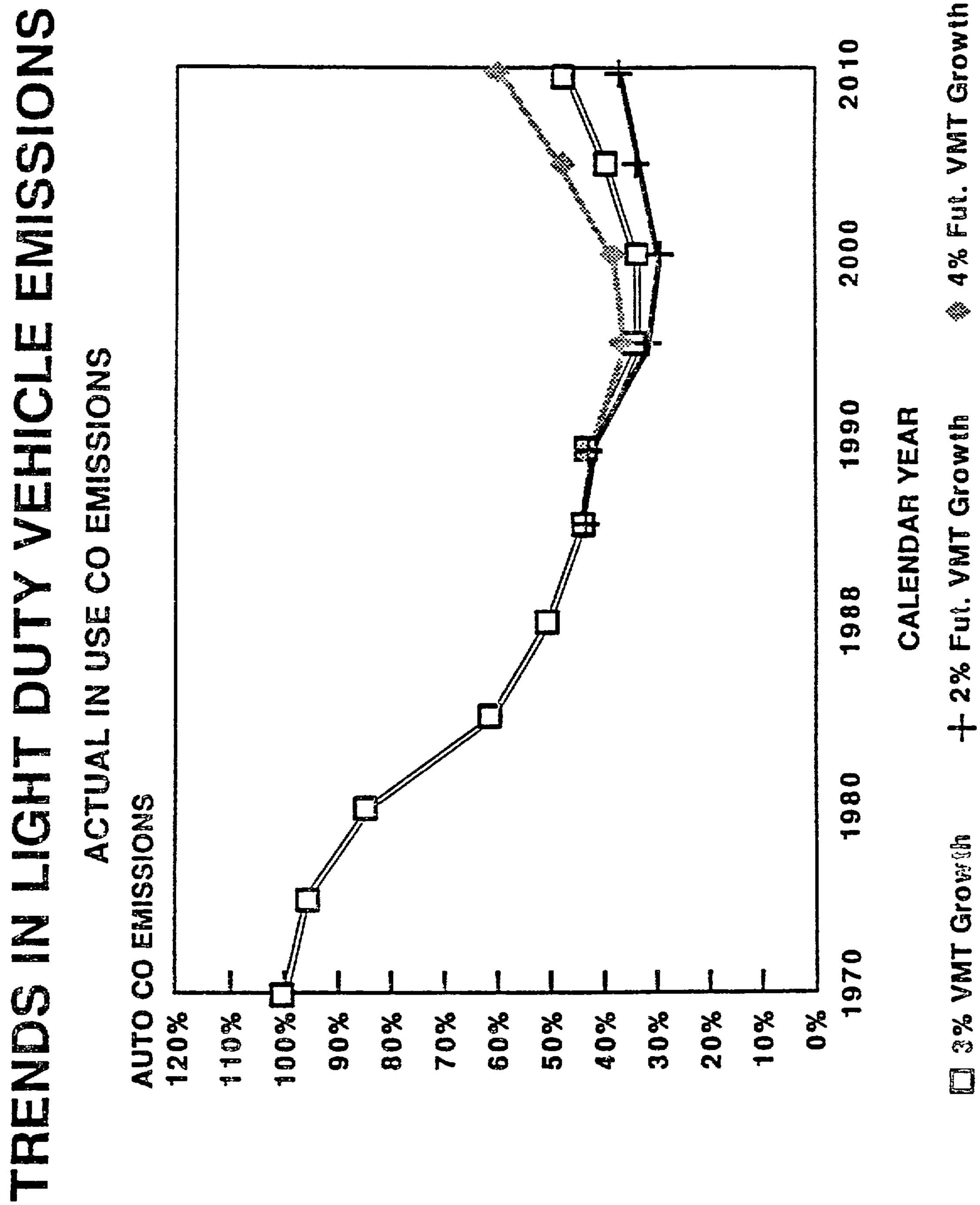


Figure 5

high occupancy or mass transit vehicles that share the transportation network. Demand management and IVHS initiatives that promote mobility need not be seen as competing or counterproductive strategies. In fact, some demand management will be essential for the gains of the IVHS initiatives to be sustained and made permanent lest congestion be restored due to excessive induced trips.

Though congestion and emission problems are closely related, environmental and transportation officials have not always worked together. The increased attention to the needs of traffic management and driver information that the new IVHS initiative bring to bear provide an opportunity to work together toward common interests because reductions in congestion bring about improved air quality. For example, the integrated traffic control project known as the Los Angeles Smart Corridor Demonstration is expected to yield reductions of 15 % carbon monoxide emissions and 8 % hydrocarbons, Approximations for the future air quality benefits of IVHS initiatives for 1995, 2000 and 2010 are not well defined because of the interaction with other countermeasures. However, benefits proportionate with those of reduced congestion seem reasonable.

Assumptions for emission projection graphs

The projected emissions shown in Figures 3-5 assume:

1. 20 m.p.h. average speed (basic FTP conditions). No adjustment for congestion — for likely decreases in average speeds.
2. Emission reductions from volatility regulations.
3. Basic inspection and maintenance (I/M) (not enhanced I/M).
4. Mobile 4.
5. Existing new car emission standards (not the lower standards proposed in some draft clean air bills). This assumption would overestimate emissions because recent developments in the House indicate that tougher auto emission standards will probably be included in future clean air legislation.
6. No emission reductions from alternative fuels.

NOTE: The consultant who prepared the emission graphs believes that current predictive tools used to generate the graphs may underestimate the emission impacts of VMT and congestion. For example, the driving cycle used to generate emission factors may not accurately reflect current driving behavior and thus would underestimate future emissions. These predictive tools which are periodically updated will hopefully improve vehicular emission projections in upcoming SIP revision work.

ENHANCING MOBILITY

In addition to the direct congestion relief and higher safety impact from IVHS technologies, IVHS is likely to have a wide range of impacts on highway users and highway operators. In particular, the introduction and use of these technologies may provide important contributions to enhancing the ability of people to use the nation's transportation system.

The primary impact will be to improve the use of private automobiles and trucks but there will also be important improvements in access to public transportationsystems, high-occupancy vehicles, and other ridesharing opportunities. This section describes some of the ways that IVHS technologies can enhance the mobility of the population.

In many of the examples enumerated in this section, the IVHS technologies will not have a *direct* impact, per se, on the populations identified but will facilitate improvements in services and operations that these groups rely upon for transportation. i.e., the existence of IVHS allows transportation officials to implement services that might not have been feasible before IVHS. The people using these new or improved services will notice an improvement in accessibility and quality of transportation services, but may not be explicitly conscious that "smart" technologies are making these improvements possible. Nonetheless, these need to be accounted for in cataloging the benefits of IVHS.

IVHS technologies have the potential to make significant improvements in trip planning and in providing en-route driving aids. For "routine" trips, there may be the ability to determine traffic conditions and current status of transit operations. For other trips, a clearer, more accurate assessment can be made of how to get there.

Automated Vehicle Location will provide real-time information on area-wide highway conditions and system-wide departure times and transit vehicle locations. This information can be made available to the automobile driver both before leaving home and while driving. In addition to receiving this information in the vehicle, it can also be provided to transit operators and transit users at bus stops, shopping centers, factories, and other employment, social, recreational, and health activity centers. The information can also be communicated to users in their homes through radio, analogue and digital telephone lines, cable video, video text, and other communication devices.

Advanced Traffic Management Systems (ATMS) will improve the safety and efficiency of traveling along highways. Automated Driver Information Systems (ADIS) will w arn drivers of bad weather, highway maintenance and construction work, congestion delays and will give other important information. At later stages of IVHS implementation, Advanced Vehicle Control Systems (AVCS) will facilitate faster and safer intercity highway travel. Drivers will be able to safely travel to cities at very high speeds using anticollision warning and avoidance devices and advanced vehicle control.

IMPROVING MOBILITY FOR SPECIFIC GROUPS

IVHS will affect all types of highway-based travel: the journey-to-work, other intra-city travel, as well as intercity travel. As a part of this process of identifying beneficiaries of IVHS, particular segments of the population who will be particularly impacted were identified.

The Older Driver

Americans aged 65 and older are the fastest growing segment of our population, increasing by 54 percent between 1960 and 1980. Within this segment, the number of people over 75 is expected to double by the year 2000. In comparison, in the year 1900 only 4 percent of the U.S.A. population was over age 65 (3 million). and in 1989 it was an estimated 12 percent (30 million). In the year 2020 it is predicted to be as much as 20 percent of the total U.S. population (65 million).

The consequences of this large a population group on highway travel are potentially significant. While people "age" at different rates, in general some of the skills needed for safe driving begin to deteriorate at age 55 or thereabouts, and more dramatically so after age 75. And yet, the percent of elderly over 65 retaining their driver's license and continuing to drive has rapidly increased from 43 percent in 1969, to 55 percent in 1977, to over 62 percent in 1984 (18 million). This percentage is expected to continue increasing to over 75 percent (50 million) by the year 2020.

Studies of travel behavior show that the population over age 65 depends more on the automobile and less on transit than any other age group. About 85 percent of their trips are by private vehicle, either as driver or passenger. Older persons travel as frequently as younger persons, although the distance traveled is as much as 80 percent less. The bulk of these trips are for shopping, family/personal business, and social/visiting, as opposed to commuting and business trips.

Older persons try to compensate for their reduced abilities by avoiding periods of congestion, driving less at night (13 percent of their trips are taken at night compared to 25 percent by the younger age groups), avoiding bad weather conditions, and by driving more slowly and cautiously. Older drivers have more difficulty with certain critical driving tasks such as staying within lanes, switching lanes, changing directions, and merging into a stream of traffic. As a rule, they take longer to reach a decision than youngest motorists.

Traffic violation rates indicate that the older driver are not as diligent as younger drivers in observing traffic signs and are cited frequently for illegal passing maneuvers, turning violations, and failure to yield right of way. Intersections and nighttime driving are particularly hazardous for older drivers, with 40 percent of older driver fatalities and 60 percent of their injuries occurring at intersections. Fatality rates also suggest that it is twice as dangerous for an older person to drive on a rural road at night as on an urban street during daylight. Nine out of 10 older driver accidents involve multiple vehicles, usually because of vision problems and cognitive deficiencies.

It is estimated that 90 percent of all information necessary for driving is acquired visually. In general, a significant decline in vision begins in the mid-fifties; visual acuity (ability to see clearly) begins a rapid decline due to the browning and hardening of the lens. In addition, the pupil begins shrinking until it reaches about one-third its normal size. It becomes harder to focus on objects and to change focus quickly, depth perception weakens, peripheral vision gradually worsens, and recognizing certain colors becomes more difficult.

After the age of 20, a person's illumination needs double every 13 years to see as clearly. Consequently, compared to a younger driver, the older driver at night is operating as though he/she is wearing two pairs of sunglasses. But this need for additional light conflicts with a difficulty in adjusting to glare. The result on the highway is a driver that more slowly responds to signals, signs, and traffic events, that has problems in determining the distance and closing speed of oncoming vehicles, and has reduced ability to detect vehicles and pedestrians.

It is estimated that about 30 percent of the population over the age of 65 has some hearing loss. Generally, high-pitched sounds become less audible long before low-pitched ones. Since high-pitched sounds are less audible to older people, they have difficulty hearing and reacting to horns, motors, sirens, and train whistles. So called "cognitive deficiencies" associated with older people include confusion, inattention, slowed reaction time, slowed decision time, and forgetfulness. These problems develop slowly and begin at widely differing ages. It is estimated that two-thirds of older pwple have some cognitive deficiency. Roadway-related problems caused by these deficiencies include trouble adjusting to varying traffic conditions, confusion when too much information is presented, and an increased tendency to lapses of alert attention.

How IVHS Can Help: The automotive, electronics, and communications industries, in consultation with human factors specialists, have developed and are testing many IVHS technologies that can aid the older driver with the driving tasks. These will enhance and perhaps extend their mobility beyond what is possible today.

Heads-up Displays provide a holographic projection of vehicle operating information such as speed and motor condition onto the windshield and focused about 10 feet forward of the driver. This enables the driver to receive information and to act on it without having to take the eyes off the road, refocusing to look at the instrument panel, then looking up again and refocusing on the road. Refocusing takes longer for the older driver, and in the extra time required, say a half second, a vehicle traveling 35 mph would cover 25 feet.

Fifty percent of all rear end and intersection related collisions and 30 percent of collisions with oncoming traffic could have been avoided had the driver recognized the danger l/2 second earlier and reacted correctly. Heads-up displays (HUD) are currently commercially available on a few models. It is predicted that by the year 2000, approximately 16 percent of the new car buyers will choose the HUD option

Infrared Imaging will provide the driver an enhanced image of the roadway ahead under adverse visibility conditions at night and in rain, fog, and snow. This will help make it easier for the older driver to operate at night by providing better vision, improved recognition, and allowing faster reaction time. It is expected that by the year 2000, approximately 16 percent of the new car buyers will have the infrared imaging equipment.

Obstacle Detection Devices of one sort or another (e.g., laser, infrared, or ultrasonic technologies) will monitor the front, rear, and sides of the vehicle for the presence of objects that the driver should avoid. They can provide both a visual warning and an audible warning (perhaps a computer simulated voice at a pitch that is easy to hear) of closing speed problems, blind spot obstacles, and backing-up risks. This technology will be particularly beneficial to the older driver at intersections and during lane changing maneuvers. It is predicted that by the year 2000, approximately 30 to 45 percent of new car buyers will choose an obstacle detection equipment option.

Driver Alertness Warnings will be able to detect deviations in normal steering and braking performance, which begin to occur with lapses of attention, and will signal a warning to the driver through audible and other sensory means. This type of device would be particularly useful to the elderly, who are more likely to be frequent users of prescription drugs with their attendant risks of drowsiness. It is predicted that by the year 2000, approximately 27 percent of the new car buyers will choose the driver alertness option.

Radar Braking and Steering Override Control technologies will not only detect a collision risk, but will eventually have automatic override capability to apply brakes at the appropriate time to prevent a collision. Limited depth perception, reduced peripheral vision, and slower decision and reaction times – common among the elderly – can be mitigated with these technologies. It is predicted that by the year 2000, approximately 22 percent of the new car buyers will choose the radar braking and 12 percent will choose the steering override option.

On-Board Replication of Maps and Traffic Signs, along with an electronic map or other navigational aids, will replicate those essential traffic control devices that may be difficult for the older driver to see due to darkness or weather and provide a measure of safety and confidence that is not now available. In addition, the navigation systems could provide route selection advice for reaching a destination while avoiding traffic congestion and reducing the stress that motorists face while operating in unfamiliar areas. This technology is currently available and is predicted to be widely deployed by the year 2000.

Two-way Communications will appeal to the older motorist with its ability to maintain constant communications with a traffic control center, much as a pilot maintains contact with air traffic control. In addition to receiving valuable and timely information about traffic conditions and recommendations for route selection, the motorist will also be able to convey emergency messages and request special assistance such as medical, police, fire, rescue, and vehicle services. With this service, more older motorists may be less reluctant to make car trips. This technology will be available initially in large metropolitan areas and along major corridors between large cities. It is predicted that by the year 2010, most major cities and heavily traveled corridors will have this communications capability, with perhaps over 50 percent of the population using the technology-

There are many other features of IVHS that will also benefit the older motorist. The features described above are merely illustrative as the features most likely to be used by the elderly to help overcome their driving task deficiencies and enable them to enjoy mobility options not now available.

Impaired Traveller

Transportation is vital to the disabled and impaired citizen. Personal mobility should not be a barrier to their enjoyment of life. There are some 8 million persons of all ages who are mobility impaired. Frequently, persons with special physical conditions have financial conditions that justify the term economically disabled. This adds up to millions that need special transportation services. IVHS technologies hold great promise to improve the nation's ability to extend and improve these services at a reasonable cost.

The nation is certainly doing a lot wrth existing technologies. Public monies going annually into transportation associated with social services exceed $800 million. Not-for-profit agencies receive an additional amount of perhaps $17 million annually from charitable organizations to provide mobility for persons with disabilities. An estimated 5,000 local social service organizations fund transportation, operating some 25,000 vehicles nationwide. Non profit agencies numbering another 3,500 add another 21,000 vehicles **to** this total. Private, for-profit carriers, including the taxi industry, do their share.

But the need is great, and it is not being met; perhaps some 2 billion annual trips are not currently being made. Current travel plus much of the unmet need could be better served with better coordination of schedule and fares, improved information to the elderly and handicapped trip maker, and cost sharing among sponsoring organizations. IVHS will help in all these areas.

For example, a single or multi-county system using IVHS could pull together all funding agencies, transportation providers, and specialized activity sponsors in a single network. The trip maker, whether living in a private or community home would have available, via large-type video text or amplified telephone, comprehensive trip making information. Customized to the travelers disabilities (wheelchair, etc.) real-time departures schedules can be compared to desired trip times, opening times, and other destination information selected by the elderly or disabled traveler. Alternatives, with estimated costs and reliabilities, can be automatically provided to the traveler, and travel orders can be confirmed.

Doctors offices, rehabilitation centers, community social and recreation services, churches, day schools and night schools, emergency services, recorded messages, paging devices (transmitter that signals when person in need pushes buttons), meals on wheels, and other locations and events of interest can be integrated into the network. Thus at any convenient location, in the home or elsewhere, using large-button telephones and other devices enhanced for sight, hearing or mobility impaired persons, the elderly or handicapped person can easily enter a whole world of information and support. IVHS can then convert the schedule and location information quickly and precisely into transportation information. Instructions can be automatically conveyed to the traveler, to the transportation service manager and to the vehicle operator. Appointment times can be confirmed, departure and arrival times coordinated with opening and closing times and other schedules and arrangements finalized.

The traveler benefits, but others do as well. Business and services, both for-profit and not-for-profit can organize more effectively and flexibly. They can be decentralized, be provided in the home or on the farm, wherever they can operate most effectively and most economically. This is increasingly important in less densely populated areas in the suburbs and in rural areas.

Funding for elderly and handicapped transportation comes from a wide variety of agencies — transportation, aging, religious, social service, and many health and medical agencies subdivided by disease and disability types. Support comes from federal, state, and local levels. Many of these support resources have spawned their own fare and subsidy policies, leading to diseconomies for the providers and suboptimal services for the user. IVHS can integrate fare collection and billing, coordinating finance as well as schedule. Traveler identification can be recorded at the time of scheduling or upon vehicle entry. Magnetically coded cards or smart cards can inform the system through home based devices or on-board recording devices of the characteristics or classification to the traveler. On-vehicle equipment can generate times, locations, and distances. Fares can be automatically calculated and charged to the traveler using stored value cards, cash, or charged to personal accounts. Similarly, subsidies can be calculated and billed to the appropriate agency.

The end results will be the provision of transportation services to meet the specialized needs of the elderly and handicapped. They will be better able to organize their day to take full advantage of the services designed for their health, their livelihood, and their enjoyment. IVHS will help move them about safely and efficiently through the day, and at the end of the day distribute the costs equitably. These groups should find significantly enhanced mobility.

Carless

Home-based or curb-side "traveler information systems" elements of IVHS which provide accurate and timely information on the availability and scheduling of transit services would be particularly beneficial to people without automobiles who must rely almost exclusively on public transit to get around. The availability and use of this information can allow better personal planning for transit trips and can provide help in finding out when particular buses will depart a particular point along it route and how to use transit to get to where you want to go. While this information will be available to all, a greater share of the benefit of this technology will be to those who do not have access to individual automobiles and are more reliant on transit. Better information will make it easier for these people to get around and will increase the range of trips that are feasible.

One example of how the use of enhanced transit information provided by ADIS systems would be for users of the system in off-peak hours. "Night Owl" service in the overnight period operates under a much sparser schedule then during the day. While there is often little delay between a random appearance at a bus or transit stop and the appearance of the bus or transit vehicle during peak periods, this is not the case off-peak — particularly in the middle of the night. The result is that transit users often have to wait long periods for their connection. Better information on when the bus or train will actually arrive at the nearest location would allow them to reduce the amount of time they have to spend waiting at dark, cold (often dangerous) transit stops. Lone passengers at a streetside bus stop are a tempting target for criminals; reducing the dwell time has direct benefits in terms of reducing a person's exposure to crime as well as improve the convenience of using transit.

As the information systems become more sophisticated, transit services may be able to be better tailored to the specific needs of people travelling in off-peak hours. This may allow better service to be offered to more people at a reasonable cost. For example, it may be feasible to divert buses from fixed routes in order to reduce the distance that passengers have to walk to rendezvous with the bus. These information systems may allow transit officials to provide special buses under more circumstances than is currently feasible.

The Automated Vehicle Identificationsystems that are used to keep track of bus fleets for operational purposes, also enhance personal security. Vehicles equipped with automated location systems for operational purposes can use these systems to quickly alert authorities on the precise location of where a crime is occurring. While the total number of transit crimes is greater during peak hours, the incidence of crime is considerably higher off-peak and the consequences are generally much greater. While this benefit applies to all transit service, its value will be particularly significant for operations in high crime areas and late at night — areas and times where use by the poor are over-represented.

Rural Residents

Transportation needs of rural residents are quite different than those of city and suburban residents, and because of the general absence of congestion problems, may be overlooked when the benefits of IVHS are enumerated. There are approximately 286 million annual one-way rural transit trips nationwide. Public transit is used to shuttle residents to larger cities for medical services, shopping, cultural events, and for connections with air service. Intercity highway travel is also an important element of rural resident transportation. IVHS will benefit rural residents both with improvements to rural transit services and to intercity travel.

Reduced Costs/Flexible Pricing Data collected on vehicles, passengers, and road conditions will allow transit demand to be met with the lowest cost service available. Alternative fare structures will be possible, allowing for more flexible fares which depend on each individual trip's characteristics. This type of market-oriented trip pricing can be charged and billed to smart cards or centralized accounts. Flexible fare structures also allow direct and user-side subsidies by public agencies, employers, and educational and social agencies.

Vehicle Systems Monitoring IVHS technology will allow in-vehicle diagnostic monitoring of vehicle systems such as equipment stress, engine temperature, brake conditions and other vehicle functions giving the driver instructions for preventative maintenance, worn parts to watch for, or driving practices to amend. This information can also be communicated to the systems manager. The technology will benefit the transit service and the public with lower maintenance costs.

Trip *Planning* Automated Vehicle Location will provide real-time information on system-wide departure times and transit vehicle locations. This information can be communicated to the transit provider and ultimately to the transit users at bus stops, shopping centers, factories, and other employment, social, recreational, and health activity centers. The information can also be communicated to users in their homes through radio, analogue and digital telephone lines, cable video, video text, and other communication devices.

Implementation of interactive communications between user and provider will occur in the final stages of advanced trip planning. Passengers will be able to make and change reservations from their homes based on real-time system information on schedules, fare rates, and availability. Systems managers will use the information to schedule services and determine fare rates. Better trip planning will benefit both the transit users and providers.

Faster, Smoother, Safer Services IVHS technology will improve trip planning and, as a result, provide faster, more reliable transit services. Implementation of anti-collision avoidance and warning devices, and in-vehicle systems monitoring will improve transit safety in their early stages of IVHS development. Later stages of IVHS implementation such as Automated Traffic Management Systems and Automated Vehicle Control Systems (AVCS) in rural areas will improve the safety and quality of rural transit services.

Operational Benefits

Improved Intercity Highway Travel Advanced Traffic Management Systems (ATMS) on rural highways, especially those leading to larger cities, will improve the safety and efficiency of traveling from rural areas to larger cities. Automated Driver Information Systems (ADIS) will warn intercity drivers of bad weather, highway maintenance and construction work, congestion delays and will give other important information. At later stages of IVHS implementation, Advanced Vehicle Control Systems (AVCS) will allow even faster and safer intercity highway travel. Rural residents will be able to safely travel to cities at very high speeds due to anticollision warning and avoidance devices and advanced vehicle control.

"Yellow pages" information could be available using ADIS to the rural resident traveling to larger cities. The traveler will be able to view maps of city locations of restaurants, hospitals, recreation centers, airports, and shopping centers. Eventually, two-way communication will allow the driver to make airplane or restaurant reservations as he or she travels to the city. This type of system will benefit rural residents.

Tourists

One of the byproducts of the development of the Interstate Highway System was the unprecedented mobility it gave to the American motorist. Americans were now able to travel further and faster than previously possible. Since Americans had always been predisposed to use the auto for recreational travel, this development served to broaden and extend the horizon of the recreational trip. Long distance recreational trips increased. These longer trips often required the motorist to pass through the various states and/or metropolitan areas.

With the increase of these trips, a large recreation industry has developed. The American Automobile Association (AAA) began to devote more and more effort to recreation trip planning and service. Their triptiks became ubiquitous – more than 7 million triptiks as well as 34 million tourbooks are now distributed annually. Motel and restaurant chains began to provide publications which not only listed the locations of their facilities but also provided maps to better direct the motorist and a list of nearby points of interest.

Even travelers who used other modes of travel such as rail or air benefitted from these auto-oriented service industries since they often rented autos for local travel once their destination was reached. The rental car industry expanded to service the increased demand.

In recent years, however, Americans have again begun to find their mobility constrained by the increasing congestion on the Interstate Highway and freeway systems. Motorists on recreational trips are often more adversely affected on a day to day basis by congestion than commuters because they are unfamiliar with the area and any alternate routes that may exist. Also, they are unfamiliar with the times of day when congestion might exist. Even if they are familiar with the area they would generally not be familiar with recent construction on or changes to the highway system. Since social and recreational trips represent 22.6 percent of all vehicle trips and 27.6 percent of all person trips as well as 30.0 percent of all vehicle miles of travel a significant number of Americans will be affected in this way.

The recreation traveler will realize significant benefits from IVHS changes. Since recreational trips seem to be fairly consistently distributed across all income groups and since it shows approximately 84 percent of these trips to be made by motor vehicle, this essentially means almost all Americans. Other impacted groups include state and local governments, recreational service industries such as motels, restaurants, and rental agencies and auto service organization such as AAA. A description of some of the many impacts of IVHS in this area follows.

IVHS benefits to recreational travelers will show up initially in the area of Advanced Transportation Management System (ATMS) improvements. The recreational trip is the most efficient trip in terms of vehicle occupancy (2.5 persons per trip) so most recreational travelers can take advantage of any HOV lane options available *if they have knowledge of them.* Advances in surveillance, detection, and communication technology will help the unfamiliar motorist to obtain information on both the options available to him and how to take advantage of these options. This information can be used to avoid delays when passing through unfamiliar areas.

Benefits of IVHS will also come from Advanced Driver Information System (ADIS) improvements. Initially, these benefits may stem from ADIS deployment in rental car fleets. As another possibility, AAA could take advantage of navigational equipment by providing *Etriptiks* consisting of map disks which would not only provide navigational information but also information on points of interest and lodging and eating places in the area. IVHS radio channels in the cars will provide advisory information allowing the motorist to avoid delays and construction and use alternate routes. Recreational service industries could also provide map disks showing location of their facilities and nearby attractions and services.

Another benefit of ADIS deployment in rental car fleets is to facilitate driver familiarization with IVHS technology. This could lead to more rapid deployment rates in personal autos as drivers see the benefits of the new technology. A demonstration of this sort is being considered in the Orlando area by a combination of General Motors, FHWA, FLORIDA DOT, City of Orlando, and AAA. They intend to develop a plan for deploying smart vehicle components in a rental fleet.

The second stage of benefits will stem from improvements to the ADIS technology already deployed as well as increased deployment of ADIS equipment to personal vehicles. As an example, highway advisory information could be sent directly to the in-vehicle route guidance system. The new technology could also provide the ability to update maps as well as provide real time incident information and necessary route changes. Technology may also be available for enroute lodging and dinner reservations.

Third stage IVHS benefits should stem primarily from Advanced Vehicle Control System (AVCS) improvements and could include such things as automatic trip programming and automated tours. Longitudinal placement and collision avoidance technology which should also be available will enhance safety.

Personal Security and Protection

In 1986, there were about 1.2 million automobile thefts; the value of the vehicles and equipment stolen was over $5.5 billion. In addition to that, there were many thefts of commercial over-the-road trucks. Even more serious are personal attacks on individuals that take place in automobiles. While the number of such occurrences is relatively small, there is anxiety on the part of many that a vehicle breakdown or accident will occur while driving in the middle of the night or in desolate or high-crime areas.

There are already systems available that allow law enforcement authorities to locate stolen automobiles. For the most part, these are used by people with very expensive automobiles. In one system, automobiles are equipped with a radio transponder that can be activated by the owner if the vehicle is stolen. Police are supplied with a radio receiver to locate the current position of those vehicles. Several trucking companies that have installed satellite location systems have recovered stolen vehicles through the use of this technology.

When ADIS vehicle identification technology is developed and implemented to provide real-time, personalized information to individual vehicles or used to pay tolls automatically, these technologies could be adapted to locate stolen vehicles. The same technology that informs highway authorities of the location of vehicles could also provide a distress call in emergency situations. Vehicles “lost” in snowstorms and other severe weather conditions would now have a better chance of being found than they currently do. Those persons disabled or hindered by the elements could remain with their car and not have to try **to** reach safety on their own.

Any estimate of the net benefits of IVHS technology should consider the number of crimes that might be averted if police could be notified automatically. The use of this technology will make it substantially more difficult to successfully steal vehicles as well as provide a measure of reassurance to people who break down.

Enhanced Fleet Management

Safety improvements from IVHS will benefit motor carriers in terms of safety and reduced insurance costs. The traveling public will also benefit from improved motor carrier safety. While these improvements apply equally to both passengers cars and trucks, safety among commercial vehicles is a particular concern because truckers are on the road for longer periods, and if they have an accident, the effects are generally more severe. In addition, there are particular benefits to commercial and fleet operators.

Improved Regulation/Permitting Motor carriers are already heavily regulated. Much of this regulation causes expensive delays and paperwork for both carriers and government regulators. The advent of M-IS gives the potential to significantly reduce the delays in regulation and provide a fairer, more efficient regulatory system.

Automated Vehicle Identification and Automated Vehicle Location (AVI/AVL) will enable regulators to identify commercial vehicles in every state. The standardization of AVI/AVL technology among the states is an important issues to the trucking industry. AVI/AVL supplemented by weigh-in-motion (WIM) devices will allow automatic truck and document inspection and weight limit compliance without the need to stop. State regulatory officials can automatically check the adequacy of the truck's inspection records, check the driver's licensing and physical examination records, identify hazardous cargo, determine the number of continuous hours on the road, monitor vehicle speed, and identify stolen vehicles. If a truck is in non-compliance, a message sign can signal the driver off the road to an inspection station for a more in-depth inspection or alert law enforcement authorities. These technologies can lead to totally automated record keeping for both motor carriers and regulatory agencies. Similar technology will be used for automated toll collection. This will benefit carriers by reducing the time and papenvork currently required in carrying out motor carrier regulations. Governmental entities will benefit by having improved enforcement of safety and over-size/overweight regulations. The public will benefit from reduced wear on infrastructure due to better enforcement of regulations. AVI/AVL is adapt to be implemented in the secondary stages of IVHS implementation.

Reduced Fuel Costs In 1989, commercial trucks consumed an average of 1,343 gallons of fuel per vehicle. Cost/benefit studies on Advanced Traffic Management Systems show a fuel savings of 12 percent. This would imply an average savings in truck annual fuel consumption of about 161 gallons per year. Nationwide the fuel savings would be 6,853,342,200 gallons per year or about $7 billion per year. This will benefit motor carriers with reduced fuel costs and benefit the nation with reduced dependence on foreign fuel.

Improved Vehicle Systems Monitoring New technology will become available to monitor motor carriers' vehicle performance. The technology will test equipment stress, engine temperature, axle weights, brake conditions and other vehicle functions giving the driver instructions for preventive maintenance, worn parts to watch for, or driving practices to amend. This information can also be communicated to the fleet manager. Eventually, these computerized systems will also allow electronic trailer inventory. These changes will benefit motor carriers by lowering maintenance costs and maximizing vehicle performance.

"Yellow *Pages"* Function With the implementation of "yellow pages," information can be communicated to commercial truck drivers, including such information as trucks stops, available parking at truck rest stops, repair stations, and diesel fuel availability. This will improve on-road time and reduce driver distractions. With two-way communication and ADIS, truckers will be able to make hotel reservations and order food and refreshments while on the road.

Real-rime Routing The later stages of IVHS implementation as they relate to motor carriers involve the implementation of real-time routing. This will allow drivers or dispatchers to specify a destination and have the system pick the optimum route, taking into consideration traffic conditions, roadway geometries, weather, and other factors. Ultimately, AVCS will actually take the driver to his of her destination.

PRESERVING THE NATION'S TRANSPORTATION INFRASTRUCTURE

The U.S. highway transportation system has substantial scope and capacity to move people and freight quickly, inexpensively, and safely. We have invested considerable resources, particularly over the last 35 years, in building and maintaining an elaborate network of high-speed limited access highways that link all portions of the country.

As the lnterstate Highway is nearing completion, there has been considerable discussion of the need to preserve and enhance this transportation infrastructure. This issue is being given particular emphasis by the team preparing Department of Transportation Secretary Sam Skinner's National Policy Statement. It also received particular attention at the Town

Meetings sponsored by the Department of Transportation.

For the foreseeable future, highway travel is likely to remain the dominant mode of personal transportation. Most Americans want to rely primarily on their automobiles for their travel needs. Moreover, the movement of business to suburbs results in commuter and business travel patterns that are often not conducive to the use of public transit. Thus, the automobile will continue to be the primary source of mobility for most Americans. One creditable forecast is that highway traffic volumes doubled on America's highway network from 1.9 trillion vehicle miles of travel (VMT) in 1988 to 3.8 trillion VMT in 2020. Unless improvements to the system are made, this growth in traffic will increase congestion and reduce urban and rural mobility.

At the same time new road capacity will continue to be built (especially in outlying suburban areas of growing metropolitan areas), but the high cost of both land acquisition and construction, and local opposition to further construction in major metropolitan areas will make this a less feasible alternative.

Fresh approaches are needed to address the imbalance between road capacity and demand. We need to find ways to use existing highway capacity more effciently. Solutions to road congestion must encourage greater use of public transit and ride sharing, as well as variable peak-load tolls and other non-traditional highway allocation techniques. Nevertheless, IVHS technologies could increase the capacity of the highway system.

In general, the impacts discussed in this section do not represent dramatic changes, per se, in highway travel or in highway facilities management. Instead, the use of the "smart" technologies make it easier to undertake certain policy actions. In this sense, they are "facilitators" to methods of improving what we are calling "infrastructure management."

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The point needs to emphasized the implementation and use of IVHS technologies will not *replace* the need for new highways on a one-for-one basis. The primary impact of IVHS will be to *improve* the efficiency and capacity of highways that already exist as well as those that must be newly constructed. There will still need to be continued investment in new and expanded highways.

IMPROVEMENTS IN INFRASTRUCTURE FACILITIES MANAGEMENT

IVHS technologies can be expected to improve the management of the existing infrastructure, given its operating limitations, primarily by providing significant amounts of real-time information to the motorist and to the public (or private) operating agencies so that travel can be made safely and efficiently. The information provided by IVHS technologies has three important implications for improved management of the existing infrastructure. First, the Information can make the operations of the system more efficient by more effectively using the available facilities, services, modes, and routes. Second, the efficient operation of the system, because of IVHS technologies, may preclude the urgency or need for major system expansion. Third, efficient operations can also lead to an extension of the life of particular facility, thereby postponing the need for replacement.

Improved management of the existing infrastructure is tied to the efficiencies gained through the use of information provided by IVHS technologies. The real-time information made possible by implementing IVHS technologies can include the following:

- Location of reconstruction and maintenance activities,
- Location of underused or overused facilities and services,
- Identification and location of good operations,
- Identification of restricted or out of service facilities,
- Identification of alternate (detour) routes and conditions,
- Identification of ridesharing and transit opportunities, and

- Monitoring and routing of heavy and hazardous shipments.

By making real-time information readily available, the traveler can identify and quickly select routes, mode-s, facilities, and services to efficiently make his/her trip. To the traveling public, the IVHS technologies allow for an expanded array of opportunities and alternative choices for trip making. Providing real-time information on opportunities for trip making can reduce the traveler's dependence on one particular mode, route, service, or facility. Information from IVHS technologies can lead to efficient trip making.

IMPROVEMENTS IN TRAFFIC SYSTEMS MANAGEMENT

Obtaining, utilizing, and disseminating information made available through IVHS technologies allows the transportation operating agencies (e.g., departments of transportation, local public works departments, transit agencies, police ridesharing agencies, and parking authorities) to exercise more control and coordination over their systems. For example, by quickly detecting and locating incidents, public agencies can reduce the time that it takes to develop a coordinated response that includes establishing emergency operations, designating alternative routes, and managing the traffic control system to allow the alternate routes to handle the increase in traffic volumes.

Public agencies can utilize the real-time data base available from IVHS technologies to increase mode choice and average vehicle occupancies. For example, the technology can provide information to commuters on available carpools, vanpools, and transit services for the particular day and time period that they need to travel. Such a service would allow commuters to utilize the services as needed, increasing the opportunity for casual or informal ridesharing. By providing the opportunities for ridesharing and transit use, vehicle occupancies, especially for the commute trip, can increase.

ATMS affects the management of the existing infrastructure and appear to have more near-term implications. The technology is beginning to be put in place in many urban areas. Examples include:

- Computerized traffic control systems in place at about 20 percent of the signalized intersection locations.
- Adaptive and interactive signal control now in the developmental stages.
- Incident detection and response systems being developed in a number of urban areas.
- Automatic vehicle identification systems that are being used to provide smooth access to restricted highways or for quicker toll collection.
- Identification systems to monitor hazardous cargoes or track stolen cars.

ADIS provide drivers with information on congestion, navigation, and location, traffic conditions, and alternative routes. These systems are the link to the driver, providing him/her with the necessary information on opportunities for trip making. The information could include local accidents, construction areas, weather and road conditions, alternate routes, and ridesharing and transit services. In consort with crash warning systems, information could be provided on potentially dangerous driver, vehicle, road, or environmental conditions. Specific types of ADIS technologies include:

- On-board replication of maps and signs,
- Pre-trip electronic route planning,
- Traffic information broadcasting systems,
- Safety warning systems,
- On-board navigation systems, and
- Electronic route guidance systems.

Much of this technology is in the developmental stages; however, the beginning of its impact appears to be near-term (i.e., less than five years) based upon current demonstrations.

Freight and fleet control operations include technologies and fleet control operations intended to enhance the efficiency of operating trucks and fleets of vehicles. Such systems also improve the efficiency of regulatory compliance, vehicle inspection, and fleet monitoring operations. Several of these types of systems are being used today and many more are being planned for the near future. It appears that the effect of this technology on infrastructure management is near-term.

AVCS technologies help the driver perform certain vehicle control functions. Using data collected by on-board sensors, AVCS provides information to vehicle operators which allows them to make decisions quickly and accurately or which allows action to be taken independent of the operator. Some of this technology has near-term implications, particularly in reducing the number of minor incidents that cause delay and reroute traffic. Much of this technology is longer-term (20 to 30 years) and sophisticated in nature. As the technology develops, it offers the opportunity for more control and management of the infrastructure.

The focus of attention for IVHS technologies in the next 10 to 20 years is likely to be the Interstate highway system. The 43,000 mile system makes up only about 2.6 percent of the roadway mileage in urban areas, yet accounts for about 30 percent of the total travel. Maintaining this infrastructure is essential as travel demands and replacement costs grow. For the 34 highest population urban areas, there are estimated to be presently about 55,000,000 workers using about 50,000,000 autos. These numbers can be expected to grow as we go further into the 90s and beyond. To make the IVHS technologies achieve the desired purpose and create the desired opportunities, it will have to be available in some form to this level of population.

A very desirable purpose of IVHS technologies is to reduce vehicle demand for highway facilities by creating opportunities for more use of carpools, vanpools, and transit. As discussed earlier, IVHS technologies can create opportunities for casual ridesharing and transit use. This can reduce vehicle demands for a highway, thus possibly precluding the urgency or need for major system expansion and/or replacement. It can extend the life of an existing facility and thus save or reallocate the money that would typically go for highway expansion.

For example, it now costs $5 to $10 million a mile to widen a highway by one lane. This would increase capacity by about 1,500 vehicles per hour. By comparison, an effective ridesharing program costs about $500,000 to create 160 vanpools and 150 carpools. This would decrease highway usage by over 1,600 vehicles, thereby reducing or eliminating the need for an additional lane. An effective, well used ridesharing and transit program that can be created through IVHS technologies can have a similar impact on maintaining the existing highway infrastructure in the urban areas.

In summary, IVHS technologies can provide essential real-time information needed by the traveler and the operating agency to expand and efficiently use the choice of modes, services, facilities, and routes available under all circumstances. This would be a significant impact on maintaining the existing infrastructure.

IMPROVEMENTS IN TRAFFIC DEMAND MANAGEMENT AND FINANCING CAPABILITIES

Whether they live in town or in the suburbs, those who dwell in American's metropolitan areas need mobility and have gotten it — until recently. In 1980, about 170 million people live in urban areas in the United States, representing 74 percent of the total population. They made 125 million work trips every day (30 percent of total trips) and with a transit mode split of 8.1 percent; 85.2% take that trip in an auto with door to door convenience. Average trip speed are for auto commuters was 32.5 mph in 1980, which is not all that bad.

But mobility comes at a cost, not only in dollars, but in air pollution, international energy dependence, and climatic degradation. And those multiple costs are weighing heavily on the nation, on transportation providers, and on all transportation funding agencies. The federal government and the state bear most of the dollar costs, with the "feds" taking the lead in worrying about energy independence and the climate. The cities bear the primary burden of air pollution. But nobody wants to compromise on mobility.

IVHS is an emerging and decidedly promising tool for preserving and expanding mobility, without incurring the kind of costs that the added VMT would do based on today's technology. IVHS can mean attractive *shared ride services* which lead to a cascade of benefits, central to which is enhanced mobility. Public mass transportation has been supported by funding agencies and the American taxpayer, but absent the user taxes and land-use designs found in other countries that are more successfully addressing their urban mobility crises. As a result, the U.S. has not succeeded in getting its urban travelers into buses and trains on fixed routes and fixed schedules. But with IVHS, we may increase *average vehicle occupancy* through a host of new IVHS based paratransit services. These new services are likely to eclipse traditional transit services. IVHS will also enhance conventional bus and train service. The potential benefits are enormous.

If we could increase our average urban vehicle occupancy by just ten percent, it would grow from 1.15 passengers per vehicle to 1.27. This should not be difficult. A 10% increase is roughly equivalent to encouraging one out of six people who is now driving to work alone to pool with one other single occupant driver. This action would save over 4 million gallons of fuel each day at current travel levels. And just this modest ten percent improvement in vehicle occupancy in the nation's urban and suburban areas would eliminate the need, at today's travel levels, for at least 5,000 additional lane miles of roadway, which at $10 million per mile would be equivalent to a total of $50 billion.

To visualize these new systems and services, one must go beyond the current idea of a bus or rail transit authority and visualize all the other institutions interested and capable of influencing demand and exploiting new NHS technology. IVHS should be of interest to not just state and county highway departments, but can be seen as a tool to employers, taxi companies, counties, and specialized service providers, regional car and van pooling agencies, transit and paratransit providers, high occupancy toll road operators, shopping malls and downtown business districts, and any other agency wishing for themselves and their employees and customers the benefits of improved access and mobility at lowest cost. The traveler, the planner, the manager, and the vehicle operator are all beneficiaries.

The Traveler The traveler, as a passenger in a high occupancy vehicle, benefits from lower costs, better planning, and easier, more reliable trip making. In home information and interactive IVHS communication devices will allow travelers to prepare and confirm their trip plans based on real-time system information on schedules, fares, and availability. Examples of in-home devices may include analogue radio, analogue and digital "telephone" lines, cable video (CoAxial) cable, "video text" and other electrical, fibre-optic and radio linkages. This same information can be displayed by IVHS in real-time in bus stop shelters, or bus stop signs, at carlvanpool collection facilities, at transfer locations, and at terminals. This information can be automatically displayed at major pedestrian collection sites such as shopping malls, building lobbies, factory entrances, and other employment, social, recreational, and health activity centers. Collection facilities also include parking and pooling locations designed to intercept and collect automobile travelers. Terminals include both locations for transfer between highway modes and between highway and air, water, and rail modes.

IVHS system capabilities can also inform single occupancy vehicle trip planners in their homes about permanent or momentary disincentives to single occupancy travel. This information might include congestion pricing, SOV access restrictions, and high occupancy tolls. At the same time, IVHS can inform the SOV traveler of preferable HOV options, including details of schedule and price.

IVHS input devices in-vehicle and at fixed locations would allow passengers to make and change reservations and in other ways query and inform system managers of their intentions. Interactive IVHS will allow managers to respond with information and actions, including trip specific reservations as well as system adjustments.

In-vehicle information can be customized for HOV vehicles giving *HOV-preferential* response to traffic obstructions. Obstructions such as accidents, breakdowns, construction sites, flood and wind damage, and other roadway interruptions require system and driver response. IVHS can customize information and direction of HOV vehicles. In-vehicle diagnostic monitoring of vehicle systems can measure, predict, and anticipate conditions leading to vehicle malfunction and failure, warning drivers and directing corrective action. Passengers are thus assured of vehicle and trip reliability. In-vehicle fare collection equipment can be programmed to day, hour, route segment, and other system characteristics. Traveler characteristics (E&H, student) trip length, zone and other specific trip maker factors can also be encoded normally and using pre-coded card and passenger counting devices. As a result, passengers can take advantage of a wide variety of fare structures. In-vehicle real-time information on system wide scheduled departure times, on-time and estimated departure times provides for in-route changes of linked trip plans by passengers in response to system changes after travel begins.

Passengers and riders can be informed and entertained by IVHS. Interactive communications that would distract a SOV driver can make a passenger trip more convenient and pleasant. One or two-way links via satellite, distant antenna1 or wayside antennal can permit the conduct of social or business affairs as is now done using cellular phones. Passive communications can inform and entertain passengers as TV now does in some limousines. Lap top computers could upload or download files via in-vehicle systems. All of these features can make the passenger trip more pleasant at a reduced cost. The passenger can conduct "business," making theater and restaurant reservations, obtaining commuter social and cultured information, and preparing and processing computer data files for storage or in-vehicle uploading. As a result, passenger travel time can be made very professionally productive.

Sharing of costs of trip by "pool" driver and occupants is facilitated. IVHS calculates costs to maintain and fuel vehicle passengers by m-vehicle monitoring of fuel consumption, trip time, mileage is automatically, accumulating tolls and other charges and allocating all charges to occupants during trip or monthly. Traveler benefits from HOV incentive pricing. Road user charges such as tolls that favor HOV travels can be passed on automatically and immediately to HOV traveler.

The Vehicle Operator The vehicle transit operator, whether in conventional transit operation or a more dynamic scheduling and/or routing mode is the second major beneficiary of IVHS. The bus driver's ability to maintain a schedule is greatly enhanced by voice and digital information provided to his vehicle from wayside or distant (satellite or antennae) locations. Through on-board comparison with scheduled locations, speeds, times, IVHS provides instructions to driver for corrective actions, if possible. Flexible and dynamic routing and scheduling are increasingly cost effective with improved on-board computer devices. Taxi drivers are currently assisted in finding pick-up and drop-off locations using radio based IVHS. In the future, all HOV "Dial-A-Ride" drivers will be informed by IVHS on-board and system computers can inform drivers and passengers of routing decisions as they are made, particularly if they affect already loaded passengers. Freed from the time and distractions associated with the current "fare collection" duties of bus drivers, IVHS will enable the driver to concentrate on faster, smoother, and safer vehicle handling. Dwell times will be reduced.

Initial route planning for vehicle operators is greatly aided by time sensitive and date sensitive demand information provided by IVHS. Updating at layover points is also possible. This is very important for carpool-vanpoolandparatransit flexibility. Depending on service policy, trips may vary daily as to pickup and dropoffs. Trouble free and detailed instructions may make many SOV drivers willing HOV drivers.

Visual, audio, and mechanical IVHS signals to the driver can greatly enhance safety. Sensors in the roadway and between the HOV and adjacent vehicles can guide the driver in positioning his vehicle, setting speed, and guiding turn and lane change movements. IVHS can, in other ways, warn against dangerous moves and direct safe moves. This advantage takes on increasing importance as HOV speed vehicle size and passenger loads increase.

Management The planner and manager are the third significant set of beneficiaries. Whether dealing with IVHS generated data in the boardrooms or in the dispatching center, improved systems management is promised. IVHS data flow on vehicles, passengers, and road conditions allows the vehicle controller/-dispatcher to meet demand with the lowest cost service available, directing passenger and vehicle flow according to known cost and productivity rates and revenue generation rates. Basic "matching" services directed by a regional, local, employer, or other program, whether fixed or dynamic are better made, faster and cheaper using IVHS technologies. Matches could be made immediately prior to trip making as well as more permanently as is now the case.

Sensitive and flexible IVHS fare structures allow direct and user-side subsidies by public agencies, employers, and educational and social service agencies. Such subsidies can be accomplished on-board, centrally as the trip is made, calculated and "paid" periodically by institutions, or contracted at "fixed price" based on reliable historical data. IVHS aids to on-board fare collection will greatly facilitate market oriented trip pricing. IVHS will be able to code passenger class or trip purposes, such as elderly, student, and other special pass or user-side subsidy information. Combined with location and distance codes, IVHS will allow extremely flexible fares to be computed, charged, and collected, or charged and billed to "smart cards" or centralized accounts.

For the manager of the highway network, real-time IVHS data on flows and capacities of vehicles and people in the system allow central control of the "switches" and "gates" that regulate system operations. The management of both time of travel and speed of travel, optimized for total persons is made possible through identification and monitoring of HOV vehicles using IVHS. System access control, using entry ramps, lane restrictions, speed limits, occupancy-based tolls (collected at gates or on-the-fly) and exit ramp controls are all system switches available to the highway system manager to optimize PMT/VMT. The controls may take the form of physical barriers, wayside signs, or m-vehicle instructions. Historical data, current information on system condition, and wayside or in-vehicle IVHS communications allow the manager to provide variably pricing devices to regulate vehicle flows. Pricing is perhaps the control method preferred over categorical restrictions and exclusions which are less flexible and less equitable.

Emergency response is greatly enhanced by IVHS systems. Managers, knowing location, vehicle type, and road conditions, can dispatch, route, and inform emergency response forces. This feature is important where multiple occupants of HOV vehicles are involved.

In-vehicle and wayside IVHS systems allow monitoring the off-on passenger movements of bus passengers. Vehicle size and headways can be designed to meet varying m-route demand as well as developing broad and long-term O-D and other trip making data bases. Route and schedule planning that is responsible and cost effective is greatly enhanced by IVHS systems. Automatic fare collection using vehicle monitoring, passenger boarding, and alighting information, time of day, passenger class, is instant and affordable. Smart cards can be used and billing of HOV passengers by management using IVHS systems is greatly facilitated. Historical IVHS data allows the planner to predict the consequences of alternative fare structures. It allows the manager to select from very selective and desegregated data specific vehicle and roadway pricing structures based on service and rate of return policies of the service provider(s).

CONCLUSIONS AND RECOMMENDATIONS

CONCLUSIONS

The preceding analysis strongly supports a thesis that there are, indeed, substantial benefits to be gained from deployed IVHS systems.

The assessment demonstrates that benefits increase rapidly as deployment increases. It follows then that early program stages provide benefits best described in qualitative terms while fully developed systems can be judged quantitatively. Of course, partial or incremental installation moves one toward the quantitative end of the benefit assessment scale.

It was found useful to structure the analysis to reflect this conclusion. Thus, the framework is to estimate market penetration of IVHS components at milepost years 1995, 2000 and 2010. In some instances 2020 was an added increment.

Another useful tool was the taxonomy of benefits. This provided a method to capture and classify the very large array of potential benefits, many of which could easily escape casual or hurried review of IVHS complexities. The other taxonomy use was as a vehicle to quickly focus on thematic areas judged to be of highest, or most critical, priority and impact.

An interesting dichotomy developed. On one hand it was found that systems which are to be deployed incrementally over long time periods are hard to judge as to impacts. Conversely, it was learned that component technologies are difficult to deal with in isolation when it is obvious that synergistic interactions of unknown magnitude will take place. However, in spite of these procedural problems, the analysts were able to quantify many of the expected beneficial results with a high level of confidence in the predictions' reasonableness.

A major reassuring finding is that IVHS is not just for urban systems. Numerous benefits were also found for rural areas and for targeted inpacts such as elderly and disadvantaged travelers, fleet operations, clean air, safety, transit operations, infrastructure preservation and tourism.

Overall, there is ample justification to proceed toward IVHS deployment. However, one should realize that this work on cataloging benefits is a relatively short time voluntary effort by an expert group of professionals who have presented a supportable case that the IVHS work is unquestionably worth doing. Nevertheless, there should be some additional effort toward building upon and refining what is presented here. The main objective would be to expand the investigation to help in determining the proper levels of financial, governmental and industrial resource commitment which lie ahead. Regardless, there is already enough evidence at hand to move forward with the first incremental steps.

Some specific findings of interest which were reported follow:

Safety

Prometheus estimates that one-half extra pre-collision second would allow drivers enough evasive action time to avoid 50% of all accidents. The analysts here agree that such an objective is reasonably attainable and, thus, have used that premise as a springboard to estimating some outcomes:

- 14,800 lives lost and $21 billion in accident costs can be prevented annually and lane blocking accidents reduced 11% by 2010.
- Rural areas have the most to gain since 57% of fatal accidents occur in rural areas which is where the speed at collision is likely to be the highest.
- It was demonstrated that specific kinds of IVHS technology can be linked directly to specific collision types and then specific estimates of benefits can result. However, there are additional benefits due to overall system improvements. For example, congestion reduction will smooth traffic flow which reduces rear-end collision experience which further smooths traffic flow. Thus, such an iterative process will provide benefits beyond the finite estimating done thus far.
- Ultimately, if there is to be a fully automatic highway, the system reliability must exceed the present one million safe miles per injury accident in order to be safer. But, at or near 100% reliability the gain will be almost total avoidance of the present huge human and monetary highway traffic accident loss.
- By 1995, there will be a 0.17% total accident reduction.
- By 2000, there will be a 1.70% total accident reduction.
- By 2010, there will be a 18.90% total accident reduction.
- By 2020, 46,000 deaths, 1.7 million injuries and $65 billion in cost will be avoided each year.

Congestion

Traffic congestion has become the bane of modem industrial cities and much attention is rightfully directed to finding ways to alleviate it consistent with a socially desirable objective of safe, fast, and reasonably priced mobility. An interesting finding is that 56% of all congestion is non-recurring. This implies that major improvements are possible if one could monitor dynamic traffic conditions and reliably and accurately inform and advise (and perhaps one day control) the driver.

One estimate is that 39 large U. S. cities incur congestion costs greater than $41 billion annually.

Expected IVHS contributions to reducing this drain on our national resource are:

- In its simpler forms, IVHS can decrease congestion by 15% at a value of $1.2 billion annually. This provides benefit to cost ratios ranging from 1.3 to 3.2 depending on the size of the city. (Just retiming traffic signal networks can make a substantial contribution to congestion relief on arterial streets).
- Fully deployed combinations of advanced traffic management systems and advanced driver information systems can produce congestion decreases ranging from 25 to 40 % .
- Full automation could virtually eliminate vehicle congestion (but, operation of some subway systems suggests that attracted trips would produce new pedestrian congestion).

Operational Benefits

- It is possible nationwide to see a 10% or $75 billion, annual improvement by 2010.
- Congestion relief is expected to result in 10 to 50% fuel savings depending upon individual engine sizes.
- Unchecked traffic congestion is the single most significant contributor to degraded air quality. It is estimated that improvements will be coincident with congestion reduction.
- Congestion relief will be beneficial to transit vehicle operation.
- Demand management and IVHS mobility enhancement need not be competing strategies. Some demand management is required so that excessive induced, or attracted, trips do not destroy the gains made by IVHS.

Enhancing Mobility

Many people believe that IVHS is a strategy for the cities and then, occasionally, as an afterthought acknowledge that safety probably is also a major factor. However, it became clear in the taxonomy development and, later, in the detailed investigation that numerous other factors are also important - thus making the case for the taxonomy.

Some of the higher priority findings are:

- Older and disadvantaged drivers can benefit by having specific devices available to offset some of their incapacities. It is expected that the following market penetrations will occur:
- Heads-up displays - 16% by 2000
- Infrared imaging - 16% by 2000
- Obstacle detection and warning - 30-45% by 2000
- Driver alertness warning - 27 % by 2000
- Radar braking and steering override - 22% by 2000
- On-board replication of maps and signs - widely deployed by 2000
- Multi-purpose two way communication - 50 % by 2010
- Several major areas of impact by IVHS were identified:
- Improved access for the economically disadvantaged
- Improved access to rural residents
- Improved service for tourists
- Improved trip planning
- Enhanced fleet management - It is estimated that 12% or 6.9 billion gallons of fuel can be saved annually
- Improved transit fleet management

Preserving the Infrastructure

There were 1.9 trillion vehicle miles of travel in 1988 and this is expected to double to 3.8 trillion by 2020. Unless some drastic action is taken, this means that several aging highway components will wear out faster than expected. This is in the context of a highway system that is grossly underfunded in meeting its mounting rehabilitation needs. Unmet needs at the moment are at the tens, and perhaps hundreds, of billion dollars level.

- Some important IVHS impacts identified are:

  Improved infrastructure facilities management

Improved traffic systems management. One aspect of this is real time traffic condition information.

Traffic demand management

- An attempt was also made to estimate a scale of the impacts. It is thought that for the next 10 to 20 years most of the IVHS benefits will occur on the 43000 mile interstate freeway system which has 2.6 of urban street miles but which carries 30% of urban travel. In the 34 most populous cities 55 million workers will be using 50 million cars.

It will cost $5-10 million/mile of one lane widening to accommodate an additional 1500 vehicles in the peak hour. The same result can be achieved by spending $500,000 to put the drivers of 1500 cars in van and car pools, or, a far larger result is possible by IVHS techniques. At the moment, reliable per-mile comparable costs are not available but they are likely in the order of $500,000 annually. However, benefit to cost estimates previously cited clearly show that IVHS will produce positive results while conserving resources.

Professional Development

A major research program in an exciting area like IVHS, based on cutting edge technology, would send a signal to the young people of the United States that transportation is a field of the future. It would have the effect of raising the level of consciousness about transportation as a "high-tech*' field in our undergraduate programs, leading to more interest in graduate programs in transportation. Research funds would be helpful in providing assistantships for the talented people we would attract. These people would then go on to make contributions to the transportation field throughout their professional lifetimes. Thus, in addition to the transportation benefits of IVHS implementation, we foresee long-term benefits for the transportation profession and the education and research communities as well.

As with many major research programs, it is expected that there will be positive unplanned side effects. The U.S. Space Program led to the accelerated development of many consumer products, and there is reason to expect that an extensive research effort in will lead to the development of concepts, ideas, and products that cannot be foreseen at this time.

RECOMMENDATIONS

One could seriously question at this juncture what can be legitimately recommended, and to whom, given uncertainties of hardware development, market penetration and a national will to forge meaningful public/private partnerships to improve surface trans portation.

Macroscopically it is now more appealing than ever to assume some extraordinary risks against enormous potential gains. In fact, one might suspect that the risks are not as great as once thought.

Microscopically and specific to these estimations of benefits some recommendations are evident:

- Proceed to initiate a national IVHS program
- Organize policy making and program delivery mechanisms
- Provide adequate funding
- Focus on research, development, demonstration and deployment with initial focus on demonstration project, designed to both field test technologies and to verify estimates of benefits
- Work toward greater quantification of benefits for the component impacted parts of "enhancing mobility" and "infrastructure preservation."
- Plan to communicate to key decision makers these irrefutable findings that IVHS technologies are, indeed, a major way to beneficially gain capacity and safety on America's highways. They may, in fact, be the only way in localities where physical expansion is impossible.

Obviously, the work presented here is only a beginning. The results, though, which were unknown at the outset, provide strong indicators drawn for expert opinion and the literature that IVHS is not "Buck Rogers" dreaming but rather is real and deserves to be part of America's transportation future.

This document represents an initial pass at estimating benefits resulting from IVHS deployment. Clearly, a good deal of work remains and refinement will continue over time. Several areas worthy of particular mention are as follows:

1. The document makes no reference to costs as this was beyond the scope of this initial effort. IN the future, costs and benefits need to be firmly tied together with some sense of their distribution over various groups.

2. In many instances, benefits have been estimated without reference to particular technologies. For more detailed cost benefit analysis, the tie of benefits to specific technologies is appropriate. In terms of this report, we need to fill in the cells of the taxonomy, reflecting benefits for impacted groups for individual technologies.

3. Quantification of benefits was possible in this first pass document for some categories, but for others (e.g., environmental benefits). In the future more complete quantification is appropriate.

4. There is a clear interaction of safety and congestion benefits that is not reflected in this document. That is, as congestion is ameliorated we expect safety improvements to result. This effect was not quantified. Further work is required here.

5. The lessening of congestion due to IVHS deployment will doubtless lead to the attraction of more traffic. A first pass at reflecting this effect appears in Chapter 3. We must continue to refine our approach to this important phenomenon.

APPENDIX A

THE INTERSTATE HIGHWAY SYSTEM

The concept of an "Interstate System of Defense Highways" was first proposed in 1919 by General John J. Pershing just after WWI. The then Lieutenant Colonel Dwight D. Eisenhower took a 62 day trip across the country in 1919 from Washington, D.C. to San Francisco, and concluded that it would be in the best interest of the United States to build an extensive highway system that would provide military access across the country in order to allow for rapid and effective mobilization in the event of another war.

In 1922, General Pershing identified a 56,000 mile "Defense Highway System" which was eventually recommended to the U.S. Congress in 1939 by the U.S. Bureau of Public Roads (now the Federal Highway Adnunistration). In 1944 Congress designated a 40,000 mile Interstate Highway System, but did not authorize funding to implement such a program.

At the conclusion of WWII, General Lucious Clay recommended an interstate highway system to President Eisenhower as being essential to national defense. Both General Clay and President Eisenhower were impressed with the German Autobahn System which was in place before the start of WWII, and they felt that such a system should be a top priority for the U.S.

The Interstate System was formally initiated by President Eisenhower in 1956 when he signed the 1956 Federal Aid Highway Act which established a Highway Trust Fund and designated a 41,000 mile (now a 42,500 mile) Interstate System of Defense Highways.

The Interstate Highway System was inspired by the need to connect critical urban centers for defense purposes. However, as the system nears completion, it is obvious that many unexpected benefits were realized that were not quantifiable in 1956. There are accrued benefits measured in hundreds of billions of dollars that include:

Safety in Design

- Interstate Fatality Rate

  Urban: 1.31 fatalities per 100 million VMT

  Rural: 1.90 fatalities per 100 million VMT

- Non interstate highway fatality rate

  Urban: 2.53 fatalities per 100 million VMT

  Rural: 5.20 fatalities per 100 million VMT

Traffic

- The system represents <u>one percent</u> of the nation's total road and street mileage, but carries <u>twenty percent</u> of all the nation's traffic.

Speed of Travel

- Time savings are substantial for commercial, business and recreation travel.

Economy

- Created new jobs directly and indirectly

  Promoted economic growth and development, directly and indirectly

  A virtual reshaping of the truck industry and logistics/manufacturing interface

Operational Benefits

Environmental

- About 12 percent of the total cost of the system has been devoted to mitigating adverse environmental impacts.

In 1970, the Federal Highway Administration (FHWA) prepared a report on the "Benefits of Interstate Highways" that was transmitted to Congress and subsequently printed for the use of the House Committee on Public Works (Committee Print 91-41, September 1970) (15). That report summarized benefits of the Interstate System in terms of 1) benefits to highway users, and 2) general economic and community benefits of Interstate highways. User benefits included savings in travel time and vehicle operating costs, improved safety, more efficient goods movement, and reduced congestion on other highways within Interstate corridors. Land use changes, improved accessibility, higher land values, benefits to industry and commerce, enhanced nonwork opportunity, and opportunities for community development and economic growth were among the general economic and community benefits discussed.

The general economic and community benefits of Interstate highways are difficult to quantify; in the 1970 report they were evaluated in largely qualitative terms. (In the context of what we are trying to do for IVHS, it is interesting that in 1970, qualitative estimates still dominate the analysis.) Since 1970 several studies have been conducted to try to further quantify community benefits of Interstate highways. Those studies found that economic, social and other community benefits vary from area to area depending on unique local conditions, plans and policies.

The connectivity and high design standards of Interstate highways allow higher speeds and shorter travel times between major centers of population and production than on most other highways. These characteristics have led motorists and truckers to use Interstate highways far in excess of their share of total highway mileage. While the System comprises only 1 percent of all public road and street mileage, it carries nearly 20 percent of all highway travel. The Interstate System is particularly important for interstate commerce; more than 40 percent of ail travel by tractor-trailer combinations is on Interstate highways. While the greater speeds and shorter travel times largely explain the high volumes on Interstate highways, greater safety is one of the most important benefits of the Interstate System. Interstate highways are more than twice as safe as other highways in terms of the number of fatal accidents per 100 million vehicle-miles of travel (VMT). They are four times safer than non-Interstate highways in terms of the number of persons injured per 100 million VMT.

The location of Interstate highways in high travel corridors and the design standards which enhance the speed and safety of travel thus account for the user benefits of the Interstate System.

Benefits of Interstate highways to users in urban areas are not limited to higher speeds and reduced operating costs. Interstate highways have influenced urban development patterns as well, tending to make those patterns more efficient for highway transportation. A 1980 study of the *Land Use and Urban Development Impact of Beltways,* jointly sponsored by the Department of Transportation and the Department of Housing and Urban Development, found that beltways can provide incentives for "nodal" development, mixed-use centers and better transit. Beltway interchanges were found to be favored locations for regional shopping centers, multifamily housing, and industrial and office park development. By attracting these and other large traffic generators, beltways promote development patterns which focus traffic on the highest-capacity, most efficient parts of the highway network and reduce the proportion of travel that must be made on less efficient surface streets.

Improved highway safety is one of the most important benefits of the Interstate System. In 1981 the fatality rate (measured as the number of traffic fatalities per 100 million VMT) on the Interstate System was only 40 percent of the rate on other Federal-aid primary highways. The number of accidents involving personal injury per 100 million VMT likewise was only 40 percent of the number on other Federal-aid primary highways. Based on differences in 1981 fatal and injury accident rates, 6,000 more persons would have died in 1981 and 330,000 more persons would have been injured in traffic accidents if there were no Interstate highways and Interstate travel was on other Federal-aid primary highways.

Operational Benefits

Travel is so safe on Interstate highways because of their high design standards. Travel on Interstate highways has actually become safer between 1970 and the present, despite tremendous increases in traffic and in the proportion of small cars on the road. Improved safety can be attributed to three factors--the reduced speed limit, the improved crashworthiness of vehicles, and the safety improvements that have been made on older Interstate highways to being them up to higher safety standards.

In hindsight, it is possible to identify the benefits derived from the Interstate Highway System.

However, it is clear that :

1. Benefits have accrued that we simply did not foresee in the 1940's and 1950's,
2. The magnitudes of benefits were not well understood, even when the categories were obvious,
3. The virtual reshaping of various industries, specifically the intercity traveling industry and the logistics function, were not foreseen.

Consideration of these factors can be useful to us as we embark on this IVHS Benefits study.

APPENDIX B

SUMMARY OF RECENTLY COMPLETED BENEFIT-COST ANALYSES OF HIGHWAY TECHNOLOGIES

Two recent NCHRF' projects have attempted to quantify both the costs and benefits of specific highway technologies [4] [9]. The summaries of the benefits identified in both studies are summarized briefly below in order to provide the reader with some indication of the difficulties associated with undertaking such an analysis. Both studies used traditional cost benefit analyses based upon accepted methods; the work in both cases is thorough, as exhaustive as possible and based upon the best available data. However, in both cases the authors report that the results must be considered as being tentative because:

- The technologies are still emerging and in many cases untried.
- There is limited demonstration data available to verify many assumptions.
- There is a need to better understand the tangible and intangible benefits that may be achieved.
- We need a better definition of performance standards that must be quantified for these purposes.

Assessment of Advanced Technologies for Relieving Urban Traffic Congestion NCHRP 3-38(l)

In this study [4] the sources used for undertaking the preliminary benefit-cost assessment included information obtained from system vendors, researchers and system users. In addition, existing estimates of potential benefits were used, and simple computer modeling techniques were developed in some instances. Because of the limited availability of data, the report concentrates on assessing those technologies that have the greatest probability of making an impact on urban congestion. Some assumptions had to be made concerning the characteristics of an urban area. For that reason, the Seattle metropolitan area was selected as a typical area and where important data were available for use in this analysis.

Following is a summary of the technologies and systems selected for assessing benefits and costs; and the conclusions reached concerning potential tangible and intangible benefits to be achieved.

1. For Driver Information Systems

The technologies evaluated were:

a. Computerized rationalization of direction signing

b. RDS traffic information broadcasting system

c. Self-contained on-board navigation systems

d. Electronic guidance systems

e. Automatic vehicle identification technology for automated toll collection

Operational Benefits

Following is a list of the tangible and intangible benefits for each of those technologies:

a. For Computerized Rationalization of Direction Signing

Tangible Benefits	Intaneible Benefits
Optimum route identification	Eliminate excess driving
Savings in travel time	Increased driver confidence
Money saved	Intuitive savings

b. For RDS Traffic Information Broadcasting System

Tangible Benefits	Intangible Benefits
Reduce delay from traffic incidents	Reduce accident risk
More efficient detours	Increase driver confidence
Reduce risk of secondary accidents	Reduce driver anxiety
	Improve police patrols
	Improve access for emergency vehicles

c. For Self-Contained Onboard Navigation Systems

Tangible Benefits	Intangible Benefits
Reduce travel time	Improved routing advice
Reduce travel costs to drivers	Better route planning to all who purchase system drivers in general
Reduce congestion	

d. For Electronic Guidance Systems

Tangible Benefits	Intangible Benefits
Reduced travel time	More efficient route choice
Reduced travel cost	Reduce recurring congestion for Individual consumers and Drivers in general
Better traffic data	Better planning methods
Reduce pollutants	Reduce driver stress
Reduce VMT	

e. For Automatic Vehicle Identification Technology for Automated Toll Collection

Tangible Benefits	Intangible Benefits
No cash or ticket handling	Increased motorist efficiency

Operational Benefits

Tangible Benefits	Intangible Benefits
Increase Toll Plaza capacity	Improved administrative procedures
Reduced vehicle delays	
Reduced pollutants	
Reduced construction needs (for Toll Plazas)	
Staffing reductions	

2. Traffic Control Systems

The technologies evaluated were:

a. Optimized vehicle actuation

b. Fixed time coordination

c. Partially adaptive coordination

d. Fully adaptive coordination (SCOOT)

e. Ramp control

Following is a list of the tangible and intangible benefits identified for each of these technologies:

a. For Optimized Vehicle Actuation

Tangible Benefits	Intangible Benefits
Reduced travel time	System efficiency
Reduced travel costs	
Reduced congestion	

b. For Fixed Time Coordination

Tangible Benefits	Intangible Benefits
Reduced fuel consumption	System efficiency
Reduced stops and delays	Improved transit operation
Reduced congestion	Vehicle & pedestrian safety
Reduced travel cost	Improved data collection
Decreased air pollution	Training

c. For Partially Adaptive Coordination

Tangible Benefits	Intangible Benefits
Save fuel costs	System efficiency
Save operating costs	Improved transit operation
Reduced congestion	Vehicle & pedestrian safety
Save time	Improved data collection

	Operational Benefits
Decreased air pollution	Training

d. For Fully Adaptive Coordination (SCOOT)

Tangible Benefits	Intangible Benefits
Save fuel costs	System efficiency
Save operating costs	Improved transit operation
Reduced congestion	Vehicle & pedestrian safety
Save time	Improved data collection
Decreased air pollution	Training

e. For Ramp Control

Tangible Benefits	Intangible Benefits
Reduced delays	Reduced congestion
Reduced fuel consumption	Improved freeway operation
Reduced air pollution	

3. Automatic Vehicle Control Systems

The technologies evaluated were:

a. Antilock Braking Systems

b. Speed control systems

c. Variable speed control

d. Radar braking

e. Automatic headway control

f. Automatic steering control

g. Automated highway system

Following is a list of the tangible and intangible benefits identified for each of these technologies:

a. For Antilock Braking Systems

Tangible Benefits	Intangible Benefits
Reduced number of accidents	Reduced risk of accidents
Reduced accident costs	
Reduced insurance costs	

Operational Benefits

b. For Speed Control Systems

Tangible Benefits	Intangible Benefits
Vehicle operating costs	Driver Comfort Economic Efficiency

c. For Variable Speed Control

Tangible Benefits	Intangible Benefits
Improved safety	Optimize speeds
Improved fuel efficiency	Optimize traffic flow

d. For Radar Braking

Tangible Benefits	Intangible Benefits
Reduce accidents Reduce congestion Reduce rear end collisions	Improve network flow

e. For Automatic Headway Control

Tangible Benefits	Intangible Benefits
Reduce accidents Reduce congestion Reduce fuel consumption	Enhanced comfort and convenience
Increase highway capacity Reduce vehicle operating costs	

f. For Automatic Steering Control

Tangible Benefits	Intangible Benefits
Increase highway capacity	Better utilization of roadway space within existing ROW
Reduced accidents	

g. For Automated Highway System

Tangible Benefits	Intangible Benefits
All Tangible Benefits	All Intangible Benefits

In general qualitative terms, the technologies described above did produce positive benefits relative to assumed costs for implementation. But the research concluded that there are many uncertainties concerning both costs and benefits, which make it difficult to form definite conclusions concerning the justification for implementing those technologies. In spite of those uncertainties, based upon the best possible available data the following three advanced technologies were recommended for further more detailed investigation in future research to be undertaken:

1. Externally linked electronic route guidance
2. The Radio Data Systems (RDS) for traffic information broadcasts
3. Adaptive traffic control based on the SCOOT System

The report concludes that if one assumes " . . . that the methods for reducing congestion discussed in this report cost less than the benefits they provide, they would be cost effective to adopt. However, the problem of allocating costs still remains, and is difficult. It is an especially difficult problem because many of the kinds of savings that can be obtained from these methods are spread thinly and may not be obvious

to the average motorist. People may not be willing to support investments in these measures either individually or through public subsidy. The challenge is to provide information on savings in a way that can be communicated to the average consumer in order to develop the support required. "

Feasibility of National Heavy Vehicle Monitoring System for Commercial Vehicles, NCHRP 3-34

This report [9] concluded that it is cost-effective for states to develop Heavy Vehicle Monitoring applications for data collection, weight enforcement and weigh station clearance, as summarized below.

Use of WIM/AVC for Data Collection

The study found the use of WIM/AVC for data collection to support highway planning, design, and research to be cost-effective. FHWA's Traffic Monitoring Guide recommends sufficient data collection sessions to achieve 95 percent confidence that the mean values of the truck weights observed are within plus or minus ten percent of the actual weight of the truck population. This criterion can be achieved for five-axle, tractor-semitrailer trucks using portable WIM/AVC at temporary sites. If permanent WIM/AVC sites are established, this criterion can be achieved for all vehicles with approximately the same number of sites.

Use of WIM for Weight Enforcement

The study found the use of WIM for weight enforcement screening to be cost-effective. A strategy of allocating enforcement effort to highway segments and time periods in proportion to the volume of heavy-vehicle VMT combined with randomized deployment of primary- and wing-enforcement teams among those highway segments was judged to be most productive. Benefits to the state were measured in terms of reduced pavement damage; net benefits were greatest at about two and one-half times the current level of effort for an "average state." Cost benefit analysis suggested that doubling fees and fmes for overweight travel would be as effective as doubling the level of enforcement.

Use of WIM, AVC and AVI for Automatic Weigh Station Clearance

The study found that the use of WIM, AVC and AVI for automatic weigh station clearance was feasible and cost effective for states and participating motor carriers. A strategy of pre-clearing and bypassing AVI-equipped trucks – allowing the trucks to bypass a weigh station at highway speeds without slowing or stopping – generated the greatest net benefits for motor carriers and states. The "average weight-station state" could expect to break even on its investment in an automatic weight station clearance system if fifteen percent of the statewide heavy truck fleet participates in the program. The primary benefits of an automatic clearance program accrue to participating carriers in the form of lower operating costs from reduced delays. These benefits accrue to legal carriers; clearance programs will have a negligible effect on illegal operators who can detour around weigh stations

APPENDIX C

SUMMARY OF TRADITIONAL METHODS OF BENEFIT'-COST AND COST EFFECTIVENESS ANALYSES FOR HIGHWAY PROJECTS

The professional literature on the topics of traditional "benefit-cost" and "cost-effectiveness" analysis is extensive. However, traditional approaches may not be appropriate for the kind of analysis being discussed in this paper.

Two relatively recent publications provide a convenient summary of both topics, which will be used in this Appendix to set the stage for the development of a "Framework" described in this paper. The first reference is "Benefit-Cost Evaluation, * by Douglas B. Lee (October, 1987) [ll] [12]. The author concludes that the evaluation of capital investment alternatives should encompass assessments of efficiency, effectiveness and equity. Lee defines the three criteria as follows:

"Efficiency The efficiency goal can be stated a number of ways: find the alternative that is most worthwhile, that creates the highest net benefits for society as a whole, that makes the most productive use of the resources available, or has the highest present work. The test for efficiency is marginal benefits equal to marginal costs, along the relevant dimension(s) of output. The most efficient investment alternative is the one for which incremental benefits are greater than incremental costs, no matter which alternative it is compared against. Benefit-cost analysis is the framework for evaluating efficiency, even when some benefits are not amenable to quantification or dollar evaluatton."

"Effectiveness Effectiveness indicators can supplement both efficiency and equity analysis by comparing alternatives along selected characteristics. Measures of effectiveness are directed at how well an alternative works, how well it satisfies the objectives proposed for it, and how it compares on various indicators with other alternatives. The critical requirement for calculation of an effectiveness measure is that it be comparable across all alternatives. Because there is no way to aggregate performance measures across more than one indicator, there is no need for the list of indicators to be either exhaustive or non-overlapping. Each effectiveness indicator is a single independent slice across all the alternatives. Measures of primary output (passengers or passenger miles) can be compared to total or incremental costs, to obtain some useful overall indicators of performance. With multiple objectives, however, cost-effectiveness analysis in the narrow and formal sense has limited application because rarely can costs be uniquely assigned to particular outputs (e.g., the portion of capital cost that produces time savings versus the portion that reduces air pollution). Dividing total cost by any single effectiveness measure implies that only that particular measure has any value, and the rest are worthless. Many effectiveness measures can be constructed, and they can be arrayed in a matrix form against project alternatives, but they cannot be combined into a single summary measure."

Equity Not only is the question of aggregate net benefits at issue, but so is the question of how the costs and benefits are distributed among different groups and locations. Analysts can provide information regarding monetary and in-kind transfers that will take place if one alternative is implemented rather than another, and can propose countermeasures to offset adverse impacts, but it is for the policy makers and the courts to decide what is fair. An "adverse" impact is usually a transfer from poor to rich, or a gain at the expense of a minority or disadvantaged group. Such transfers are clearly regarded as inequitable according to explicit policy guidelines, but the empirical measurement and the means for correcting undesirable transfers are almost never so clear. Equity impacts should be illuminated to the maximum extent feasible, but redistributional and other equity objectives should not be the primary purpose of most transportation investment projects because such investments have only weak potential for discriminating in favor of the needy. "

Operational Benefits

The above summary indicates that a traditional cost-benefit analysis is not always the analytical tool most appropriate to assess complex investment decisions. A more appropriate method may be the use of a cost-effectiveness analysis.

NCHRP Synthesis Number 142 (13) summarizes the methods that are used by State Highway and Transportation Agencies to undertake cost-effectiveness analyses.

When considering whether or not a project should be built, it is important to set priorities for highway projects that consider user and nonuser costs and benefits. One of the measures for prioritizing, particularly for determining the individual merit of a project or most appropriate level of investment in a project, is a cost-effectiveness analysis.

Analysis methods being used by 40 states to undertake cost-effectiveness evaluations were assembled. The various methods reported were then summarized into a series of categories:

1. *Systems Analysis Packages.* This category refers to multifaceted computer-based cost-effectiveness packages.
2. *Sufficiency-Rating-Based Packages.* Several states, already making

   use of sufficiency ratings based on the safety, service, and structural measures of their highways, have added elements of traffic service/congestion and cost of improvements to develop a

   cost-effectiveness index.
3. *Standard Benefit/Cost Analysis.* Benefit/cost evaluations based directly

   on AASHTO's Manual on User Benefit Analysis of Highway and Bus Transportation Improvements are in this category.
4. *Pavement Management Systems.* Many states have developed these systems

   to optimize the use of reconstruction, rehabilitation and resurfacing funds for, say, a lo-year program.
5. *Operations Cost-Effectiveness Measures.* This category refers to the large number of traffic safety and operations improvements.
6. *Construction Cost-Effectiveness Measures,* to develop the most efficient

   construction techniques.
7. *Maintenance Cost-Effectiveness Measures,* to establish cost-effective operations for routine maintenance.
8. *Private Investment Cost-Effectiveness Measures.* Many examples

   are known of private investment in highway projects related to individual private developments. These investments may be made to obtain a variance from zoning regulations, to meet highway department requirements, or simply to make the private development more accessible to motorists.

NCHRP Synthesis Number 142 concludes that although some states have developed and applied practical and very useful analysis methods to develop cost-effective solutions for highway and bridge problems, many have not established systematic methods for doing so. Reasons given include the need to collect and process large amounts of data, inadequate funding for such activities, and lack of acceptance by decision makers. However, most of the states surveyed believe that it would be worthwhile to devote much more time, attention, and money to cost-effectiveness analysis.

APPENDIX D

CATEGORIES OF IVHS - Benefits and Groups Participating in these Benefits

In Chapter 2, Figure 1, we noted broad categories of IVHS benefits and groups participating in these benefits. In this appendix, we present more detailed information on each.

Table 1 gives a more detailed set of IVHS benefits under the major categories of travel, economic, environmental, and information. Table 2 gives a detailed set of participants in IVHS benefits under the major categories of users, general population, and organizations.

We will continue to refine this categorization over time, as system definition matures.

TABLE 1: THE CATEGORIES OF IVHS BENEFITS

A. TRAVEL

Time
- Average (Speed)
- Reliability
- Predictability (control)

Safety
- Fatalities
- Injuries
- Property Damage

Availability/Accessibility
- Routes
- Modes (e.g., ridesharing)
- Services

Comfort
- Stress
- stops

security
- Emergency Services

Cost
- Operating Cost
- Fuel/Energy
- Parking
- Insurance

Distance Traveled
- Vehicle miles of travel

B. ECONOMIC
- Product Innovation
- Sales (Revenue)
- Productivity
  - Improved Shills (Human Capital)
- Competitiveness
  - Supplier Industries (U.S.)
  - International
  - Standard Setting

Economic Development
- Economic Growth
- Improved Standard of Living
- Enhanced Land Use, etc.

C. ENVIRONMENTAL
- Air Pollution
- Noise
- Amenity
  - Guideway
  - Flow
- Meeting Environmental Standards

D. INFORMATION
- Efficiency
- Traffic Enforcement
- Improved Transportation lnvestment and Operating Decisions, etc.

TABLE 2: GROUPS PARTICIPATING IN M-IS BENEFITS

1. USERS (Groups)

People
- Urban
- Suburban
- Rural
- Carless
- Commuter
- Elderly
- Handicapped
- Tourists/Visitors
- Military
- Regions

Freight (Consumers)
- Manufacturers
- Retailers and Other Private

Firms
- Defense

2. GENERAL POPULATION

Other Transportation System Users
- All Categories

Non-Users
- The General population when not traveling, e.g.:
- System abutters
- Enjoying living standard changes
- Changing settlement patterns, etc.

3. **ORGANIZATIONS**

Public Sector Operators
- State DOT's
- Traffic Departments
- Transit Agencies
- Department of Defense
- Authorities (Airports/Toll)

Road/Ports
- Policy/Emergency
- Environmental
- Planning
- School Systems
- Human Service Agencies

Private Sector Operators
- Trucking Companies
- Bus Companies
- Taxi
- Limousines
- Small Package Delivery
- Terminals
  - Freight
  - Air
  - Water
- Emergency Services
- Railroads
- Airlines

Industry
- Auto Manufacturers
- Electronics/Communications
- Auto Suppliers
- Construction
- Academic
- Research
- Energy
- Financial
- Other Industry

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