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WORKING NOTE

The United States Department of Transportation Status' Report on the Automated Highway System Program

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Abstract

Recent research in automated highways has clearly indicated that automated vehicle control technology offers major improvements in the safety and efficiency of existing vehicle-highway systems. With this in mind, Congress included Section 6054(b) in the Intermodal Surface Transportation Efficiency Act of 1991 to enhance and focus the Nation's research into automated highways. The United States Department of Transportation Automated Highway System program responds to that guidance. It is a government-industry-academia collaboration to apply automated vehicle control technology to the existing US highway system to greatly improve the mobility, safety, and quality of highway travel. The efficiency of automated highways is also expected to help conserve energy resources and to be compatible with urban air quality goals.

The Automated Highway System program was initiated in 1992 as part of the US Department of Transportation's Intelligent Transportation Systems program. The purpose of this document is to provide a status report of the Automated Highway System program, in response to Congress' request, as part of the 1994 Appropriations.

KEYWORDS: Automated Highway System, Intelligent Transportation Systems, Intermodal Surface Transportation Efficiency Act of 1991

Foreword

The purpose of this document is to provide a status report of the United States Department of Transportation's (US DOT) Automated Highway System (AHS) program. Specifically, this report is in response to Congress' request, as part of the 1994 Appropriations, for a status report on the AHS program by April 1, 1995 [Senate]:

FHWA [Federal Highway Administration], in consultation with NHTSA [National Highway Traffic Safety Administration], is directed to submit to the Senate and House Committees on Appropriations an interim report by April 1, 1995, describing the AHS program being undertaken in response to title VI, part B, section 6054(b) of the Intermodal Surface Transportation Efficiency Act of 1991. This report should contain a 5- and 10-year strategic plan of the proposed AHS and thoughts on the future implementation of a national AHS; specify goals, objectives, measurable milestones of the proposed AHS prototype; project associated Federal and non-Federal costs; describe the potential performance benefits of the AHS and summarize the key findings resulting from the initial set of precursor system studies; identify and discuss major technical, legal, and policy issues affecting successful implementation; and discuss the public/private sector partnership approach undertaken to implement the AHS. The report should offer recommendations, including any necessary legislation, that may be needed as to how the AHS program should proceed with further test tract [track] experiments, and later, to national operational tests and eventual deployment beyond the legislatively directed 1997 prototype test.

The AHS program was initiated in 1992 as part of the US DOT's Intelligent Transportation Systems (ITS) program. The ITS is responsive to the guidance contained in the Intelligent Vehicle Highway Systems (IVHS) portion of the Intermodal Surface Transportation Efficiency Act of 1991 (ISTEA).

The AHS program is specifically responsive to the language in Section 6054 (b) in the ISTEA:

The Secretary [of Transportation] shall develop an automated highway and vehicle prototype from which future fully automated intelligent vehicle-highway systems can be developed. Such development shall include research in human factors to ensure the success of the man-machine relationship. The goal of this program is to have the first fully automated roadway or an automated test track in operation by 1997. This system shall accommodate installation of equipment in new and existing motor vehicles.

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Executive Summary

The Automated Highway System (AHS) Program has been established to provide the stepping stone into automated vehicle-highway transportation in the 21st century.

This document provides a status report of the U.S. Department of Transportation's (US DOT) Automated Highway System (AHS) program. This report is in response to Congress' request for a status report on the AHS program by April 1, 1995.

Recent research in automated highways has clearly indicated that automated vehicle control technology offers major improvements in the safety and efficiency of **existing** highways. With this in mind, Congress included Section 6054(b) in the Intermodal Surface Transportation Efficiency Act (ISTEA) of 1991 to enhance and focus the Nation's research into automated highways:

The Secretary [of Transportation] shall develop an automated highway and vehicle prototype from which future fully automated intelligent vehicle-highway systems can be developed. Such development shall include research in human factors to ensure the success of the man-machine relationship. The goal of this program is to have the first fully automated roadway or an automated test track in operation by 1997. This system shall accommodate installation of equipment in new and existing motor vehicles.

The AHS program responds to that guidance. It is a government-industry-academia collaboration to apply automated vehicle control technology to the U.S. highway system to greatly improve the mobility, safety, and quality of highway travel. The efficiency of automated highways is also expected to help conserve energy resources and to be compatible with urban air quality goals. And in many cases, these improvements will be made using existing highway infrastructure.

The program focuses on a planned evolution to AHS from today's vehicle-highway system. This transition will be simplified because some of the basic automated vehicle controls needed for an AHS are starting to appear in today's vehicles; use of this technology is expected to increase over the next decade. Drivers will be offered Intelligent Transportation System (ITS) services such as **adaptive cruise control**, which is a cruise control system that maintains a safe following distance from the vehicle in front of it; **collision warning and avoidance** to help

prevent both rear-end and side-swipe crashes; and **lane keeping**, which will hold a vehicle safely in its lane. Similarly, ITS technologies such as infrastructure-to-vehicle communications for Traveler Information Services and Advanced Traffic Management Systems will be deployed in the coming years. The AHS program will build upon and integrate with the evolution of these ITS services to ensure overall compatibility. To this end, current AHS activities are fully coordinated with the ongoing development of a National ITS Architecture. With nationwide planning and infrastructure integration, AHS will become the next logical major evolutionary step in our highway transportation system.

There are substantial issues associated with the role of vehicle-highway automation on sustainable transportation and society in general which must be addressed along with the technology issues of performance, reliability, and affordability. Research focused in these areas is a key part of the AHS program, combined with extensive stakeholder involvement. The program seeks a national consensus of the AHS stakeholders on both the system approach and deployment strategy based on results of this research.

The envisioned AHS would operate properly equipped vehicles under full automated control on dedicated lanes. All vehicles in the AHS lane would maintain a safe operating distance from the vehicle in front, and stay in their lane of travel. With all vehicles in the lane automated, the opportunity for human mistakes and inefficiencies would be significantly reduced. It is currently assumed that many AHS lanes will be adjacent to, and similar to, the other freeway lanes, and entry to it may be similar to entry to some of today's High Occupancy Vehicle (HOV) lanes or toll facilities.

Automation is essential! for our nation's surface transportation system in the 21st century.

Our vehicle-highway system is expected to continue as our Nation's primary mode of transportation for the foreseeable future. Americans also desire "green mobility," that is, more efficient transportation with proper care for the environment and land use.

Our Nation's vehicle-highway system presently carries 89 percent of all passenger miles of travel and 32 percent of the Nation's ton-miles of freight revenue [National Transportation Statistics, 1992]. It is a primary and essential link in our Nation's economy with an in-place infrastructure and societal role which is expected to continue.

It is increasingly difficult for our vehicle-highway system to meet the growing travel demands.

The reality is that the Nation's highway transportation system is rapidly reaching the limit of its ability to handle additional demand and serve the increasing transportation needs of the public and commerce. The increasing daily congestion of our Nation's highways reflects this. This travel demand on our highways is projected to continue increasing into the future.

Automation is one of the most promising approaches for improving vehicle-highway system performance.

The ITS program is investing substantial resources to improve the performance of our current transport systems. ITS is focused on such areas as improved information flow among vehicles, travelers, and the infrastructure, the enhancement of safety and security, and the dismantling of institutional barriers. Over the next decade or so, deployment of the ITS services within a coherent national architecture will result in gains in safety and transportation efficiency. Vehicle-highway automation is the natural evolution of these technology investments, integrating crash avoidance enhancements on vehicles and communication capabilities in our highway systems. The promise of AHS, therefore, is an expansion of the collision avoidance safety benefits and a major performance gain in flow capacity for a given right-of-way compared to today's systems based on manually driven vehicles.

In fact, AHS is capable of providing a level of performance and service that is a generation beyond other ITS services. An AHS can double or triple the efficiency of today's most congested highway lanes while significantly increasing safety and trip quality. An AHS would serve all highway users, opening up new opportunities for transit bus operation, enhancing the safety and productivity of heavy trucks, and offering improved convenience and dependability to the traveling public. Its efficiency can help reduce both fuel consumption and individual vehicle emissions, and will ensure maximum use of our existing highway infrastructure investment.

The AHS also provides near-term spin-off safety and efficiency improvements.

The AHS program is addressing automated vehicle control technology. This technology is increasingly being used in other ITS services to help save lives, reduce crashes, and enhance trip quality. The AHS program research and development is enabling the earlier introduction of these near-term crash avoidance safety products. Further, the AHS program is providing a framework so that near-term use of automated vehicle control technology in ITS services will be consistent with their potential transition to AHS.

A long-term strategic program and partnership is necessary to accomplish highway automation.

The US DOT role is essential to the exploration of highway automation, in supporting long-term, high-risk research and development (R&D) that industry and the States cannot undertake alone. The AHS program is the most comprehensive long-range R&D effort within US DOT focused upon an efficient and safe highway system to carry us through the 21st century. A strategic program for automated vehicle control R&D has been defined and US DOT has formed a public/private partnership to research and define the AHS approach.

The US DOT partnership is with the National AHS Consortium (NAHSC), a team of the Nation's major vehicle/highway system stakeholders--industry, State and local governments, user representatives--who will eventually build, own, operate, and use AHS. If AHS, as a large-scale effort, is to be successfully developed and implemented, this partnership must continue. Neither the public nor the private sector can implement AHS alone or provide all the needed expertise. The vehicle manufacturers must cooperate with the highway builders and operators to develop vehicle and highway instrumentation and equipment that complement each other and gain the full benefits of automation.

The US DOT will continue to facilitate the partnership on a cost share basis with non-Federal partners, and represent the Nation's transportation and societal needs in the NAHSC.

Automated highways enhance our Nation's international competitiveness in the next century.

The U.S. program in highway automation is by far the most focused and comprehensive internationally. This program puts our industry and nation in a global leadership position. Deploying AHS as part of a robust surface transportation system should increase transportation productivity and strengthen our Nation's ability to effectively compete in a global economy. It will provide rapidly expanding new markets for the U.S. automobile, vehicle electronics, and highway construction industries. The markets will grow first with the introduction of more near-term ITS products and services, and then continue to increase with full highway automation. The 20 percent cost sharing commitment by non-Federal consortium partners shows the promise of these new markets.

Results have already shown that AHS holds great promise for addressing most of our Nation's highway transportation needs early in the next century-both the opportunities and the challenges.

The Analysis Phase of this Program has been underway for over two years. Part of this Phase included "Precursor Systems Analyses" (PSAs) that involved in-depth research by 15 industry teams during 1993-1994. The findings show that the promise of AHS is real, although there are clearly many substantive issues and challenges ahead. However, the unanimous opinion of this community of researchers is that no "show stoppers" were found. Many challenges were

addressed, particularly in societal and institutional areas, which are now receiving further attention by the NAHSC, and will be key to national consensus discussions.

Some of the key findings of these analyses are:

- **Travel safety** – this should be significantly better than today’s highways; some estimates were up to 80 percent improvement [Calspan]. This is based on analysis of causal factors in crashes, and of automated reactions that would help avoid inadequate and inconsistent human responses that often result in crashes. However, more investigation is needed to determine how the human driver will interact with the automated system. Human factors studies of the human-automation interface are ongoing, and will be specifically targeted to understanding how to integrate the human role into an AHS.
- **Efficiency** – AHS can increase the number of vehicles traveling on a highway lane by two to three times as driver merging, weaving, unsafe car following and lane changing are eliminated. By tailoring the AHS for transit vehicle, commercial trucks, and High Occupancy Vehicle (HOV) operation, researchers found that AHS can have a dramatic impact on movement of people and goods; it was found that AHS is very supportive of transit vehicle operations. The best means of integrating the volume of vehicles carried by AHS into a regional traffic network so as to ensure an overall increase in transport efficiency, is a challenge that was addressed extensively in the PSA work, and will be the focus of continued NAHSC investigations. For AHS to decrease overall congestion, it must be part of a region’s integrated transportation plan that includes demand management in those urban areas where it may be needed.
- **User comfort and access** – participants in focus groups anticipated far less stress in highway travel on AHS; some concerns for equity of access were expressed.
- **Trip time reliability** – travel times on AHS should be more dependable because of the consistent AHS traffic flow. It was noted that traffic volumes at AHS entry and exit points must be carefully addressed so as to avoid congestion- The researchers concluded that an AHS deployment must be integrated with a region’s other transportation resources.
- **Air quality** – it was concluded that AHS could reduce tailpipe emissions of individual vehicles during travel due to fewer rapid accelerations and reduced congestion, and can fully support alternate fueled vehicles. However, the capacity and attractiveness of an AHS may attract additional vehicular traffic and encourage single occupancy vehicle (SOV) travel. Researchers recommended that AHS deployment be responsive to comprehensive land use planning. In dense urban areas, deployment should be coupled with demand management policies to ensure reduced congestion, and to discourage increased SOV traffic. The environmental impact of larger volumes of vehicles traveling in a concentrated corridor should also be considered in deployment.
- **Mobility** – the AHS may attract the drivers who avoid today’s freeways; this may include senior citizens and the persons with disabilities. A national AHS network would enhance the Nation’s mobility for all users, including truckers. Smooth

transition to full vehicle control, defining a highly reliable and safe system which is also affordable and accommodating nationwide compatibility and local/regional tailoring are examples of system aspects that must be resolved.

- **Acceptance** – the introduction of new approaches and technologies often creates tensions. AHS deployment will face the same challenges that other transportation improvement programs encounter in the planning and approval process. In addition, an AHS deployment will need to face the challenges that are unique to the integration of this new technology into the community.

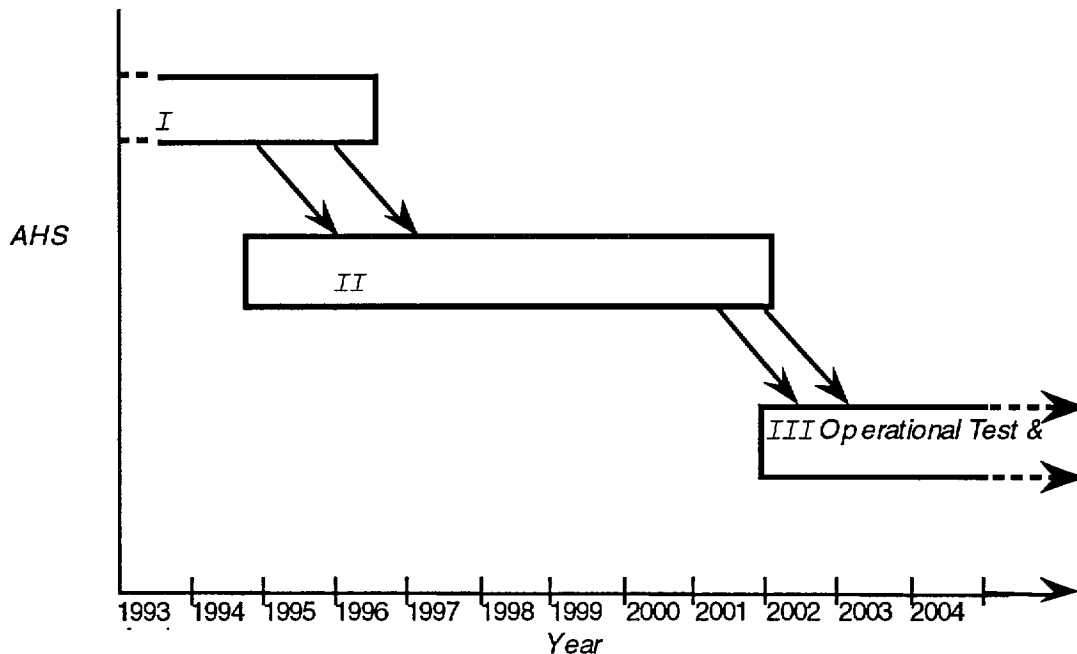


Figure E-1

The National AHS Consortium, a public/private partnership, will objectively choose the approach to highway automation that best meets the Nation's needs.

The AHS program is planned around three broad phases as shown in the Figure E-1. The National AHS Consortium is responsible for conducting the second phase, Systems Definition, which has been underway since late 1994. The talent and perspective of the many stakeholders are fundamental to the program approach in all phases.

- The **Analysis Phase** establishes an analytic program foundation. It consists of:

(1) Precursor Systems Analyses (PSA) by 15 contractor teams that addressed automated vehicle control requirements and issues in 16 areas; (2) a human factors study effort to develop an AHS human factors design handbook; and (3) National Highway Traffic Safety Administration (NHTSA) analyses to investigate other ITS automated vehicle control-based services that avoid collisions through warning and control; these services may be part of the planned evolution into the AHS.

The PSAs identified issues and risks associated with various AHS concepts and design areas. A final conference of the PSA researchers was held in November 1994, and all contract teams have submitted final reports. The National AHS Consortium (NAHSC) is actively using these findings in their research.

In addition to being publicly available through the National Technical Information Service (NTIS), all PSA research reports will soon be available on a CD-ROM and can also be accessed through an Internet connection to US DOT.

- **The Systems Definition Phase** is being conducted by the NAHSC working in partnership with the Federal Government. The consortium includes representatives from the vehicle industry, highway industry, State and local governments, regional and metropolitan transportation agencies, and electronics/communications industries associated with the vehicle and communications market.

The milestones of the consortium program are as follows: (1) establishment of performance and design objectives, (2) a 1997 proof-of-technical-feasibility demonstration, (3) identification and description of multiple feasible AHS system concepts, (4) selection of the preferred AHS system configuration, (5) completion of prototype testing, and (6) completion of system and supporting documentation including a planned evolution from other ITS services.

The AHS prototype will demonstrate the potential of automation applied to vehicles and highways as a system, as well as the potential benefits of a deployed system. The NAHSC is focused on the joint goals of sustainable transportation and improved mobility through prudent and innovative use of technology.

NAHSC activities are in full swing. A Stakeholder Participation program, as part of the broader Outreach effort, has resulted in the acceptance of dozens of organizations as Associate Participants to date, with many more expected to join as the program progresses. Systems requirements development, concept definition and evaluation, planning for the 1997 demonstration, societal and institutional analyses, and exploration of the potential of automation for commercial freight movement and bus transit, are examples of the many areas of intense activity.

- **The Operational Test and Evaluation Phase** is currently not funded. It would logically follow a successful completion of the Systems Definition Phase and include

(1) integrating the preferred AHS system configuration into the existing institutional, technological, regulatory and highway environment; (2) evaluating this configuration in a number of operational settings; and (3) establishing guidelines by which the US DOT will support AHS deployment.

RECOMMENDATIONS

Continue Congressional support for the AHS Program through Phase II until AHS feasibility is determined and the system for the Nation has been chosen.

Since the passage of ISTEA established the program, a national consortium of state/regional transportation agencies, vehicle manufacturers, and highway industry representatives has been formed and is conducting the AHS program in cooperation with the US DOT. These stakeholders are committing their skilled resources and management energies. This momentum must be maintained to realize the promise of the automated highway in operation.

The ISTEA legislation emphasized the 1997 Demonstration as an important milestone; it has been framed in a full program of six major milestones over the next seven years. For this reason, it is imperative that the support for the program go beyond the demonstration milestone.

Therefore, continued Congressional support for AHS in subsequent authorizing legislation is necessary to maintain consistent investment by the non-Federal partners, and to determine the preferred feasible configuration for the Nation.

Establish Congressional support for AHS Operational Test and Evaluation (Phase III)

Beyond the 1997 demonstration is the selection and prototype testing of the preferred AHS configuration. Upon completion of the systems definition phase, the preferred configuration will next undergo operational test and evaluation. The support for this phase of the program is crucial to the successful deployment of AHS. Only through operational testing can the public understand, experience, and appreciate the promise of AHS. As described in Section 6, much of the cost associated with the operational test and evaluation phase will be shared by private sources through public/private partnerships.

Section 1

Introduction

The Automated Highway System (AHS) Program has been established to provide the stepping stone into automated vehicle-highway transportation in the 21st century.

1.1 Purpose

The purpose of this document is to provide a status report of the United States Department of Transportation's (US DOT) Automated Highway System (AHS) program. Specifically, this report is in response to a request in the Senate Committee on Appropriations report accompanying the US DOT and related Agencies appropriations Bill, 1994, for a status report on the AHS program by April 1, 1995:

FHWA [Federal Highway Administration], in consultation with NHTSA [National Highway Traffic Safety Administration], is directed to submit to the Senate and House Committees on Appropriations an interim report by April 1, 1995, describing the AHS program being undertaken in response to title VI, part B, section 6054(b) of the Inter-modal Surface Transportation Efficiency Act of 1991. This report should contain a 5- and 10-year strategic plan of the proposed AHS and thoughts on the future implementation of a national AHS; specify goals, objectives, measurable milestones of the proposed AHS prototype; project associated Federal and non-Federal costs; describe the potential performance benefits of the AHS and summarize the key findings resulting from the initial set of precursor system studies; identify and discuss major technical, legal, and policy issues affecting successful implementation; and discuss the public/private sector partnership approach undertaken to implement the AHS. The report should offer recommendations, including any necessary legislation, that may be needed as to how the AHS program should proceed with further test tract [track] experiments, and later, to national operational tests and eventual deployment beyond the legislatively directed 1997 prototype test.

1.2 Background

The AHS program was initiated in 1992 as part of the US DOT's Intelligent Transportation Systems (ITS) program. This program, which is responsive to the guidance contained in the

Intelligent Vehicle Highway Systems (IVHS) portion of the Intermodal Surface Transportation Efficiency Act of 1991 (ISTEA), is a major government-industry-academia collaboration aimed at applying advanced technology to the US highway system in order to improve mobility and transportation productivity, enhance safety, maximize the use of existing transportation facilities, conserve energy resources, and reduce adverse environmental effects.

Within ITS, the AHS is a user service that applies modem electronics to provide fully automated (hands off and feet off) vehicle control; that is, the vehicle's throttle, braking and steering are controlled by the system. An AHS moves vehicles on dedicated highway lanes in a manner that is compatible with, and evolvable from, the present highway system. The promise of AHS is unique in that it offers major improvements in both the safety of highway travel and in the efficient operation of highways, in many cases using existing highway rights-of-way.

With this in mind, Congress included section 6054(b) in the ISTEA to substantially enhance the Nation's research into automated highways:

The Secretary [of Transportation] shall develop an automated highway and vehicle prototype from which future fully automated intelligent vehicle-highway systems can be developed Such development shall include research in human factors to ensure the success of the man-machine relationship. The goal of this program is to have the first fully automated roadway or an automated test track in operation by 1997. This system shall accommodate installation of equipment in new and existing motor vehicles.

The AHS program responds to that guidance. The objective of the program is to develop an affordable, user-friendly, fully automated vehicle-highway system that is significantly safer and more efficient, and that enhances the quality of highway travel. The AHS is the stepping stone into automated vehicle-highway transportation in the 21st century that will be realized through national deployment of compatible AHS systems.

The Federal Government has a unique role since the Government is not the eventual owner, operator or supplier of the AHS. These will be the roles of the major AHS stakeholders-State and local governments, vehicle, highway and electronics industries, and the system users. The US DOT role is as AHS program facilitator, supporter of longer range research, and representative of the Nation's transportation and societal needs.

The program is being conducted as a broad national public/private partnership between the Federal Government and an AHS consortium composed of the major stakeholder organizations to ensure their participation

To undertake and manage the Federal aspects of the AHS program, the US DOT established the AHS program office within the Federal Highway Administration (FHWA) Office of Research and Development (R&D). The program is closely coordinated with the National Highway Traffic Safety Administration (NHTSA) and the Federal Transit Administration (FTA). One specific area of coordination is with NHTSA's program to develop performance

guidelines for crash avoidance systems that may serve as the building blocks for major AHS subsystems and components.

1.3 Report Organization

Section 2 presents the vision of AHS and why it has the potential for solving many of today's major transportation problems. Section 3 describes the strategy followed in establishing the AHS program. Sections 4, 5 and 6 describe each of the three phases of the program and their associated technical and programmatic issues. Section 7 addresses some of the net benefits of AHS deployment. Section 8 describes some of the key challenges to be faced in achieving a successful deployment of AHS. Finally, section 9 presents recommended programmatic and legislative changes.

In addition to these major sections, four appendices are included: Appendix A gives a brief history of AHS-related research prior to 1992; appendix B lists the members of the contract teams that performed the Precursor Systems Analyses (PSA) described in section 4; appendix C describes some of the Analysis Phase findings including findings of the PSA study efforts; appendix D describes the core members of the National AHS Consortium (NAHSC); and appendix E lists the Associate Participants to Date.

With respect to the specific language found in the Senate Appropriations Report that requested this report (see Foreword), responses are addressed in the following sections:

- “a 5- and 10-year strategic plan . . . and thoughts on the future implementation of a national AHS”-sections 2 and 3.
- “specify goals, objectives, measurable milestones of the proposed AHS prototype”-sections 5.1 and 5.3
- “project associated Federal and non-Federal costs”-sections 4.4, 5.4, 6.4 and 7.3
- “describe the potential performance benefits”-sections 2.3, 2.4, and section 7.
- “summarize the key findings resulting from the initial set of precursor system studies”-sections 4, 8, and Appendix C
- “identify and discuss major technical, legal, and policy issues affecting successful implementation”-section 8.
- “discuss the public/private sector partnership approach undertaken to implement the AHS”-section 5.
- “offer recommendations . . . that may be needed as to how the AHS program should proceed with further test track experiments, and later, to national operational tests and eventual deployment beyond the legislatively directed 1997 prototype test”-section 9.

Section 2

Vision of the Automated Highway System

Vehicle-highway transportation will continue to be the backbone of the nation's transportation system well into the 21st century. Automated highways are the key for the increased vitality and social acceptability of this system.

An efficient, robust surface transportation system **is** essential to the United States. Vitality of the Nation's commercial growth, international competitiveness, national security, quality of life, social fabric, lifestyle, and even its world status all depend on transportation mobility; that is, easy access to reliable, dependable, affordable, extensive transportation.

There is a strong demand for quality ground transportation in the United States. Vehicle-highway transportation, the core of which is the Interstate Highway System, is a major element of today's United States transportation, carrying 89 percent of all passenger miles of travel and 32 percent of the Nation's ton-miles of freight revenue [National Transportation Statistics]. The demand for quality transportation is expected to continue increasing. Even if there is major growth in light and heavy rail traffic, the vehicle-highway system is expected to play a major role in meeting the Nation's surface transportation demand in the 21st century [Deen].

2.1 Today's Vehicle-Highway System Faces Growing Problems

Today's vehicle-highway system-with its 4 million miles of streets, roads, and highways and its 190 million vehicles-functions surprisingly well [Deen]. However, it is not keeping pace with **society's** increasing transportation needs. The total vehicle miles traveled (VMT) in the Nation is predicted to nearly double by the year 2020, and our population will be half again as large by the middle of the 21st century [Shucet].

The vehicle-highway system, then, must continue to be improved for the foreseeable future. The system must be able to address a number of problem areas; many of today's transportation problems will continue to grow with the increasing demand unless steps are taken to resolve them:

- **Safety** – although traffic fatalities continue to decrease, there are still approximately 40,000 lives lost annually on the Nation's roads and highways, and there are over

1,700,000 serious disabling injuries [FARS and GES, 1992]. The annual cost to the Nation in dollars is estimated at over \$137 billion.

- **Congestion** – traffic volume has increased between 38 and 54 percent for each of the last three decades. Since capacity has not kept pace, 70 percent of all urban interstate peak-hour traffic is congested, and this figure is predicted to grow to 80 percent by the year 2000 [Highway Facts, 1991]. It is projected that congestion will worsen by 300 to 400 percent over the next 15 years unless significant changes are made.

Today, congestion costs the Nation an estimated \$100 billion in lost productivity annually. It also increases driver frustration and discomfort as congestion worsens and travel times become less predictable. Moreover, shipping costs rise as delivery times become less reliable.

- **Air Quality** – as population mounts, traffic volume and congestion will worsen, and clean air requirements will become more stringent. The key emissions produced by individual vehicles have decreased between 70 percent (oxides of nitrogen) and 100 percent (lead) since 1970 [Deen, 1994]. Nevertheless, the vehicle-highway system is still one of the largest contributors to air pollution in urban areas, as a result of increases in VMT, vehicles idling in congestion, and the driving habits of the vehicle operators. The Nation's concern is reflected in the Clean Air Act (CAA) and amendments, which have established emission guidelines that must be considered in transportation planning.
- **Trip Quality** – trip quality for many United States drivers and passengers continues to erode. The reasons for this erosion include safety concerns, driver frustration and discomfort as congestion increases, and lack of predictable trip times. Also, some drivers, including the elderly, are intimidated or frightened by freeway travel.

2.2 Drivers Limit Improvements to Today's Highways

The vehicle-highway community has continually improved the system. Improvements in highway design, traffic management, and vehicle safety design have allowed modern freeways to sustain passenger vehicle flow rates of up to 2,200 vehicles/lane/hour, while decreasing the number of fatalities per 100 million miles traveled by 30 percent, from 2.6 to 1.8 (FARS, 1992). And, as noted above, emissions per VMT have been reduced substantially.

The ITS program is investing substantial resources to improve the performance of our current transport systems. Other elements of ITS are focused on such areas as improved information flow among vehicles, travelers, and the infrastructure; and the dismantling of institutional barriers. For example, in-vehicle traveler information services are developing approaches for communicating between the roadside and vehicles. Additionally, automated vehicle control is being applied on a limited basis for services that extend the convenience and safety of cruise control, and that assist the driver in avoiding collisions, both frontal and side.

The AHS represents a natural evolution of these ITS vehicle communications and control technology investments. The AHS program addresses the causal factors of today's crashes such as driver reaction times, visual abilities, inattentiveness, and fatigue. These are major contributors to collisions and congestion on our Nation's highways, accounting for about 90 percent of today's crashes [Indiana Tri-Level Study]; and they limit lane flow rates to today's levels.

2.3 Vehicle/Highway Automation Will Address These Problems

A significant body of research strongly suggests that the application of modern technologies to automated vehicle control on our highways will dramatically impact our Nation's vehicle-highway transportation system by improving the safety and efficiency of highway travel for a broad spectrum of vehicle types, including passenger vehicles, heavy trucks, and transit vehicles. Projections of double or triple the safety and efficiency of today's highways have been made [Calspan]. This impact would be comparable to that of the jet engine on aviation 40 years ago, or that of the word processor on the office 15 years ago. In sheer economic terms, if the AHS even approaches these kinds of benefits, this program will represent one of the most productive Federal investments ever made. [Slater, 1993]

AHS use will be simple. Drivers of vehicles equipped for AHS will enter into special, designated lanes-perhaps similar to today's high occupancy vehicle (HOV) lanes-at which point control of the vehicle's forward and sideways movement will be assumed by the system. The assumption of control may be somewhat similar to the way the "cruise control" feature on today's vehicles assumes control of the vehicle's throttle. With AHS, control of the vehicle's braking system will also be assumed to ensure safe distancing from the AHS vehicle in front; control of the vehicle's steering will be assumed as well so the vehicle will remain in its lane. When the vehicle reaches the exit selected by the driver, it will be moved into a transition area where the driver will again assume control and continue driving on his or her trip.

By assuming vehicle control, the AHS provides a major new approach for use by transportation planners as they address these problems. Below, the goals toward which the AHS will be designed, developed, and deployed are given along with examples of some AHS characteristics that will meet these goals:

2.3.1 Driving Safety Will Be Greatly Improved

The AHS will greatly reduce human-caused crashes for vehicles operating in dedicated AHS lanes. Given that today's number of vehicle and system failures and external intrusions remains constant, the AHS should improve the safety of highway travel by up to 80 percent on AHS facilities [Calspan]. Specific goals include the following:

- Eliminate driver error by providing full control of the vehicle while in AHS lanes.

- Allow no collisions under normal operation (i.e., when there is no system malfunction or outside intrusion, such as an earthquake).
- Should there be malfunctions, the AHS will incorporate fail-soft and fail-safe designs. Fail-soft and fail-safe designs have been used successfully in the defense/aerospace industry to minimize the effects of risks to the system. AHS will be designed to minimize the number of crashes that occur and to minimize their severity.

2.3.2 More Vehicles Can Be Accommodated on Today's Highways, Even in Adverse Weather

The AHS will reduce congestion by using today's highway rights-of-way more effectively. AHS lanes could have double or triple the flow rate (measured in vehicles per hour) of manual lanes. Also, because in some instances AHS lanes can be narrower, it may sometimes be possible to add more lanes to an existing highway right-of-way. In dense urban areas, to ensure that the added capacity from AHS results in congestion reduction rather than increased VMT, the AHS implementation may need to be coupled with demand management policies. Specific goals include the following:

- Allow safe operation at increased traffic density and speed per lane because of the tighter operating tolerances possible with fully automated control.
- Provide smooth traffic flow control:
 - Provide uniform driving performance by eliminating traffic flow variances caused by human distractions, and by reducing accelerations, decelerations, and weaving.
 - Manage entries and exits so that AHS lanes maintain optimum speed and spacing in heavy-demand traffic.
- Provide effective, safe traffic i-low in adverse weather conditions, including immunity to many weather-related slowdowns (e.g., fog, glare from the sun).
- Maintain tight tolerances on AHS steering accuracy so that AHS lanes can be narrower than manual lanes, thus allowing more lanes of traffic on existing highway rights-of-way than is the case today.

2.3.3 Fuel Consumption and Emissions Can Be Reduced

The AHS, when coupled with policies that are aimed at limiting growth of VMT, will help meet the Nation's long-term air quality goals. The AHS will be used by environmental and transportation professionals to (1) reduce emissions per VMT, and (2) enhance the operation of other pollution-reducing transportation approaches. Specific goals include the following:

KEY TARGET AHS SYSTEM CHARACTERISTICS

The AHS is being designed to incorporate the following key characteristics:

- **Affordability.** The AHS must be affordable and cost-effective to users and operators.
- **User Desirability.** The AHS must be practical, desirable, and user-friendly.
- **Consistency with Surrounding Non-AHS Roadways.** AHS operation must integrate with adjacent connecting non-automated traffic operations, and be consistent with the continued efficient operation of those roadways.
- **Dual-Mode Vehicle Instrumentation:**
 - Only vehicles instrumented for and operating under full automated control will operate on AHS roadways.
 - AHS-instrumented vehicles will be able to operate on regular (non-instrumented) roadways, and use some of the AHS instrumentation for safer operation including collision avoidance.
 - A design goal is that it be possible to retrofit future vehicle models with AHS instrumentation.
- **Reliable, Modular System Technology.** The AHS must be highly reliable and modular to accommodate continuing advances in technology.
- **Evolvability.** The AHS will not be a standalone system; it will evolve from and integrate with today's vehicle-highway system, and other transportation services; the driver's role will evolve as AHS evolves.
- **Support for Various Vehicle Types.** The AHS will support all normal vehicle types, including cars, buses, and trucks, although not necessarily intermixed.
- **Freeway Type of Roadway.** In general, an AHS roadway is expected to have freeway characteristics.
- **Intermodality.** AHS must reflect the intermodal nature of our surface transportation system; consideration must be given to ensure convenient transfer between modes such as private vehicles and public transportation.

- Ensure reduced fuel consumption and tailpipe emissions per VMT for internal combustion engines through smoother vehicle operation (fewer accelerations and decelerations), reduced congestion, and automated monitoring of emissions performance.
- Support and enhance the operation of all alternative propulsion systems; also, provide a base upon which roadway-powered electric vehicle (RPEV) systems might feasibly be developed.

2.3.4 Quality of Travel Will Be Improved

The AHS will make highway travel less stressful and more enjoyable than travel on today's highways. Specific goals include the following:

- Enhance personal mobility, particularly for the elderly or drivers who, for whatever reasons, **may tire** easily or have difficulty dealing with the stress of freeway driving.
- Increase travel comfort compared with today because there will be a feeling of increased safety and less frustration due to congestion and/or unreliable travel.
- Reduce the strain of driving on crowded, high-speed highways.

2.3.5 Trip Time Reliability Will Be Greatly Enhanced

Transit operators and commercial shippers, as well as the public at large, will be able to count on more reliable trip times. This should help make transit operations more desirable and should help reduce transportation costs for industrial concerns, particularly those using "just-in-time" inventory control.

2.3.6 Traffic Demand Management and Transit Will Be Enhanced

The AHS will support and enhance community travel demand management policies, such as HOV lanes, congestion pricing, and extensive transit use. AHS also will provide a base upon which a feasible "dual-mode" transit system could be built. "Dual-mode" denotes the capability for automated operation on the AHS lanes, and normal manual operation on residential streets. **When** automated transit vehicles are operated on dedicated lanes, their operation becomes similar to light rail. But the dual-mode transit vehicle has the capability of normal manual operation when not on the AHS transit vehicle route.

2.3.7 Trip Times Will Be Reduced

AHS users can expect dependably shorter trip times due to reduced congestion and smoother traffic flow. Potentially higher operating speeds may provide shorter trip times in rural areas.

2.4 The Automated Highway System Will Provide Major Benefits to All Stakeholders

The AHS must be viewed as a desirable option for vehicle-highway system enhancement by all of the system stakeholders—those who will design, develop, deploy, operate, and use the AHS. In achieving the goals outlined above, the AHS must provide major benefits to all of these groups, including users, communities, State and regional transportation agencies, United States industry, and society as a whole.

2.4.1 Users

The AHS will make travel more desirable to users than travel on today's highways. It will do so by providing the benefits of safety and trip quality that were previously described.

2.4.2 Communities

The AHS, when integrated with a community's land use plans, will provide an alternative for meeting the community's transportation needs. AHS could have several specific benefits including:

- A decrease in the additional land needed for highway rights-of-way by allowing increases in traffic flow to be handled on existing rights-of-way.
- Less need for emergency services (e.g., fire, rescue, emergency room treatment) because of fewer accidents on the highway. Better response times from these services (including police) when they are needed in the community due to the increased efficiency of the transportation system.
- Increased efficiency for State and Metropolitan Planning Organizations (MPO) programs to reduce VMT, including transit, HOV lanes, and demand pricing.

2.4.3 State and Regional Transportation Agencies

The State and regional transportation agencies are key stakeholders in the AHS. For them to integrate AHS into their planning activities, they will need to view AHS as a desirable, cost-effective investment alternative that will help them meet regional land use goals and transportation needs. AHS will need to be incorporated into the State Implementation Plans (SIP) and regional or local Transportation Implementation Plans (TIP).

The AHS will provide the following benefits:

- A long-term upgrade for major highways that smoothly transitions from today's vehicles, highways, and drivers.
- Smooth installation and practical operation through automated design, deployment and maintenance approaches.

- Favorable return on investment compared with other transportation options.
- Less new construction.
- Integration with and support for transit operations by providing enhanced support to transit vehicles and other HOVs.
- Integration with other ITS services.

2.4.4 United States Industry

The AHS will also offer major benefits to industry:

- All vehicle manufacturers, highway construction firms, and vehicle electronics companies will enjoy substantial, long-range market opportunities, both in the United States and in other countries, because of open architectures and interoperability standards.
- Trucking firms will benefit from safer highways and more efficient roadway operations, particularly more reliable point-to-point travel times, that will translate into realistic just-in-time inventory control and lower operating costs.
- Industry in general will benefit from increased transportation reliability, mobility, and flexibility.
- Our national expertise in high technology systems, resulting from several decades of defense and aerospace research and development, can be applied to this new application.

2.4.5 Societal Interests

This long-range AHS effort can also be expected to provide benefits that address the Nation's societal needs:

- Reduced fossil fuel consumption and emissions per VMT.
- Support for response to national emergencies, both civil and national defense.
- Support for enhancing the Nation's robustness and vitality.

2.5 The Evolution to Automated Control Has Begun

The evolution to automated vehicle control has already begun. Today's cruise control feature provides a rudimentary form of automated control by controlling the vehicle's throttle and transmission to maintain a constant speed. *Adaptive cruise control* is a control enhancement. It extends cruise control by sensing the vehicle in front and maintaining a safe separation from

that vehicle through control of the throttle, transmission, and braking systems. Another example of control enhancement is **lane keeping**. This feature controls the vehicle's steering to keep it in its lane. It is used today in some transit systems in Europe. Usually, the driver can turn these features on or off as he or she chooses. Both the adaptive cruise control and lane keeping features have been demonstrated and are expected to enter the automobile marketplace soon.

These examples highlight areas where work is being conducted in automated vehicle control. Work is being conducted by both the automobile industry and by the research community. Because of its proprietary nature, information regarding the work being conducted by the automobile industry is somewhat limited. It is known, however, that the automobile industry is researching such advanced topics as adaptive cruise control, collision avoidance, and steer-by-wire systems. In the research community, the University of California Partners for Advanced Transit and Highways (PATH) program, with sponsorship from the California Department of Transportation (Caltrans) and FHWA, is studying several of the fundamental technologies necessary for developing automated highway systems. A major focus area of the PATH approach involves specially equipped vehicles following magnetic reference markers embedded in the lane center of the pavement. The Carnegie-Mellon University (CMU) Robotics Institute, sponsored by the Department of Defense (DOD), is a world leader in autonomous vehicle control technologies, with vision-based control a major focus area for this work. An experimental CMU vehicle recently completed a cross-country test drive, with automated steering control successfully keeping the vehicle in its lane 97 percent of the time. These are just two of the examples of active programs in the research community.

As highway automation research and development progresses, both through independent research and the AHS program, spin-off technologies will enable the more rapid development and earlier deployment of collision avoidance products, which will save lives and reduce crashes in the near term. Examples of spin-off technologies such as adaptive cruise control and lane keeping were described above. These interim products will provide near term market opportunities for business and gradual exposure to automation to the public. Increasing levels of automation will be seen as part of a natural evolution.

Current efforts in automated vehicle control shows that there is already sufficient interest for some of the key stakeholder groups to invest some of their own resources into technologies relevant to AHS. In addition, these efforts show that AHS will be building upon continued work in the area of automated vehicle control-not starting from scratch. A long-term strategic plan is required that will incorporate these interim technologies in "planned" evolutionary deployment stages that lead toward full AHS. The AHS program will develop and implement this plan.

The greatest benefits will come when both the longitudinal and lateral movements of the vehicles is automated and the vehicles operate in dedicated lanes. This is because human errors and inefficiencies cannot disrupt the operation. It is this type of fully automated operation upon which the AHS is based.

The Concept of AHS is Not New

The concept of automated highways is not new, in fact it has been around for quite a while. The General Motors (GM) Corporation pavilion at the 1939 World's Fair presented a futuristic vision in which vehicles moved under automated control along the road.

Popular Mechanics also depicted futuristic visions of a vehicle-highway system in which vehicle movement would be mechanically controlled, and passengers could enjoy the scenery as they were moved along an automated guideway.

Earlier studies in automated highway systems concepts were limited to the technology available at the time. In the late 1950s, research into automated vehicle control was conducted by various industrial organizations, Government agencies, and academic institutions, both in the United States and abroad. These approaches were based on mechanical control. By the early 1960s the first transistor computers had appeared. Then and in the 1970s researchers began to think of potential uses of computers at the roadside to provide traffic management, as well as lateral and longitudinal control. It was then that the research began to consider the feasibility of an overall network of automated vehicles operating on a highway system. However, the size and processing power of the computers at that time presented problems for a feasible automated highway.

With the advent of microprocessors, microelectronics and micro-sensors, the concept of automated highways is again being addressed, but with major processing power on-board the vehicle. With sponsorship from the California DOT (Caltrans) and FHWA, the University of California PATH program has carried on substantial research efforts in highway automation from the late 1980s through the present. In addition to the PATH work, technologies initially developed for the DOD are being researched for possible application to vehicle-highway systems. Other Government agencies including the Department of Energy (DOE) and the National Institute of Standards and Technology (NIST) are studying technologies applicable to AHS. (See Appendix A for a more detailed description of AHS history.)

The United States is not the only country with visions of automated highways. Automobile manufacturers in Europe and Japan are performing internal research into advanced vehicle control technologies (e.g., adaptive cruise control, steer-by-wire). In addition to this internal research, both the Japanese and some European governments are funding programs in the area of advanced vehicle control.

In the United States, the AHS Program is the next, and most feasible, step toward realizing the dream of automated highways.

2.6 The Automated Highway System Will Integrate With Other Transportation Services

The AHS will not be a stand-alone system; it will evolve from and integrate with other transportation services. It will allow safer, more efficient highways to be built that help planners meet a region's land use plans and environmental guidelines.

The overall AHS program will provide national standards and specifications to ensure that AHS vehicles from New York, for example, are able to operate on AHS systems in Oregon.

Within a region, the AHS will be integrated within the existing ITS architecture, and will be tailored by State and regional transportation and environmental planners to meet their community's transportation needs.

Tailoring of the AHS will be extensive since AHS technology can be adapted to a variety of transportation services. The AHS will support passenger cars, trucks, buses in a varied array of highway configurations; an AHS system could be designed to support all four-wheeled (or greater) vehicles, either intermixed or on exclusive lanes. Below are some examples:

- **Heavily Congested Urban Highway** -AHS lanes could be implemented to alleviate the daily congestion found on many of the nation's highways. The primary focus of these lanes would be to service the recurring congestion during morning and evening peak periods and beyond.
- **Exclusive Transit Vehicle Lanes** – separate lanes could be set up for transit vehicles on certain highways; for example, a reversible express bus lane could be established on a major artery in a large urban area. AHS would allow the vehicles to operate more efficiently and safely, and with greater trip predictability. The exits could correspond to parking lots and/or to terminal points for local transit vehicles. “Dual-mode” transit vehicles will enable the route flexibility that riders demand.
- **Only High Occupancy Vehicles (HOV) in Rush Hour** – because of limited parking and street space in many central business districts, transportation planners could decide that only vehicles with multiple passengers, including transit vehicles and Vanpool and Carpool vehicles, would be able to use the AHS lane(s) in rush hour.
- **Exclusive Commercial Vehicle Lanes** – in areas of high truck traffic, such as between major east coast cities, separate lanes could be established for heavy vehicles. As with the transit vehicle lane, the AHS technology would ensure safe, efficient movement of goods with far greater trip predictability. The lanes could be extended into nearby docking facilities.

- **Sparse Rural Areas** – AHS-equipped vehicles on rural roadways could be designed to operate intermixed with non-AHS vehicles to help prevent the two major causes of rural crashes-animals and road departure. The AHS equipment would maintain a safe distance from the vehicle in front and help detect obstacles, including large animals, in the roadway. It would also help the driver keep the equipped vehicle in its lane and avoid road departure crashes. The driver could choose to turn the AHS services on or off as desired.
- **Roadway Powered Electric Vehicles (RPEV)** – a region could stimulate the electric vehicle market by supplying power from the roadway to keep the vehicle moving without draining the vehicle's batteries. The vehicle would continue off the highway via battery power. Since there is possible correlation between the hardware necessary for RPEV and AHS, the incorporation of RPEV into an AHS system seems to offer substantial benefits for an RPEV system.

2.7 Our Future Automated Highway System

Automated highway technology is seen as the next major upgrade to the Nation's highway system. Planning for this national network will include (1) national standards to ensure compatibility among the individual AHS systems; (2) an AHS overlay on the Interstate Highway System; and (3) a national system of signing and conventions for automated highway travel. The AHS will be implemented one system at a time by State and local agencies to meet their individual community needs; however, each individual implementation will also be a part of the US DOT's plans for the nationwide network of automated lanes within today's Interstate Highway System. It is in this way that the US DOT can ensure that our massive investment in the Interstate Highway System is enhanced and the Nation's highways remain robust and responsive as demand increases through the first half of the 21st century. The architectural structure of our automated highways will emphasize flexibility and modularity so that the basic system can continue to be enhanced and expanded throughout the next century.

POSSIBLE AHS HIGHWAY CONFIGURATIONS

The AHS technology allows for adaptation to a range of configurations to suit local needs:

- **Mixed AHS and Non-AHS (Rural)** - AHS-equipped vehicles operating with non-AHS vehicles on non-AHS roads under partial control (e.g., adaptive cruise control, lane keeping).
- **Mixed Light and Heavy Vehicles (Rural)** - Single AHS lane supporting mixed vehicles, with occasional passing lanes.
- **High-Speed Dedicated AHS Lane (Rural)** - Low-density-traffic, high-speed lane, with infrequent entry and exit points and enhanced obstacle detection (for animals).
- **Higher-Density Lane (Urban)** - Higher-density lane operating under increased control to achieve optimum speed for maximum throughput,.
- **Multiple AHS Lanes (Urban)** - Multiple lanes with lane-changing ability, possibly with lanes dedicated to different performance levels, such as heavy vehicles or transit vehicles.
- **Central Business District** - High-density, slower-speed lanes with frequent entry/exit points.
- **Reversible HOV Lanes** - Reversible, dedicated HOV lanes at peak hours, possibly trucks in off-hours.
- **AHS Lanes Dedicated to Special Vehicles** - Lanes dedicated to transit and/or commercial vehicles, as well as guideways dedicated to light (or very light) AHS vehicles.

Section 3

Automated Highway System Program Overview

A national public/private partnership will objectively choose an automated highway system that best meets the Nation's needs and allows for full and open competition in its testing and deployment. This system will revolutionize highway travel.

3.1 Program Strategy

The US DOT strategy is to use a public/private partnership between the US DOT and a consortium of the key AHS stakeholders to select the AHS concept and approach **for** operational testing and eventual national deployment in the United States. The intent is to build upon AHS research to date, and to make maximum use of state-of-the-art technologies in information systems, communications and sensors developed for the defense/aerospace industry or others. This Nation is riding the crest of an information technology wave that is revolutionizing virtually every aspect of American life, including how we work, entertain, and travel. The AHS is a recent, but very important addition to this information technology revolution. It will use this technology to solve some of the Nation's major highway transportation problems. As part of ITS, AHS will be compatible with, and operate within the National ITS Architecture being developed under US DOT's National ITS Architecture program.

The public/private partnership is a necessary part of the AHS strategy. If AHS-as a large-scale effort-is to be successfully developed and implemented in today's diverse, specialized society, links must be forged, collaborations founded, and partnerships established. Neither the public nor the private sector can implement AHS alone. Neither defense contractors nor the transportation industry can provide all the needed expertise. The vehicle manufacturers cannot build AHS without cooperation of the highway builders and operators since vehicle and highway instrumentation must complement each other. The researchers and engineers cannot proceed without input from the users.

The NAHSC is a shared-funding partnership (80 percent Federal funding, 20 percent private funding) that is implementing the AHS program and providing leadership to the diverse interests involved in solving the Nation's transportation problems using automated vehicle control technology. To give this consortium a head start, a set of US DOT-funded independent studies have been conducted to identify the major AHS requirements, issues, risks and

approaches. These studies supplement earlier, as well as on-going, research into automated highways.

The US DOT has guided the consortium structure to (1) ensure that there is a balanced representation of the major stakeholder categories; (2) ensure that all interested, relevant parties may join in the consortium at varying levels of participation; and (3) solicit input from all that may be affected by AHS through national outreach efforts. US DOT has also ensured that 35 percent of all Federal funds are to be used for competitive procurement of services and goods from non-consortium members, and that small and disadvantaged businesses as well as historically black colleges and universities be given full opportunity to participate in these procurements.

The selected AHS approach will be chosen collaboratively by the stakeholder members of the consortium in concert with the US DOT, with full consideration of all interested parties and their needs and concerns. The selected system will be specified to such a level that (1) there is compatibility among all AHS systems installed throughout the Nation; (2) the safety and robustness of all United States AHS systems can be ensured; and (3) no single entity, industry, or company will have a monopoly, and all industry will be able to compete fairly with their AHS products.

Once the preferred AHS system approach has been identified, a prototype of the system will be thoroughly tested to ensure its viability, and to refine the design for optimum safety and performance. At that point, the system will be specified so that contractors can design products for one or more AHS tests in operational environments

Operational tests involving the public will show how well the AHS works under real operating conditions, and provide the basis for credible assessments of the robustness, ease of use, safety and efficiency, and public support for the system. These tests will also provide an indication of the extent to which the AHS can integrate into existing institutional, technological, and regulatory environments. Hence, test deployments will likely include regional solutions to urban corridor congestion (for which an accelerated AHS deployment could become a key strategic element), management of commuter flows, and other opportunities where analysis shows high potential benefits from the AHS.

The AHS deployment and implementation will be structured to encourage healthy competition among companies for all aspects of the system, including vehicle electronics, roadway equipment, and perhaps even ownership of the roads themselves. The specifications and standards developed throughout the AHS program will ensure this through open architecture. In this way, the AHS program can help meet the ISTEA goals of establishing a significant presence in this emerging technology by establishing a broad technology base upon which to build the United States AHS system as well as provide AHS capabilities worldwide.

3.1.1 Objective Decision-Making a Key

Part of the strategy is to ensure that the evaluation of the alternatives is objective and balanced, with all stakeholder interests being adequately considered. The AHS will be a complex system that incorporates state-of-the-art technologies, and will have a highly visible deployment in an environment where requirements often conflict. Thus, the major AHS system decisions must be defensible and satisfy the needs of the public; Federal, State, and local governments; and industry:

- Consumers must be convinced that benefits offset any additional costs.
- The Federal Government must be convinced that AHS helps meet the Nation's transportation and societal needs.
- State and local governments must see that AHS will improve the efficiency of their transportation systems on a desirable, cost-effective basis.
- Industry must see market potential, including near-term "spin-off" products that may evolve to AHS, and the ability to produce affordable systems in response.

Tradeoffs will need to be made among these four areas so that a fair balance is achieved. Clearly, the "best" technical design is of no value if the public will not use it.

3.1.2 Response to Environmental Legislation

The ISTEA complements the Clean Air Act-Amended (CAAA) by providing funding to help improve air quality through the development of a balanced, environmentally sound, intermodal transportation program. It provides an expanded Federal source of funding for projects that reduce mobile source emissions, and for transportation planning and research. It also creates a major new program to deal with transportation-related pollution--Congestion Mitigation and Air Quality Improvement--which focuses on non-attainment areas.

An AHS deployment will conform with the CAAA through revisions to the current SIP. An AHS can offer significant contributions to the control of pollution from surface transportation systems through enabling more efficient travel. There are strong indications that tailpipe emissions of individual vehicles will be reduced due to smoother travel and less congestion. More directly, alternate fueled vehicles and zero and low emission vehicles (e.g., electric powered) could be incorporated into AHS.

However, the increased capacity from AHS may attract additional vehicular traffic. Further, the environmental impact of much larger volumes of vehicles traveling in concentrated corridors must be understood and accounted for. Approaches and policies for ensuring that this added capacity ultimately results in reduced congestion and increased passengers-per-vehicle will be studied and further defined.

3.1.3 Planned Evolution

In conducting the AHS program, a continual focus will be on defining and establishing a natural evolutionary path from today's vehicle-highway system to when the fully automated AHS begins to supplement the operation of the system.

This transition will be simplified because some of the basic automated vehicle controls needed for an AHS are starting to appear in today's vehicles; use of this technology is expected to increase over the next decade. Drivers will be offered ITS services such as **adaptive cruise control**, which is a cruise control system that maintains a safe following distance from the vehicle in front of it; **collision warning and avoidance** to help prevent both rear-end and side-swipe crashes; and **lane keeping**, which will hold a vehicle safely in its lane. Similarly, ITS technologies such as infrastructure-to-vehicle communications for Traveler Information Services and Advanced Traffic Management Systems will be deployed in the coming years. The AHS program will build upon and integrate with the evolution of these ITS services to ensure overall compatibility. With nationwide planning and infrastructure integration, AHS will become the next logical major evolutionary step in our highway transportation system.

3.2 Program Approach

To undertake and manage the Federal portion of the AHS development, the US DOT has established an AHS program within FHWA under the policy guidance of the US DOT ITS Joint Program Office (JPO). The program is closely coordinated with FTA and NHTSA, especially NHTSA's program to develop performance guidelines for crash avoidance systems that may serve as the building blocks for major AHS subsystems/components. PTA is assisting in exploring opportunities for automated bus operations to serve communities in urban areas.

The AHS development program is broadly structured in three phases, as shown in figure 3-1. **The Analysis phase**, much of which is completed or near completion, is establishing the analytical foundation for the Systems Definition phase of the program. It consists of (1) a human factors study, (2) multiple PSA studies addressing AHS requirements and issues, and (3) collision avoidance analyses to investigate avoidance-oriented vehicle warning and control services that may someday evolve into the AHS. The **Systems Definition phase** will be carried out by the consortium described above, which consists of the major AHS stakeholders.

The milestones of the consortium program are establishment of performance and design objectives, a 1997 proof-of-technical feasibility demonstration, identification and description of multiple feasible AHS system concepts, selection of the preferred AHS system configuration, completion of prototype testing, and completion of system and supporting documentation. The **Operational Test and Evaluation phase**, which follows the Systems Definition phase, will include (1) integrating the preferred AHS system configuration into the existing institutional, technological, and regulatory environment; (2) evaluating this configuration in a number of operational settings; and (3) establishing guidelines by which US DOT will support AHS deployment.

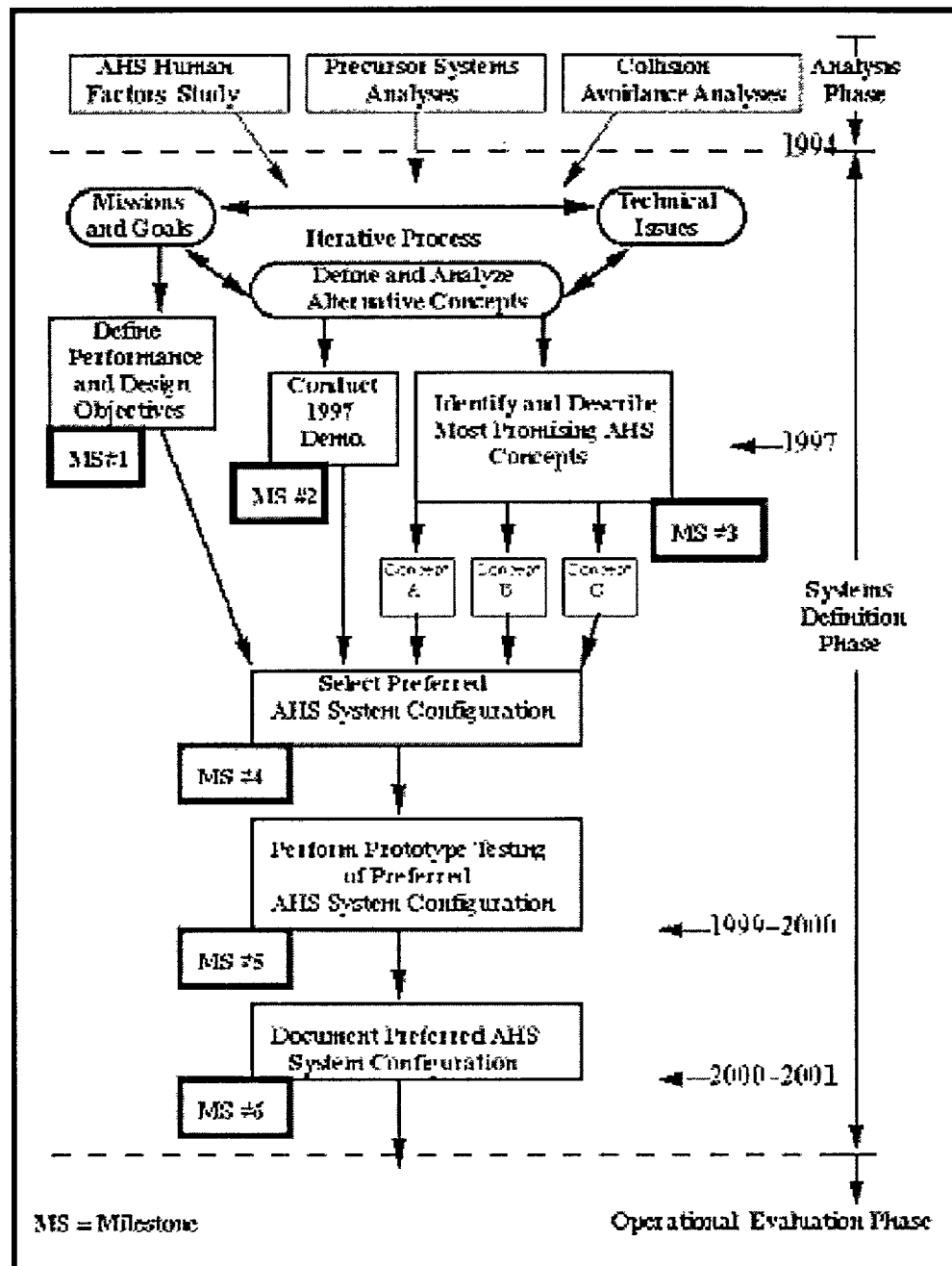


Figure 3-1. AHS Program Strategy

Following successful operational evaluation, US DOT will begin support for the deployment of AHS systems across the Nation.

The three phases of the program are described in detail in the following sections.

Section 4

Analysis Phase

Results have already shown that AHS holds great promise for addressing most of our Nation's major highway transportation needs early in the next century.

4.1 Purpose

The US DOT defined this initial phase of the AHS program to provide an analytical base for the remainder of the program. Accordingly, three areas of activity were defined and are being pursued including: (1) a human factors study that is developing a handbook to provide guidance in AHS human factors design; (2) 15 PSA studies that were focused on identifying and describing the key AHS requirements and issues; and (3) investigations into approaches for avoiding crashes using warning and vehicle control techniques. These latter activities are addressing technologies and design approaches that may evolve into AHS.

4.2 Description

The following is a description of the overall approach and the issues, risks, and technologies being addressed in each of the three analysis efforts that comprise this phase of the program.

4.2.1 Human Factors Analysis

Human factors aspects of automobiles have been the subject of intense study and practice for several decades. The focus has been on the driver controlling the vehicle; the human factors objective has been to place the operator effectively and comfortably in command of the safety, performance, and efficiency with which the vehicle makes the trip. The AHS introduces two new tasks—relinquish control to the automated system, and accept control when it is returned.

The FHWA selected Honeywell, Inc., to analytically and empirically examine the driver interaction with the AHS. Basic design approaches will be identified to allow drivers to understand and use the AHS. The technical investigations will be documented, and overall guidelines will be defined in a human factors handbook scheduled for completion in March 1996.

The human factors handbook will provide input to the NAHSC throughout the Systems Definition Phase and on into the Operational Test and Evaluation phase. The handbook will provide guidance in development of AHS demonstrations and in preparation of operational tests. It will be a living document to be updated as the consortium design and testing expands the knowledge of the AHS human interaction. It is to be a supplement to the extensive human factors work that already exists for human-vehicle interaction in general.

The research effort includes interaction with various sets of drivers using the driving simulator currently in operation at the University of Iowa as shown in figure 4-1. Some of the areas of study include approaches for assuming control from the driver, and returning control back to the driver, reaction to spacing between automated vehicles, and the driver role while on the AHS.

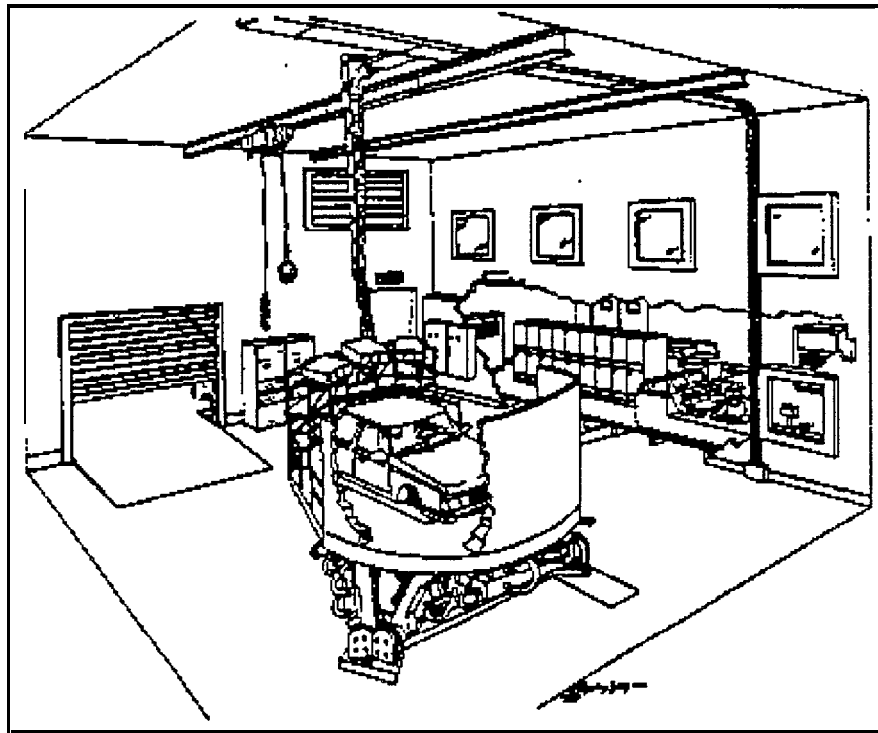


Figure 4-1. Iowa Driving Simulator

4.2.2 Precursor Systems Analyses

In initiating the AHS program, there were many unanswered questions regarding AHS such as what are its requirements? What would the people that would own, operate and use the system expect from it; that is, what are its benefits? What are the primary issues and risks to be addressed in developing and operating such a system, both technical and non-technical?

These questions, together with the desire to get the future AHS stakeholders involved, led the US DOT to award 15 PSA contracts in 16 research areas to define the requirements for an automated highway, and to identify and investigate the issues and risks related to AHS design, development and implementation. The mechanism for accomplishing this was a Broad Agency Announcement released in November 1992 [AHS BAA]. The areas defined for research are described in table 4- 1.

The PSA teams, individually and collectively, represented a wide variety of perspectives, including those of State transportation departments, academia, the aerospace and automotive industries, defense contractors, and technical consulting organizations. In all, 55 entities, including 14 State departments of transportation, were involved in the PSA research effort.

Several contractors addressed each of the activity areas. This overlap added value to the overall body of research, in that each discrete effort provided a different perspective and emphasis in identifying and analyzing issues and risks. Two teams, led by Calspan and Delco, were selected to address all 16 activity areas. These teams generated additional insights into the issues because they could explore the extensive interdependencies across the activity areas. The contractors and subcontractors for each contract team, their business locations, and the activities addressed by each team are listed in Appendix B.

The perspectives and experience of the highway engineering profession were crucial to this research, and transportation consultants were well represented within the contract teams performing the highway-based analyses. To enhance the results of the analyses and maintain a “real-world” perspective, frequent contact was made with participating State and local highway officials to gain feedback on issues such as AHS deployment, operations and maintenance, and network-wide impacts.

The vehicle manufacturing industry was represented with participation by GM, Ford, Delco, and Freightliner.

These analyses also benefited substantially from the experience and expertise of the defense industry. Several of the contractors selected (including Martin Marietta, Northrop-Grumman, Rockwell, and Raytheon) have had extensive involvement with complex defense systems on the scale of an AHS and have studied similar technologies, such as autonomous ground vehicles for military applications.

The PSA studies were conducted in a highly interactive and collaborative environment. The program benefited substantially from the atmosphere of collegiality among the individuals performing the research. Information and research were actively shared-often between companies who are competitors under normal business circumstances.

As a key part of this collaborative approach, FHWA sponsored an Interim Results Workshop in April 1994. The researchers met and shared results with a wide array of transportation and technology professionals invited to offer insight and perspective. In November 1994, at the conclusion of all the contracts, FHWA sponsored a second conference to present final results. In addition to being publicly available through the National Technical Information Service (NTIS), all PSA research reports will soon be available on a CD-ROM and can also be accessed through an Internet connection to US DOT.

Table 4-1. PSA Activity Areas

- **Urban and Rural AHS** Comparison-an analysis defining and contrasting the urban and rural operational environments relative to AHS deployment.
- **Automated** Check-in-issues related to certifying that vehicle equipment is functioning properly for operation, in a manner enabling smooth flow into the system.
- **Automated** Check-out-issues related to transitioning control to the human driver and certifying that vehicle equipment is functioning properly for manual operation.
- **Lateral and Longitudinal Control Analysis-analyses** of automated vehicle control.
- **Malfunction Management and** Analysis-analyses related to design approaches for an AHS that is highly reliable and fault-tolerant.
- **Commercial and Transit AHS** Analysis-issues related to the unique needs of commercial and transit vehicles operating within the AHS.
- **Comparable Systems** Analysis-an effort to derive “lessons learned” from other system development and deployment efforts with similarities to the AHS.
- **AHS Roadway Deployment** Analysis-issues related to the deployability of possible AHS configurations within existing freeway networks.
- **Impact of AHS on Surrounding Non-AHS** Roadways-analysis of the overall network impact of AHS deployment and development of mitigation strategies.
- **AHS Entry/Exit** Implementation-analysis of highway design issues related to the efficient flow of vehicles on and off of the AHS facility.
- **AHS Roadway Operational Analysis** -- issues related to ongoing AHS operation.
- **Vehicle Operational** Analysis-issues related to the operation of an AHS vehicle, including the retrofitting of vehicles for AHS operation.
- **Alternative Propulsion Systems Impact**-analysis of possible impacts of alternately propelled vehicles on AHS deployment and operation.
- **AHS Safety Issues**-broad analysis of safety issues pertaining to the AHS.
- **Institutional and Societal** Aspects-broad analysis of the many non-technical issues critical to successful deployment of the AHS.
- **Preliminary Cost-Benefit Factors Analysis**-an early assessment of the factors that comprise the costs and benefits of the AHS.

4.2.3 Collision Avoidance

Motor vehicle crashes continue to be a leading cause of death and injury in the United States. Since the introduction of the automobile at the beginning of the 20th century, there have been nearly 3 million motor vehicle fatalities in the United States. This astonishing figure is more than twice the number of Americans killed in all the Nation's wars since 1776.

The relative contributions in crash causation of driver, vehicle and highway/environmental factors have been compared in a number of studies which have consistently shown human error to be a contributing factor over 90 percent of the time.

In the future, the challenge of rapidly increasing traffic densities, severe congestion, and an aging driver population must be met. As a result, margins for error, human or otherwise, are decreasing and average driver needs, capabilities, and limitations are changing. With these trends, the probability of a significant increase in motor vehicle crashes must be anticipated. Not only should the traditional safety programs be continued, but also additional means of preventing motor vehicle crashes should be sought.

The rapid rate of development of modern electronic technologies allows for the development of intelligent vehicle systems to give drivers an edge in this regard. The trend toward reduced margins for error can possibly be reversed by equipping motor vehicles with devices to assist drivers in performing their driving task.

NHTSA's crash avoidance research program is committed to improving motor vehicle safety by reducing the frequency of crashes and/or crash severity through the development of systems to assist drivers in avoiding crashes. This program complements the highway safety programs of other DOT modal administrations in continuing to reduce the yearly toll of crashes and the fatalities, injuries, and economic costs that result.

The NHTSA Collision Avoidance research program aims to demonstrate that improved crash avoidance performance can be achieved through the application of ITS technology, facilitate the successful development and early deployment of ITS systems that will assist drivers in avoiding crashes, and ensure that there is no loss of safety as ITS systems are incorporated into motor vehicles.

The vision is that a wide variety of innovations will become available to supplement the driver's efforts at vigilance and control by better sensing impending danger, sensing lapses in driver judgment or skill, providing assistance in performing the driving task, and eventually compensating for some driver errors. Much of the lateral/longitudinal vehicle control aspects of crash avoidance directly relate to the vehicle control requirements of AHS, and in all likelihood will serve as part of the evolution to AHS. NHTSA human factors/driver performance research will also be of great relevance to AHS, e.g., fundamental research in driver performance, development of driver status monitoring systems, and the design of the driver display component of collision warning/avoidance systems to achieve optimum safety benefit.

Safety improvements cannot be realized unless effective collision warning/avoidance systems are developed by the private sector and are purchased and used by the public either as standard or optional equipment. Therefore, the focus of the five-element ITS-collision avoidance program that NHTSA is implementing is to facilitate the development and early deployment of reliable, affordable, effective, user-friendly collision warning/avoidance systems by the private sector.

- **Thrust 1: Research Tools and Knowledge Base** – develop research tools, such as simulation models, data acquisition systems, and instrumented vehicles for gathering data on vehicle performance and driver actions, evaluating vehicle interaction with the vehicle and highway environment, and assessing the impact of collision avoidance measures on traffic flow. These tools will be used to gather fundamental driver/vehicle performance data needed by the private sector designer of collision avoidance systems.
- **Thrust 2: Defining Crash Avoidance Opportunities** – through intensive analysis of NHTSA crash data bases, develop descriptions of the specific crash problems to be addressed to ensure that countermeasures addressing these crash problems can then be specified in performance terms that match real safety needs.
- **Thrust 3: Demonstrating Proof-of-Concept** – through assessment of the capabilities of enabling technologies and first generation collision avoidance systems, develop guidelines for system performance that, if followed by product designers, will maximize safety benefits and ensure there are no safety problems. As soon as performance guidelines are available, the private sector will have product design targets, and the agency will have a basis for conducting safety impact analyses.
- **Thrust 4: Facilitating Commercial Development** – conduct in-service field evaluations in conjunction with the industry to assess system performance, reliability, maintainability, failure modes/consequences, and costs. Validation of safety specifications under real-world operating conditions will facilitate the final deployment of marketable ITS collision avoidance systems. Work cooperatively with industrial partners to foster the development and deployment of collision avoidance systems.
- **Thrust 5: Assessing Safety of Other Systems** – participate in the safety evaluations of DOT mobility and productivity enhancement technologies to ensure no loss of safety as these technologies are introduced into motor vehicles. Participate in the DOT management of the AHS initiative.

4.3 Schedules

Significant milestones for the Human Factors Study and the PSA studies are shown in table 4-2. The human factors analysis effort is a 42-month effort that began in October of 1992, and will conclude in March of 1996. In total, 14 separate interim reports are being provided, prior to 1996, that document results of the driver simulation efforts, and also provide preliminary

handbook materials. The NHTSA collision avoidance studies are a series of separate studies that are part of the overall NHTSA program and are not included in table 4-2.

The 15 PSA efforts ran concurrently beginning sometime between July and October of 1993 with all research efforts ending in November, 1994. Final reports were delivered in early 1995. Each individual contract was different to account for the wide variety of research that was conducted; however, all researchers participated in the Interim Results Workshop in April 1994 and the Final Results Conference in November 1994.

Table 4-2. Analysis Phase Significant Milestones

Date	Human Factors Study	Precursor Systems Analyses
Responsible Admin.	FHWA	FHWA
October 1992	Contract Start	
July 1993		Contracts Start
April 1994		Interim Results Workshop
September 1994	Draft Human Factors Handbook	
November 1994		Final Results Conference
Early 1995		Final Reports & Contracts End
March 1996	Final Human Factors Handbook & Contract End	

4.4 Cost and Funding Status

A summary of costs associated with the Analysis Phase is shown in table 4-3. The costs are broken down by the individual analysis effort and by fiscal year.

Table 4-3. Analysis Phase Costs (millions, then-year dollars)

	FY91	FY92	FY93	FY94	FY95
Human Factors Study		2.6	2.5		0.2
Precursor Systems Analyses			14.1	0.3	0.02
Collision Avoidance Analyses	2.3	7.5	9.0	14.5	14.8

4.5 Results to Date

This section summarizes some of the key results to date from Phase I activities. Appendix C contains more specific results.

4.51 Human Factors Analyses

An initial draft of the Human Factors Handbook was reviewed by FHWA in the fall of 1994. Work also proceeded in designing and testing the simulator to be used for the human interaction testing. Coordination meetings were held between the human factors team and the PSA teams to ensure that there was a free flow of information. Study results were also exchanged.

Some of the early findings include the following:

- The driver should not be expected to act as an immediate backup for vehicle control in an emergency situation.
- The number of non-critical messages that are sent to the driver should be kept to a minimum.
- Under some scenarios during an exit from automated lanes, the disruption to the steady state flow of traffic in the automated lanes varies with operating speed. Also, the percentage of this disruption due to the automated vehicle system response (versus the driver) increases as the operating speed increases.

4.5.2 Precursor Systems Analyses

4.5.2.1 General Results

Final reports documenting the PSA research have been made available to the consortium as has an overall PSA Summary and Evaluation report, prepared by the MITRE Corporation, that consolidates and interprets the PSA analyses as a whole. Numerous interim reports have also been made available as has a report documenting the results of the PSA Interim Results Workshop. Among the materials developed is a complete bibliography of the automated highway research conducted to date. The major finding from the PSA research was that although there are a number of problems and issues to resolve, there are **no show stoppers** for AHS at this time.

As previously mentioned, a database of the major PSA findings or issues was developed and given to the consortium for its continued maintenance and use. Access to it will be available to all automated highway researchers.

4.5.2.2 Preliminary Findings

The PSA research program did not aim to develop consensus. It was felt that independent thought at this early stage was vital to the development of creative ideas sought in the PSA efforts. But several key themes and points of agreement did emerge. These are summarized below.

- **Basis for 21st Century Highway Transportation.** Results showed that the AHS holds great promise for addressing most of the major highway transportation needs of the United States in the next century. Almost all researchers agreed that, while there are both pros and cons to AHS implementation, it will confer major performance gains:
 - **Travel safety could be significantly better than now** – some estimates were up to 80 percent improvement [Calspan, 1994]. This is based on analysis of causal factors in crashes, and of automated reactions that would help avoid inadequate and inconsistent human responses that often result in crashes. However, more investigation is needed to determine how the human driver can work successfully with the automated system. Human factors studies of the human-automation interface are ongoing, and will be specifically targeted to understanding how to integrate the human role into an AHS.
 - **Peak efficiency** – estimates are that two to three times as many vehicles will be able to travel on a highway lane under automated vehicle control than under manual control, through elimination of inefficiencies caused by inattentiveness, merging, weaving and lane changing. The AHS entry and exit traffic flow will need to be integrated with the traffic on the local arteries used for AHS access. By making AHS part of the overall integrated traffic planning process, this integration can be accomplished. The AHS implementation planning must also correlate with the land use plan and demand management plans of the community.
 - **User comfort and access** – participants in focus groups anticipated far less stress and worry in highway travel for those using AHS, but, concerns for equity and access across society were expressed.
 - **Trip time reliability** – travel times should be much more dependable because of the consistent AHS traffic flow due to automated traffic management. Avoiding congestion at AHS entry and exit points is necessary to capitalize on this calmer, smoother trip potential. PSA researchers postulated many promising approaches to these issue areas and the NAHSC will build upon this work.
 - **Air quality** – there are strong indications that tailpipe emissions of individual vehicles will be reduced due to smoother travel and less congestion. However, the increased capacity from AHS may attract additional vehicular traffic; for this reason, AHS deployment in areas of dense traffic may need to be coordinated with demand management policies. Further, the environmental impact of much larger volumes of vehicles traveling in concentrated corridors must be understood and accounted for.

- **Mobility** – the AHS may encourage use by those who are hesitant to use today’s freeways including the elderly and the handicapped. A national AHS network will enhance the Nation’s mobility for inter-city users including truckers. Smooth transition to full vehicle control, defining a highly reliable and safe system which is also affordable and accommodating nationwide compatibility and local/regional tailoring are examples of system aspects that must be resolved.
- Transit Industry as a Leader. Many felt that the transit industry could be a pioneer in AHS implementation. AHS would allow collector/distributor buses, including airport buses, to enjoy safe travel into a central business district with reliable travel times. Once downtown, the AHS controls will allow buses to operate in very close tolerance, dedicated lanes. This operation would have characteristics similar to light rail. Precision lateral control will allow buses to pull close enough to loading platforms so that wheelchair ingress and egress can be accomplished without special equipment. This is being done in Europe today.
- **Transition from Today.** Most felt that AHS must transition from today’s highway system on a planned evolutionary basis. Several approaches for doing this were postulated.
- **AHS is a Tool for Highway Planners.** AHS will be another tool for transportation planners to use in meeting their community’s needs. For some communities, it may offer a solution that balances the need for less congestion and pollution without significantly increasing highway right-of-way. In other communities, the need may not be as immediate. For example, one region may have an AHS that is based on transit needs; a second region may have a system that is restricted to passenger-size vehicles in its downtown area; and a third region may have separate lanes for passenger and heavy vehicles. The point is that it will be tailored by local decision makers.
- **AHS Program Faces Many Challenges.** The NAHSC and the US DOT will face some major challenges over the next several years as the program proceeds. The most important of these challenges are highlighted below and example approaches to them are discussed in section 8 of this report.
- **System Design Issues Examined.** PSA researchers identified and examined a wealth of system design issues, and proposed possible solutions which will:

- **Smooth Transition to Full Vehicle Control** – highway lanes cannot be instrumented and dedicated to AHS use if there are very few vehicles to use them. On the other hand, owners may not be willing to pay for AHS equipment if there are no highway lanes dedicated to AHS.
- **Congestion at AHS Entry and Exit** – even with thorough planning, there will be the potential for congestion as vehicles seek to enter AHS and where vehicles try to exit from AHS.
- **Detection of Foreign Objects** – roadway debris and other potential foreign objects along the highway presents a particular hazard for an AHS and represents a major technical challenge.
- **Nationwide Compatibility and Local/Regional Tailoring** – the US DOT visualizes the AHS as evolving to a nationwide network with nationwide compatibility. On the other hand, the AHS is envisioned as a tool to be used by an MPO and/or a State DOT to be tailored to help meet its local needs. A balance must be achieved between local and national goals.
- **How Safe is Safe?** – how safe will the public expect the system to be? What level of safety is attainable and sustainable within a realistic cost? Can the predicted improvements in system efficiency be achieved if safety requirements become extreme?
- **The Human Response** – the system must be designed so that the role of the driver through various phases of transition to the AHS is accommodated. The transfer of control to the system, and then back again to the human will need to be carefully researched.

• **Institutional And Societal Environment Issues Examined**

- **Increased Vehicle-Miles-Traveled** – an AHS that is deployed without land use considerations or without demand management policies where appropriate, might encourage/induce more VMT; if so, then overall emissions and fuel consumption may increase even though emissions are reduced on a per-vehicle-mile basis.
- **Equity** – System deployments financed with public funds must address social equity. It was pointed out that reduced congestion caused by the AHS will benefit all.

Land Use and Development – as with any new surface transportation system, the AHS implementation must correlate with, and respond to, the regional land use planning. The direct impacts have to do with entry and exit locations and non-AHS infrastructure improvements. The more indirect impacts may be on the urban form and on regional development.

- **Role of the driver** – will the driver be checked in to AHS as well as the vehicle? What sort of responsibility will the driver and passenger have, if any, during regular and emergency conditions? What will drivers be comfortable with?
- **Privacy** – can an AHS ensure that vehicle identification, location, and communications among vehicles and the roadside not lead to the potential for invasion of a person's privacy?
- **Who Pays for AHS?** – while there are many ways in which AHS costs can be covered, it is the structuring and division of these costs that will or will not give the perception of whether it is “worth it.”
- **Responsibility for Property Loss, Injury, or Death** – when an AHS assumes control of the vehicles, “the system” must also assume some level of liability for the consequences of any malfunction. How should this level of liability be determined?
- **State and Regional Institutional Concerns** – Depending on the system approach selected, AHS will introduce a new, high-technology level of complexity to those organizations which are responsible for highway functions and services. Installation and maintenance of these systems may present a significant challenge to the operators.
- **National Certification and/or Regulation** - national standards for AHS will need to be established to ensure (1) national compatibility among AHS systems that develop regionally; and (2) minimum levels of safety and performance are met.

Political Pressures Versus Engineering Realities - Studies of comparable systems emphasized that the engineering of such a system in the general public eye increases the need for very thorough testing to ensure safety, robustness and operability. However, these systems are expensive and the public and political leaders may get impatient with the cost and the amount of time it takes to develop them.

4.5.3 Collision Avoidance Analyses

The NHTSA ITS collision avoidance program has made significant progress in implementing the agency's five-element program to (1) develop needed research tools and utilize these tools to develop improved understanding of driver and vehicle performance; (2) characterize specific crash problems by analyzing agency accident databases to ensure countermeasures match real problems; (3) develop engineering and human factors performance guidelines for collision avoidance systems; (4) work with industry to accelerate development and early deployment of such systems; and (5) work with FHWA to ensure that safety is not compromised as mobility or productivity enhancing systems are introduced into vehicles.

Prior funding is beginning to bear fruit as evidenced by recent accomplishments including:

- Evaluation of rear and side object detection systems for commercial vehicles.
- Development of preliminary human factor guidelines for the design of driver displays for collision warning systems.
- Sponsorship, together with ITS America, of multiple workshops on collision avoidance systems.
- Initial problem size assessment and statistical descriptions of the following major crash types: rear-end, backing, lane change/merge, single vehicle roadway departure, opposite direction, and intersection crossing path (signalized intersection, straight crossing path; unsignalized intersection, straight crossing path; and left turn across path), as well as crashes occurring under conditions of reduced visibility or drowsy drivers.
- Initiation of six projects to develop technology-independent performance specifications for collision avoidance systems which will serve as design targets for private sector product development. Preliminary performance guidelines will be available in 1995.
- Initiation of five industrial partnerships with Ford, Eaton, Rockwell, TRW and the Environmental Research Institute of Michigan, the University of Michigan Transportation Research Institute and Leica to accelerate development of effective collision avoidance systems.
- Initiation of a cooperative agreement with the Delco Electronics/GM Partnership to develop low cost sensors for automotive collision avoidance systems.

Section 5

Systems Definition Phase

The second phase of the AHS program has been structured to define the most feasible systems approach for nationwide implementation.

5.1 Purpose

FHWA has formed a partnership with a consortium of AHS stakeholders to conduct the Systems Definition Phase of the AHS program, and to provide leadership and focus to the Nation's AHS efforts. This Phase will result in the selection of the AHS system configuration that will be operationally tested in the program's third phase, and may ultimately be deployed as a major performance supplement to the Nation's vehicle-highway system. This second program phase emphasizes identification and analyses of system alternatives, and selection, documentation, and proof-of-feasibility of the preferred AHS approach. Specific major results will include the following:

- 1997 proof-of-technical-feasibility demonstration of AHS.
- Feasible AHS concepts identification, evaluation and down-selection to the preferred system configuration.
- Preferred system configuration prototype testing.
- Standards, performance specifications, and supporting documentation.

5.2 Description

5.2.1 Consortium Description

On October 7, 1994, FHWA Administrator Rodney Slater announced the selection of the NAHSC. The consortium was selected from among applications received in response to a Request for Applications (RFA). The RFA sought a team of AHS stakeholders that supported the goals of the AHS program and were willing to enter into a cooperative agreement in which the non-Federal partners would be expected to share at least 20 percent of the program cost. The FHWA led a US DOT-wide evaluation process to select the consortium that would best lead the program through research, assessment, and testing, and into eventual commercialization. The consortium, in partnership with FHWA, is responsible for

- (1) providing a focal point for the Nation's AHS program, (2) managing the program, (3) meeting the program milestones, and (4) ensuring financial control.

5.2.1.1 Core Membership

The Core Members of the NAHSC (that is, those that formed the consortium) consist of the world's largest automaker (GM), world leaders in vehicle electronics (Delco Electronics and Hughes Aircraft), two leading highway design and construction firms (Bechtel and Parsons Brinckerhoff), world leaders in vehicle automation (University of California PATH Program and Carnegie Mellon University Robotics Institute), the largest State DOT (California), and the US DOD's system integrator for unmanned ground vehicles (Lockheed Martin). Appendix D provides a more detailed description of each of these consortium Core Members. The core membership is responsive to the United States competitiveness goals of the ISTEA, specifically, section 6052(b):

Goals.- The goals of the program to be carried out under this part shall include, but not be limited to .

- . Item (4) - "the development and promotion of intelligent vehicle-highway systems and an intelligent vehicle-highway systems industry in the United States, .."***
- . Item (6) - "the enhancement of United States industrial and economic competitiveness and productivity by improving the free flow of people and commerce and by establishing a significant United States presence in an emerging field of technology; .."***

5.2.1.2 Other Participation

The NAHSC welcomes participation by any interested, relevant organization. This participation may be as any one or all of these roles: associate participant, outreach participant, and sub-contractor. All three roles are vital in the Systems Definition phase of the program to ensure that the full spectrum of viewpoints is heard.

Associate Participant status is open to any relevant organization with a strong, positive, continuing interest in highway automation and the goals of the AHS program. Associate Participants may actively participate in the work program, including cost sharing. They may also share results of parallel research efforts. Depending on their level of participation, they have access to the program's technical materials. For commercial firms, the terms of the Associate Agreement rigorously protect proprietary information, so that United States technology leadership is preserved. The Associate Participants interact with the consortium program office and its work effort on a technical level, and participate in decision-making through representation on the Program Management Oversight Committee (PMOC) (see below).

The National AHS Consortium

Core Consortium Members:

Bechtel
California Department of Transportation
Carnegie-Mellon University Robotics Institute
Delco Electronics
General Motors
Hughes Aircraft
Lockheed Martin
Parsons Brinckerhoff
University of California PATH Program
United States Department of Transportation

Outreach Participants are organizational entities that are members of any of the AHS stakeholder categories, and are willing to work toward the definition of the role of automation in our Nation's vehicle-highway system. Each Outreach Participant belongs to a stakeholder category. The outreach participants within each category, along with the relevant Associate Participants, annually elect a category representative who has a seat on the PMOC. In the PMOC these stakeholder category representatives work with representatives of the core participants on an equal basis in establishing program direction and in making major decisions. Figure 5-1 illustrates the interaction of the core participants and stakeholder category representatives on the PMOC. It is through this interaction and participation that the consortium is working toward a nationwide consensus of AHS stakeholders.

A major share of the consortium work is being accomplished by entities other than the Core Members. The cooperative agreement between the consortium and the US DOT specifies that 35 percent of the Federal funding of the program must be used to competitively select **subcontractors**. This will help extend participation in the AHS work effort. This amounts to approximately \$56 million of the \$160 million federal share over the life of the program. The subcontracting program includes an emphasis on small businesses (SB), small disadvantaged businesses (SDB), and historically black colleges and universities (HBCU) . Overall program goals are: SBs – 10 percent, SDBs – 10 percent, HBCU – 5 percent. Thus, of the \$56 million to be contracted out, 25 percent or approximately \$14 million is being contracted to firms of this type.

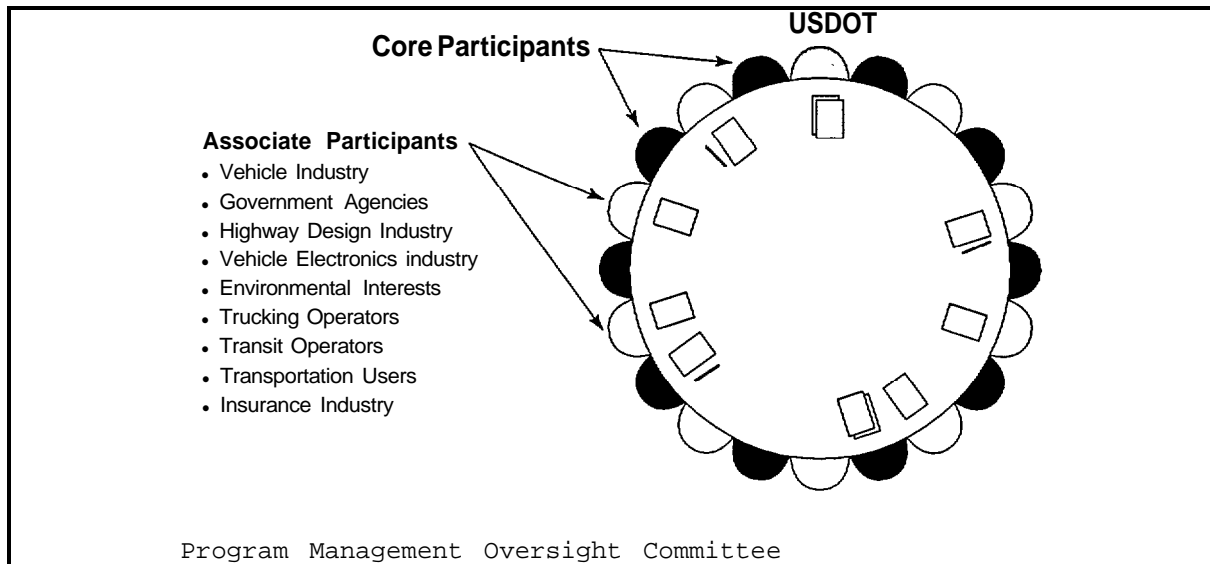


Figure 5-1. Program Management Oversight Committee

The consortium core participants, associate participants and outreach participants come from many categories of stakeholders including:

- Vehicle industry
- State, regional and local government organizations
- Highway design industry
- Vehicle electronics industry
- Environmental interests
- Trucking operators
- Transit operators
- Other transportation users
- Insurance industry

5.2.2 Consortium Structure

The NAHSC is structured as shown in figure 5-2. The day-to-day operations of the project are managed by the program office. The program office provides the focus and discipline to achieve the program goals. The core participants and stakeholder representatives of the consortium provide input and direction to the program office through the PMOC. The voices of other interested parties are heard through a structured outreach process at the PMOC and program office levels in addition to the usual outreach efforts by the US DOT. One channel for

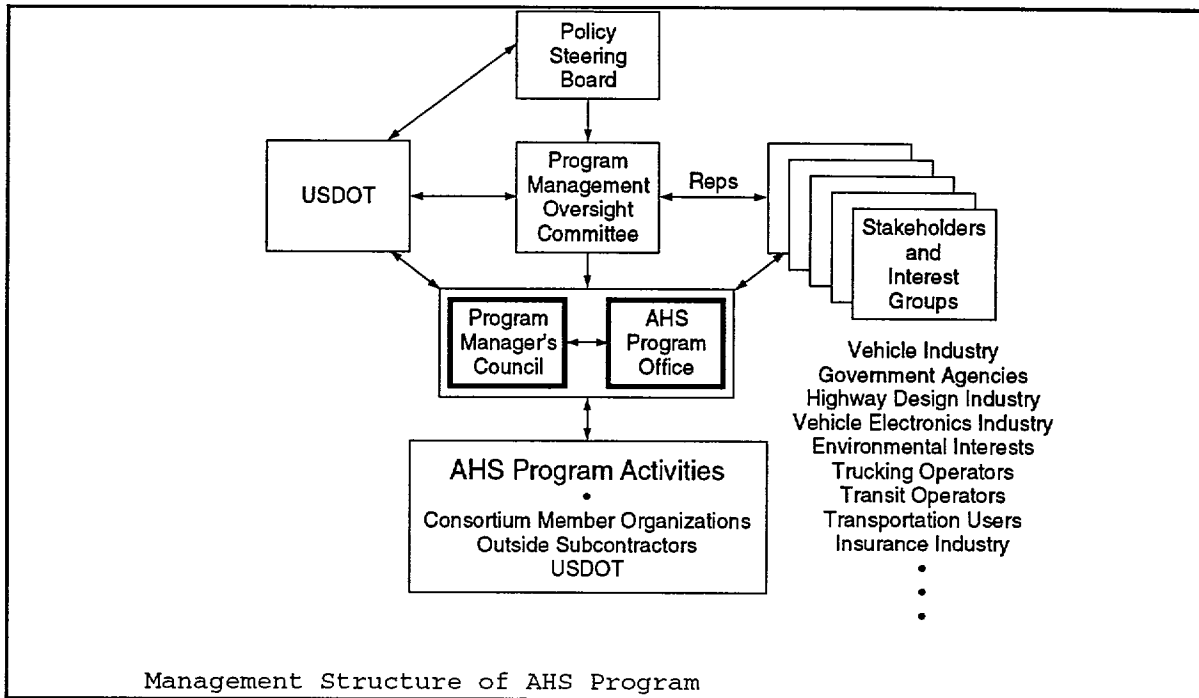


Figure 5-2. Management Structure of NAHSC

this outreach is through ITS-America and its more than 500 member organizations. The Program Manager's Council (PMC) assists the program office with planning and managing the project activities of the home organization of each core participant to assure each core participant's contribution to the overall program. The Policy Steering Board (PSB) sets broad goals and policies for the program and resolves inter-organizational issues. Within the consortium, major decisions, whether at the PSB, the PMOC, the PMC, or the program office, are made through a consensus process. The US DOT is always a party in these decisions and has the final decision in the unlikely event that consensus cannot be achieved.

5.3 Schedule

5.3.1 Milestones

The work plan for the Systems Definition Phase has six major milestones. The milestones, which are shown in table 5-1, are described below.

- **Milestone 1: Establishment of Performance and Design Objectives.** The consortium will have met this milestone once the AHS system performance and design objectives have been completed. This initial documentation will guide the subsequent analysis, development, and system synthesis stages of the consortium program.

- **Milestone 2: 1997 Proof-of-Technical Feasibility Demonstration.** The consortium will have met this milestone once the 1997 demonstration has been completed. This Congressionally mandated demonstration will be designed to demonstrate the basic technical feasibility of fully automated AHS subsystem designs, and key AHS technologies and functions. It is not expected to be a demonstration of a final prototype design; this will occur later in the program after the preferred system configuration has been selected. As part of the activities in preparation for this demonstration, the consortium will prepare an AHS exhibit and demonstration for the 1996 ITS World Congress. Milestone 2 may occur before or after milestone 3.
- **Milestone 3: Identification and Description of Multiple Feasible AHS System Concepts.** The consortium will have met this milestone once the most promising AHS concepts have been identified and fully described. The consortium will document the evaluation process leading to the selection of these concepts, including evaluation criteria and modeling and simulation support.
- **Milestone 4: Selection of the Preferred AHS System Configuration.** The consortium will have met this milestone once the system configuration to be used for continuing AHS operational evaluation has been chosen, and the basis for the selection has been thoroughly documented. The selection process used will ensure that all of the major stakeholders participate in the evaluation.
- **Milestone 5: Completion of Prototype Testing.** The consortium will have met this milestone once the major functionality of the preferred system configuration has been demonstrated in an integrated prototype test. The functions demonstrated will include all major operational aspects: longitudinal and lateral control, system entry and exit, lane changing, and malfunction management for selected system malfunctions.
- **Milestone 6: Completion of System and Supporting Documentation.** The consortium will have met this milestone once documentation of the preferred system configuration has been completed and is available to the US DOT. This material will support subsequent AHS operational test and evaluations.

5.4 Cost and Funding Status

Figure 5-3 summarizes the projected budget of the NAHSC during this phase of the AHS program. These are current projections totaling approximately \$202 M including a 20 percent cost share by the non-Federal consortium members.

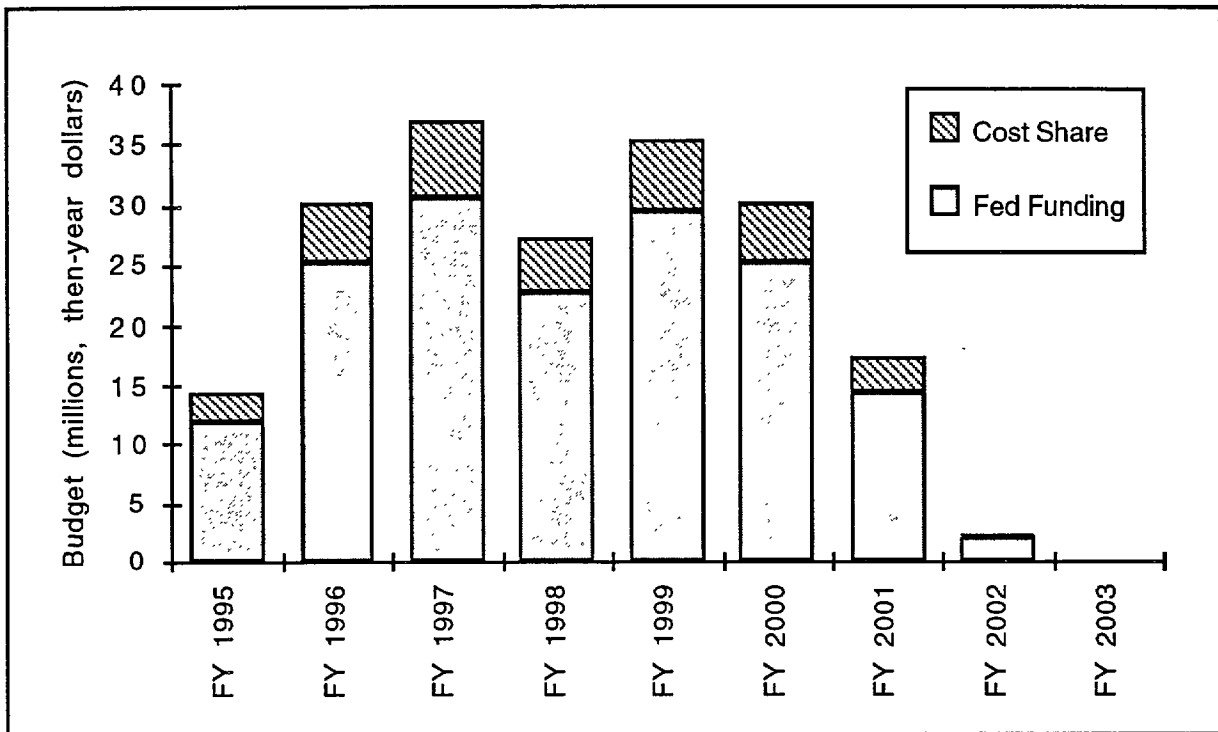


Figure 5-3. NAHSC Budget

5.4.1 Responsibilities

The NAHSC has the responsibility for successfully accomplishing this phase of the program. This includes management of the technical, non-technical, and business portions of the program. The consortium will achieve the six milestones of this phase under the guidance of its PSB.

US DOT (including FHWA, NHTSA, and FTA) is an active member of the consortium and responsible for ensuring that the consortium acts in the best interest of the Nation's transportation and societal needs. US DOT is working together with the consortium to make sure that all possible stakeholders are given the opportunity to represent their views. In addition to its role in the NAHSC, US DOT is continuing to sponsor related research deemed necessary for the success of the program. These studies could address such topics as collision avoidance, human factors, vehicle control and sensor technologies, advanced AHS modeling techniques, and independent evaluations of consortium efforts.

Other Government agencies may also play a role in this phase of the program. Both the US DOD and the US DOE are pursuing studies related to autonomous vehicle control, real time vehicle inspection, and roadway-powered electric vehicles, which involve technologies that may be applicable to the AHS. The US DOD UnManned Ground Vehicle program is in particularly strong alignment with the US DOT AHS program; these programs are coordinated

at the federal level, and technology exchange is fostered through NAHSC members Lockheed Martin and Carnegie Mellon University, who are active participants in the US DOD effort. Coordination of technology sharing and potential areas for shared funding will be the responsibility of all Government agencies involved in autonomous and automated transportation technologies.

5.4.2 Funding Status

The primary funding source for this phase of the program will be US DOT at less than 80 percent of consortium costs, plus FHWA/NHTSA costs.. The participants of the NAHSC will be responsible for at least 20 percent of consortium costs, plus any internal R&D. Other potential funding sources may include other Government agencies (for non-consortium AHS-related work), and contributions from Associate Participants.

5.5 Results to Date

The NAHSC began work in October 1994 and has initiated several major work efforts as described below.

5.5.1 National Outreach

In addition to its efforts to encourage consortium participation, the consortium is establishing a national coordination effort to ensure that (1) thoughts from a full range of stakeholders are infused into the program; (2) the consortium is aware of the activities and viewpoints of relevant entities with an interest in the AHS; and (3) key audiences are aware of the program status and direction. National coordination will include the maintenance of relationships with government and industrial organizations in which the major AHS stakeholder categories participate; outreach programs that will allow interested, relevant entities to express their needs and views of the AHS at appropriate times; relationships with appropriate standards organizations; and a public relations activity that will seek opportunities for the consortium and its management to interact with organizations and/or entities when appropriate, in coordination with FHWA.

The Associate Participant program was initiated with an Opportunities for Participation workshop, held in March 1995, which was attended by approximately 100 organizations. To date, September 1995, 33 organizations (see Appendix E) have joined the NAHSC as Associate Participants, including the Virginia DOT, Michigan DOT, the Pennsylvania Turnpike Commission, the Metropolitan Transit Authority of Harris County, Texas, the American Trucking Associations, Toyota Motor Corporation, Honda R&D North America, and ITS America. Universities, National Laboratories, and consulting firms are also well represented. Several of these organizations are now actively involved in consortium technical activities, providing outside stakeholder perspectives which are key to a robust program and national consensus. In addition, discussions are currently underway with the United States Consortium for Automotive Research (USCAR), which includes GM, Ford, and Chrysler, to join the NAHSC as an Associate.

5.5.2 Requirements Definition Effort

A key early focus of the NAHSC has been to define the top-level requirements for an AHS. Initially, these will be the AHS performance and design objectives in Milestone 1. As the program proceeds, they will be refined and expanded into initial minimum operational performance requirements for the system. These top-level requirements are captured in a System Objectives and Characteristics document, which has been published in draft form.

The first requirements review workshop was held on April 12 and 13, 1995. At the workshop, stakeholder and other interested organizations reviewed the consortium's initial thinking regarding the performance and design objectives as described in the Systems Objectives document. Feedback from this workshop has been carefully considered and reflected in a subsequent draft. The next workshop, which will be dedicated to discussion and evaluation of the evolving AHS concepts, is scheduled for October 1995. Other workshops will be scheduled periodically to provide full opportunity for stakeholder review and comment as the specifications are refined and expanded.

5.5.3 Concept Definition Effort

The process to identify potential AHS concepts has begun. A national solicitation for AHS concepts was published in May 1995 resulting in 27 respondents including several innovative submissions representing both large and small organizations. Seven contracts have been awarded to further elaborate promising concepts. This effort provides an opportunity for interested parties to express their ideas on how an AHS might be designed, installed, and maintained. In addition, the NAHSC is conducting an internal effort to comprehensively identify all concept possibilities and perform a systematic evaluation. This initial concept definition activity will result in the description of six "concept families" for further evaluation.

5.5.4 Planning for the 1997 Demonstration

The NAHSC "Demo Team" is nearing completion of a detailed description of the content of the 1997 demonstration, which will be conducted on HOV lanes (closed to the public) located in the median of I- 15 in San Diego, CA. This work is on schedule and preparations are underway. Additional smaller scale demonstrations at other sites around the country are also being considered.

The demonstration will provide proof of the technical feasibility of fully automated AHS concepts, designs, technologies, and functions. What is shown will not necessarily be the AHS of the future. But it will be practical, real-life applications of the latest technologies **to the** driving task, with the focus on establishing that the benefits of an AHS are technically feasible. The demonstration will also give the world its first glimpse of what the AHS of the 21st century might look like and how it could perform.

What will be demonstrated in 1997? Current plans call for 10-20 passenger vehicles moving along the road under system control. Entering vehicles will merge automatically with the traffic stream, and exit the system in automated mode as well, returning control to the driver in a simple fashion. The cars will stay in their lanes and maintain a safe distance from other cars.

Because of the high potential for benefits to bus transit operators and trucking interests, for which there is a growing enthusiasm amongst the stakeholders, heavy trucks and buses will likely be included in the demonstration, operating separately from the passenger vehicles.

‘The AHS is no longer a fantastic device for futurists, dreamers, and science fiction writers. The technology exists, and we will see it in action in just three years.’ [Public Roads, 1994].

5.5.5 Societal and Institutional Studies

The NAHSC has taken particular note of the societal and institutional issues included in the PSA findings and also those identified by various transportation community (e.g., TRB, ITS America) and by other stakeholder groups. A special working group of the core NAHSC members has been formed specifically to address societal and institutional concerns.

A comprehensive set of tasks has been initiated. In overview, they seek to understand the benefits and impacts for a region or local area into which AHS is deployed. The estimated impact on urban form, and on rural transportation patterns, will be examined through expert analysis and modeling. ITS, and AHS particularly, has the potential to expand the surface transportation performance envelope within the existing infrastructure. There are unknowns in environmental and community impacts to be researched. One critical area for study will be the evolving regional transportation planning process, and how AHS may be mainstreamed so as to become a credible alternative available to the local and regional transportation decision makers.

Transportation services affect individuals as well as influencing regional, even national, economic growth. The roles of the human operating within, and operating in control of, an AHS, issues of human-centered automation, and how an AHS can be deployed so as to support social desires for an equitable, sustainable transportation system, will be explored through case studies, focus groups, citizen juries, and traditional public meetings.

5.5.6 Added Emphasis on the Potential of Automation for Commercial Freight Movement and Bus Transit

The application of highway/vehicle automation to commercial freight transport has strong potential to greatly increase the safety and efficiency of these operations and stimulate broad economic benefits- Similarly, automated bus transit operations offer the efficiency and flexibility needed by transit operators to increase ridership.

Relevant analyses supporting concept development and selection are already incorporated into the existing program for these heavy vehicles. Both US DOT and NAHSC see significant value in extending beyond analysis to include heavy vehicles in consortium demonstration **and** prototyping activities.

A particularly strong interest has been expressed by transit stakeholders, an example being the early involvement of Houston Metro as an Associate Participant. The vision for automated bus transit, serving commuter markets, is focused on the opportunity for early deployment of AHS

as an alternative to the very high cost mechanical guidance systems being used for transit. It should be possible to build lighter, more flexible, lower cost electronically guided transit with all the positive attributes of a tram or light rail system. Using AHS capabilities, transit low floor buses may be operated automatically with fast and convenient level platform loading now only available in light and heavy rail systems. Electronic coupling of the buses will also provide similar capacities to rail systems, but without the constraints that mechanically guided systems have. The flexible, low cost features of current manually operated bus systems will be retained while gaining the speed, customer loading convenience, reliability, and productivity of rail systems.

US DOT and NAHSC are currently negotiating to amend the existing cooperative agreement to encompass this activity. In keeping with the AHS program emphasis on stakeholder participation, it is expected that the NAHSC would engage a high-technology heavy vehicle manufacturer, on a cost-sharing basis, to perform this work.

Section 6

Operational Test and Evaluation Phase

Operational tests of the chosen AHS approach will be conducted with public participation at one or more locations.

6.1 Purpose

The Operational Test and Evaluation Phase of the AHS program will follow the Systems Definition Phase. The objectives of this phase are: (1) integrate the preferred AHS system configuration from the Systems Definition Phase into the existing institutional, technological, and regulatory environment; (2) evaluate this configuration against the program goals in an operational setting; and (3) establish guidelines by which US DOT will support AHS deployment.

6.2 Description

The Operational Test and Evaluation Phase will be a multi-year effort to study the AHS in one or more operational settings throughout the Nation. The AHS operational facility will be tailored to the AHS system configuration selected in the Systems Definition Phase. If multiple variations of the system configuration appear promising, these variations may be tested simultaneously in separate appropriate locations. In addition, for any one location, a variety of vehicle-mounted equipment may be used to further test the soundness of the configuration specifications.

The sites selected for operational testing of the AHS should be amenable to the concept being tested and to a thorough, objective evaluation. The selection of the operational test sites will depend on facets of the AHS Systems Definition that are currently unknown. Hence, it is too early to speculate on possible sites for AHS operational testing, but some preliminary criteria for choosing test sites could include ozone non-attainment level; level of recurring congestion, Carpool, Vanpool, and HOV participation level, or amenable bus transit facilities.

Several issues need to be addressed during this phase of the program. Many of the technical issues will have been resolved during the Systems Definition Phase. The most important issues in the Operational Test and Evaluation Phase are high-level issues that must be resolved before the AHS is deployed, such as the following:

- Is the level of user acceptance and projected market penetration sufficient to proceed with the AHS?

- Will the AHS meet its primary goals of safety, efficiency, and air quality?
- Can AHS fit within institutional and regulatory structures of the next decade and beyond?

6.3 Roles and Responsibilities

Contracts will be competitively awarded to public/private partnerships for development of operational test equipment that meets the AHS standards and specifications developed in the Systems Definition Phase. These public/private partnerships will agree to perform the Operational Test and Evaluation in a shared-cost arrangement. This arrangement will likely include a greater share of funding by the non-federal sector than in the R&D of the Systems Definition Phase.

The major players in the Operational Test and Evaluation Phase are expected to include the public/private partnership(s), the Systems Definition Phase consortium (possibly), and US DOT. The primary responsibility of the selected public/private partnership(s) is to implement and conduct the Operational Test(s) and Evaluation. The partnership(s) will most likely comprise representatives from State and local government, industry, and academia.

The NAHSC from the Systems Definition Phase may have the opportunity to play a role in the Operational Test and Evaluation Phase. Some possible roles could be to provide overall test and evaluation management, independent evaluation, and/or design validation (i.e., assuming responsibility for ensuring that a contractor's AHS design is compatible with national standards), and to serve as equipment and/or software licensor.

The US DOT role in the Operational Test and Evaluation Phase will be to ensure that the AHS meets the Nation's transportation and societal needs, as well as to ensure the following:

- Sufficient highways and users for adequate testing.
- AHS design validation.
- Safety and thoroughness of the testing.
- Independent, objective evaluation.

6.4 Funding

Likely funding sources for the Operational Test and Evaluation Phase include US DOT, public/private partnership(s), and State and local governments. Substantial cost share is envisioned on the part of each of these entities.

Section 7

Deployment Benefits of the Automated Highway System

The AHS will provide net benefits to individual users as well as society as a whole.

This section addresses AHS deployment. It presents the purpose and an overall description of the deployment, associated responsibilities, and funding sources.

Deployment of the AHS will be slightly different for each location in which it occurs. The deployment of an AHS will occur as part of a State or regional transportation strategy. Each State DOT and MPO will work together (perhaps with support from a Federal AHS office) to use AHS as a tool in developing its SIPS and TIPS. Even now, US DOT and the NAHSC have recognized the need to integrate AHS into the current long range planning processes of major metropolitan areas and will be active in this area throughout the program.

An AHS will be deployed only if it is expected to have many benefits. The primary benefits will correlate with the goals of the system--improved safety, efficiency, air quality, transportation reliability and trip quality. However, there are a number of additional benefits as well. Some of the benefits are not necessarily quantifiable in dollar terms but, nevertheless, must be considered in determining the worth of the system.

7.1 Deployment Scenarios

The AHS will be tailored to meet the needs of each individual State or region. The planning will need to address how the AHS will affect and interact with the existing non-AHS roadways along the proposed AHS corridor. It will also need to address approaches for addressing market penetration or urban/rural variances, and liability shielding and/or limitation on States' punitive damages. Some possible scenarios for AHS deployment include:

- **Urban Areas.** Urban areas could incorporate AHS into their transportation system for the daily commute to and from the central business district. AHS could include transit and/or HOV dedicated lane operation. AHS "ring roads," such as beltways around major cities, could provide the suburb-to-suburb commuting needed for many workers.

- **City Pairs.** AHS could be implemented to facilitate transportation between highly traveled city pairs, for example, Los Angeles-to-San Diego, or New York-to-Boston. These implementations would address the needs of both commercial and commuter transportation including passenger cars, heavy trucks, and transit.
- **Corridors.** AHS could be used to increase the operating efficiency of some of our Nation's major travel corridors, for example, the Northeast corridor. Commercial vehicle operation would most likely be a major feature for AHS in the Northeast corridor.
- **Rural areas.** Commercial vehicle operation, perhaps in a dedicated lane, would be one area of emphasis for rural AHS deployments. Major highways supporting commercial transportation, such as, I-75 or I-80, could benefit through automated trucking operations. Safety and trip quality for the long distance traveler would be another key feature of rural AHS systems.
- **Others.** Numerous other deployment scenarios can be imagined. One such special-featured scenario is the incorporation of AHS with RPEVs. While providing all other AHS benefits, this system could also make long distance electric vehicle transportation a reality.

7.2 Deployment Responsibilities

The exact roles of the key players in AHS deployment will not be known until the system and its costs have been better defined. However, some of the key players with responsibilities will include the US DOT, State DOTs, industry, private investors, and users.

The US DOT will apply guidelines for AHS deployment to ensure overall safety and national compatibility. This responsibility may include sponsoring certification of AHS equipment to ensure that it is compatible and meets specifications. Use of an AHS product may be subject to US DOT approval. US DOT may also have to respond to applications from States for infrastructure support, and may fund a certain percentage of infrastructure costs. In addition, US DOT might provide some funding for operations and maintenance.

The State DOTs may be responsible for installing the AHS systems. They may also be responsible for operation and maintenance of the systems.

Industry's role could be to design, develop, and maintain AHS equipment.

Private investors may have a role in installing and operating private AHS roads.

The users of the system will have to acquire (buy, lease) and maintain in-vehicle equipment. They may also have to pay for road use (i.e., tolls, taxes).

7.3 Funding Sources

Options for financing an AHS are varied as for conventional transportation projects [SAIC]. The funding sources will differ just as the specific AHS deployments will. Each state or locality may implement its own means of funding the AHS as part of its overall transportation plan.

A basic goal may be to seek payment from those who benefit.

- **Users** who will benefit include the following:
 - *Commuters* in transit vehicles, van pools, and passenger vehicles will benefit from reduced, dependable trip times, less stress.
 - *Non-rush-hour* travelers will also benefit from dependable trip times and more leisure time.
 - *Intercity travelers* and *intercity freight* will also benefit.
- **Communities** will benefit since less land will be needed for highways, and there will be less demand on local emergency services. These benefits may be difficult to quantify.
- **Society**, in general, will derive broad benefits from the AHS through an increased mobility on modern highways; historically, improved transportation will help stimulate the economy and international competitiveness. Development and operation of the AHS will be supported by a new industry that provides new jobs.

Having identified those who may benefit from deployment of the AHS, it is important to consider methods for funding the AHS. Some of the potential funding sources include the following:

- **Federal** grants in response to State/regional requests for matching funds for infrastructure construction.
- **Private** toll road ownership.
- **Regional** transportation groups that float municipal bonds.
- **Public** utility approach, that is given responsibility for the region's ITS.
- **Vehicle owners** who will probably pay to have their vehicles equipped for AHS usage, but there could be exceptions; for example, Vanpools and car pools.
- **Subsidized purchase** of equipment in an area as a primer to stimulate market penetration.

Some significant financial issues and concerns that will eventually need to be addressed are discussed in section 8.2.3.

AHS DEPLOYMENT

Who May Benefit?

- Commuters
- Non-rush-hour travelers
- Intercity travelers and intercity freight
- Communities
- Society in general

Who May Pay?

- Federal programs for infrastructure construction
- Private toll road ownership
- Public utility approach
- Vehicle owners

Section 8

Challenges To Be Faced

In moving the nation's highway transportation system toward automation, major challenges will be faced.

This section describes some of the more critical system-wide challenges that, should they not be successfully addressed, could delay AHS implementation.

8.1 System Design

The overall conclusion from the PSA Final Results Conference was that the technical aspects of a fully automated highway system seem to be manageable. Basic research is not needed to achieve full vehicle control on an AHS; rather the AHS will apply technologies already researched and developed. This is not to say that there is nothing left to do; engineers will need to conduct trade-off analyses, develop basic designs, and optimize approaches for the desired level of safety, performance, reliability and cost. Some of the major areas in which engineering resources will need to focus are described below.

8.1.1 Smooth Transition to Full Vehicle Control

An AHS requires that equipment be added to both vehicles and highways. Highway lanes cannot be instrumented and dedicated to AHS use if there are very few vehicles to use them. On the other hand, adding AHS equipment to a vehicle will cost something; owners may not be willing to pay for this equipment if there are no highway lanes dedicated to AHS use. Several alternatives have been discussed as possible solutions to this “chicken or egg” problem. There are two basic approaches-national **evolution** and **regional conversion**. In both cases, it is recognized that instrumentation of AHS lanes can begin in advance of when actual AHS operation may begin.

The national evolution approach is based in the prospect that many vehicles over the next ten to fifteen years may have the capabilities needed for full vehicle control already built in. Longitudinal control capabilities will include forward-looking sensors coupled to control of the vehicle's throttle and brake. Today's cruise control actuates the vehicle's throttle. Within a few years, many believe that adaptive **cruise** control will be available for purchase. This feature will sense the vehicle ahead and maintain a safe distance from it. The **frontal collision avoidance** feature will add the potential for the vehicle to avoid a collision if the vehicle in front brakes hard or stops suddenly.

Lateral control will be provided by the **lane-keeping** feature which will control the vehicle's steering so that it automatically maintains its lateral position in the lane.

Both the adaptive cruise control and lane-keeping features can be used in mixed traffic (i.e., by vehicles intermixed with vehicles not equipped with those features), but the resulting safety and efficiency benefits will be less than their full potential because of the intermixed non-equipped vehicle traffic. For increased safety and efficiency, the regional transportation planners will, at some point, dedicate a lane for use only by cars equipped with both adaptive cruise control and lane keeping. Additionally, the dedicated lane will probably have overall traffic flow control and traffic management capabilities. At that point, full vehicle control will begin and full benefits will be realized.

Other researchers believe that a **regional conversion** to AHS will be more viable. They are concerned that the evolutionary path may not be smooth since, to them, it is not apparent that many drivers will invest in adaptive cruise control and lane-keeping features.

This vision is that one city or region at a time will choose to convert to AHS along heavy traffic corridors. For example, an initial AHS user population could develop with the conversion of transit vehicles, government vehicles and taxi fleets. Creative approaches to developing additional users could include incentives programs such as free conversion of HOV or electric vehicles, long term leases of the equipment, and/or programs to offset some of the cost with lower insurance rates. Initial public participation could also be encouraged through promotions involving one-day car rentals at low costs.

When the AHS lanes are initially opened, usage could be low; but the belief is that once drivers see the AHS lanes operating smoothly and dependably, the desire to convert will quickly increase.

8.1.2 Congestion at Automated Highway System Entry and Exit

The AHS must be incorporated into a region's overall transportation plan and its entry and exit points must integrate smoothly with surrounding non-AHS roads and lanes. Nevertheless, even with thorough planning, there will be the potential for congestion as vehicles seek to enter AHS and where vehicles try to exit from AHS. Dealing with this potential congestion will require system-wide engineering as well as engineering directed at the specific interchange.

8.1.3 Detection of Foreign Objects

Roadway debris (small objects such as boxes less than one-foot high, tread from truck tires, mufflers that have fallen off of vehicles) presents a particular hazard for an AHS; today, drivers detect and steer to avoid such debris. Many different approaches have been suggested for detecting and avoiding these materials. Combinations of these approaches may need to be used on different roadways:

- Reduce debris falling off vehicles through periodic vehicle inspections; use fences at pass-overs and in rural areas.

- In urban areas, use video cameras to detect objects that are not moving vehicles.
- Use each vehicle as a sensor; when a vehicle detects unusual action a warning can be sent to following vehicles and to the roadside traffic control computers.
- Use the driver as a sensor; that is, ask drivers to maintain a watch for roadway debris. This would require that the driver be provided with a means for reporting to the AHS system that there may be a problem.
- Use a roving roadside monitor that would constantly scan the roadway surface for foreign objects.

8.1.4 Nationwide Compatibility and Local/Regional Tailoring

The US DOT visualizes the AHS as evolving to a nationwide network so that a driver can cross the country using AHS and feel that the AHS in Los Angeles is as familiar as in New York. On the other hand, the AHS is envisioned as a tool to be used by an MPO and/or a State DOT to be tailored to help meet its local needs; thus, as discussed before, an AHS in one city may be for transit and HOVs only, while in another locale, the system use is unrestricted.

Example approaches to this issue include:

- AHS standards could be defined for different “classes” of vehicle—for example, narrow, normal and heavy. Large trucks would only be able to use lanes designated for their use; normal vehicles could only use the normal and heavy lanes; and narrow vehicles could use any AHS lane. The US DOT would then set standards for the different vehicle classes.
- All rural and intercity AHS systems would have at least one heavy vehicle lane; however, within a city’s boundary, lanes could be restricted to, for example, narrow and/or alternate propulsion vehicles only.

8.1.5 How Safe is Safe?

There are many design and engineering trade-offs that must be addressed. One example is the system’s safety. How safe will the public expect the system to be? As noted above, it will be far safer than today’s highways or the state-of-the-art highways designed for manual vehicle control in the next century. But what level of safety is attainable and sustainable within a realistic cost? Also, can the predicted improvements in system efficiency be achieved if safety requirements become extreme?

8.1.6 The Human Response

One challenge of particular concern is understanding and managing the human aspects of full vehicle control. The system must be designed so that the role of the driver through various phases of transition to the AHS is accommodated. The transfer of control to the system, and then back again to the human will need to be carefully researched. Also, reactions to the closer

operating headways possible with an AHS need to be carefully studied. The system cannot scare its users.

8.2 Institutional and Societal Environment

In the 25 years since we returned from the moon and asked why can't we get across town, the necessary **technology** has been developed to significantly improve our traffic situation through the deployment of automated systems. However, the introduction of new technologies, such as automation, often also creates tensions. Deployment of local and regional AHS will face the same challenges that other transportation improvement programs face. And there will be additional challenges that are unique to AHS-members of the public and public support institutions have stated concerns that are recognized and are being addressed by the National AHS Consortium (NAHSC).

Examples include conforming to legislation (e.g., the CAAA), allocating environmental and land use impacts, developing cooperation among local and regional jurisdictions, and securing funding sources. Such institutional and societal issues are typically more challenging and difficult to bound than technical issues. Technology is not a guaranteed "fix" for social problems, and in some cases, new technologies may create more problems than they solve. But, in his presentation to the Transportation Research Board in January of 1994, Secretary Pena commented that: "We can meet these challenges by providing 'sustainable transportation'-transportation that meets the needs of this generation without compromising the ability of future generations to meet their needs." [Volpe].

This section describes some of the areas of concern that have surfaced during the PSA studies in which the opinions of a wide range of interested parties were sought and recognized. Many feel that institutional and societal issues will be more difficult to resolve than technical issues, and that the outcome of their resolution will have more influence on the overall success of AHS.

A critical AHS Program goal is for AHS to be recognized for what it can contribute to the total spectrum of regional surface transportation needs in traditional transit, commercial, rural and urban, private and evolving public para-transit environments-that it should be viewed as a **flexible tool** available to transportation planners and decision makers when they address the complexities of doing more with what they have, not as an inflexible closed solution to one specific type of problem.

8.2.1 Societal Concerns

Applying automation to the Nation's highways is bound to involve many elements of society. However AHS is introduced (locally, regionally, on special corridors, etc.), many people will have questions about what AHS can do for them and how it will affect their quality of life. Clearly, the benefits must be credibly demonstrated (avoiding misrepresentations of either the capabilities or the limitations) in order to communicate the value to both the individual user as well as to the larger community. The NAHSC, recognizing this challenge, is planning a

comprehensive program of outreach and demonstrations. Nevertheless, AHS may be opposed by groups who are simply against more highways, mobility, and the associated impact on urban and rural form, regardless of potential net benefits.

The leading societal concerns that were identified by the PSA work are:

- **Environmental Impacts.** The NAHSC is planning research to continue the PSA efforts at understanding how AHS can play a positive role regarding air and water quality, and noise [Calspan, Walsh, 1994]. However, the concern remains that an AHS might encourage/induce more internal combustion engine vehicle miles traveled (VMT); if so, then overall emissions and fuel consumption may increase even though emissions are reduced on a per-vehicle-mile basis. ISTEA has provided the framework for addressing these conflicting requirements (those that would deliver 'green mobility') in the expanded planning role given to MPOs. MPOs should be able to take advantage of AHS's special characteristics as they incorporate AHS into their transportation plans. In non-attainment areas, AHS could be used to enhance transit, HOV traffic, congestion management and the introduction of alternative propulsion (low and zero mobile source emission) vehicles.
- **Equity.** System deployments financed with public funds must address social equity. A limiting (restrictive) deployment would be subject to proper criticism even though AHS is expected to reduce congestion on both AHS and non-AHS roads. Each region will need to consider the demographic and economic impacts of its AHS installations and pricing.
 - Should the State and/or Federal Government provide incentives and/or help to individuals to equip their vehicles with AHS instrumentation?
 - Would a toll-financed system reduce equity concerns (users pay all costs) or would it raise concerns about discrimination against people with lower incomes who would pay a greater share of their disposable income for the service?
- **Land Use and Development.** There are concerns for direct and indirect impacts of AHS on land use. The direct impacts have to do with entry and exit facilities and general infrastructure improvements that will probably be undertaken when an AHS is deployed. Beyond the concerns for the environment and equity described above, there are practical issues for surface street operations, local traffic management, signaling, and maintenance. PSA researchers conducted preliminary studies on Route 101 in the Los Angeles area, the Long Island Expressway, and I-17 running north out of Phoenix. The overall findings were that AHS deployment in relatively restricted rights-of-way could be achieved using current highway design practices. The traffic flow modeling showed improvement to the parallel surface street congestion as well as trip-

time advantages on the AHS lanes. These studies were highly site specific as any actual deployment will also be; however, they provide a useful foundation for NAHSC case studies that will continue this work.

The indirect impacts on regional development are a larger question that will be addressed extensively by the NAHSC. Planning analyses to identify the effects on land use that an AHS deployment may precipitate will be a necessary part of MPO level deliberations within the ISTEA planning framework. One need is to determine the different impacts (if any) that deploying AHS will bring compared to deploying regular highways and/or light rail. These will be very area-specific as are the predicted benefits such as trip-time value patterns and flexibility in regional development concepts.

- **Role of the driver.** Concerns identified by the PSA research include:
 - To what extent will additional skills be required to use an AHS?
 - Will the AHS be a significant aid for senior citizens and the physically impaired who sometimes avoid today's highways and their congestion and stress?
 - Will the driver be "checked-in" to AHS as well as the vehicle?
 - What sort of responsibility will the driver and passenger have, if any, during regular and emergency conditions?
 - What will drivers be comfortable with?

8.2.2 Legal Issues

Legal issues have been fully addressed in the Non-technical Constraints and Barriers to Implementation of Intelligent Vehicle-Highway Systems Report to Congress from the Department of Transportation, dated June 1994 [US DOT, 1994]. Four areas of legal issues were identified: Antitrust, Liability, Privacy, and Intellectual Property. The following paragraphs summarize that report's findings. The AHS program will build upon these analyses, and will interact within the Department to ensure integration of AHS concerns.

Antitrust issues were identified as a concern primarily because of a perception in the business community that particular conduct, especially by joint ventures, could be found to violate the antitrust laws. Such a condition would subject the parties to substantial damages. However, past judicial decisions have made clear that the antitrust laws allow private firms to form joint ventures for legitimate purposes. And Congress' reduction of antitrust liability for joint ventures, the National Cooperative Research and Production Act of 1993 (NCRPA), reduces the risk for joint ventures and limits damages due to notification procedures. "US DOT has concluded that the antitrust laws should not hinder the development of IVHS (sic) and that no remedial legislation is needed at this time." [US DOT]. Subsequent AHS program precursor analysis studies concurred with this finding [SAIC, 1994].

Similarly, DOT does not believe at this time that liability will present any barriers to the development and implementation of ITS technologies. It was noted that liability exposure could be limited by sound engineering principles; ITS performance experience and information should alleviate any reservations. PSA researchers reviewed the product liability costs for an AHS and have indicated that it can be controlled through careful design, legislation, and cost transfer. Tort liability is not seen as a ‘show stopper’ if costs are controlled and safety is secure [SAIC]. This echoes the findings of the Non-technical Constraints and Barriers report that “it is too early to consider legislation or other actions . . . ” The ongoing ITS program will provide some basis for predetermining the conditions for AHS. It will help identify those areas of future deployment and operation that are most likely to have significant liability risks as well as to identify possible solutions. The AHS consortium and its participants will continue to identify and study liability issues and concerns that may be AHS-specific, such as level of driver control of the vehicle, and the transfer of control between the driver and the system.

The ITS community must be sensitive to the public’s perceptions and demands around issues of privacy. DOT must ensure proper conduct in the handling of personal information. However, AHS technologies are less likely to be constrained when benefits are clearly understood and perceived as outweighing any adverse effects on privacy. Potential areas for concern focus on surveillance technologies, electronic payment services, ride sharing options, and the operation of commercial vehicles. This is part of a broad societal concern for impacts linked to living in the information era. This is an area in which the AHS program must remain sensitive to concerns.

The private sector is concerned that the retention of intellectual property rights by US DOT or a state agency may be too broad. They foresee difficulties in recovering pre-development and research costs. The challenge is to balance intellectual property interests of state and local agencies with those of the private sector. The US DOT found that Federal patent policy affords sufficient protection for private developers of intellectual property who employ federal funds. Concerns that the government may “crowd out” AHS developers were not considered justified. Recommendations from a US DOT-sponsored workshop on intellectual property included focusing on the subject early in the process of agreement formation. This advice was followed when the NAHSC was established.

8.2.3 Who Pays for the Automated Highway System?

Options for financing an AHS are varied as for conventional transportation projects [SAIC, 1994]. Significant financial issues include:

- While there are many ways in which AHS costs can be covered, it is the structuring and division (this relates to the potential exclusivity of AHS) of these costs that will or will not give the perception of whether it is “worth it.”
- To what extent can or should AHS infrastructure be paid for with fuel taxes?

- Can/should financing and building of the AHS infrastructure be handled by an entity that has the rights and privileges of a public utility?
- Will confidence materialize that the market share and governmental support are sufficient for investment to occur? This concern includes the ability to obtain (and operate on) public rights-of-way.
- Should high-occupancy vehicles travel free in rush hours? Should the system offer discounts for use during non-peak periods?
- Should the Federal Government provide support to States for operations and maintenance costs because of the increased level of funds required for these types of activities? The ISTEA of 1991 drew attention to the concept of funding for operations and maintenance.

8.2.4 State and Regional Institutional Concerns

The AHS will introduce a new, high-technology level of complexity to those organizations that are responsible for highway functions and services. The AHS lane instrumentation could include advanced electronic sensors, on-line computers and software, and multi-element integrated communications systems. Installation and maintenance of these systems may present a significant challenge to the operators. For example, maintenance of roadside electronics may involve relatively frequent circuit and/or software testing, component replacement, and system integration testing, as the replacement components are brought on-line. An advanced AHS will employ traffic management functions which may involve real time system monitoring; the operators for such a system will need special training. Planning organizations that recommend AHS must realize that the funds for the systems' operations and maintenance must be adequate and must be included in the State's operating budget as a non-negotiable item [Battelle, 1994].

Approaches to meeting these challenges include the following:

- **State transportation organizations are evolving.** As planning for AHS begins, funds to build up and evolve the State's transportation departments will need to be made available so that technical staff can be hired and trained. Career paths will need to be established and job descriptions created. This front-end cost will increase State DOT costs long before the AHS becomes operational.

- **Facilities management firms can be hired.** Full service management of the AHS infrastructure could be privately provided. However, this could introduce questions regarding the liability of these firms when incidents occur.
- **Facility ownership could be private,** such as a private toll road.
- **A separate public utility type of organization could be established** to fund, build, and maintain AHS.
- **Insurance companies and insurance regulators** will need to assess the affect of AHS operation on rates.
- **Programs for inspection** of AHS vehicles will need to be established.

8.2.5 National Certification and/or Regulation

National standards for AHS will need to be established to ensure (1) national compatibility among AHS systems that develop regionally; and (2) that minimum levels of safety and performance are met.

It will be necessary to certify that the vehicle manufacturers' products meet the standards and specifications. Similarly, as companies design roadside components, those will also need to be certified to ensure that they operate with the vehicles. A national organization will need to be designated as the US DOT's certification agent.

Standards for operation and maintenance of AHS systems will also be needed. This could include standards for periodic vehicle inspection, AHS check-in and AHS maintenance and traffic management and control. PSA findings referenced an appropriate model for regulations arising from a cooperative arrangement between FHWA, NHTSA, the auto manufacturers, and States [SAIC, 1994].

8.2.6 Political Pressures Versus Engineering Realities

A major new system that will directly interact with the general public faces significant pressures from two sides. The engineering of such a system in the general public eye increases the need for very thorough testing to ensure safety, robustness and operability; every possible way of system malfunction must be identified and designed around. The safety of the system must be demonstrated.

As major public sector investments, public and political leaders may get impatient with the cost and the amount of time it takes to develop them. These concerns must be balanced with the engineering needs.

8.3 The Challenges in Summary

The consensus opinion from the PSA Studies Results Conference is that there are no technical show stoppers. The engineering challenges can be met and solved.

However, legal, legislative, institutional and societal challenges may be more difficult to resolve than the technical issues, and may have more influence on the overall success of AHS. These institutional and societal issues may only be solved slowly. While AHS will be a consumer product that has major potential to mitigate (rather than solve on its own) a number of social and economic challenges, the public must determine this to be the case.

For this to happen, the AHS program must demonstrate that AHS brings major transportation benefits (safe, efficient, affordable, desirable and easy to use) and can be used to enhance a region's efforts to improve its air quality, land use, and achieve its development goals. The PSA results broadened our understanding of the pertinent issues-areas which we must explore further. Therefore, key questions for further research include how AHS will affect:

- Land use and development.
- Energy and environmental resources and their allocation.
- Transportation sustainability.
- Regional and national economics.
- Mobility/Quality of life issues.
- Travelers' safety.

The NAHSC is conducting a comprehensive program of research that specifically addresses the institutional and societal issues alongside the technical planning for enabling technologies. A substantial portion of the program resources are earmarked for outreach, public forums, environmental analyses, and for addressing institutional issues. Another major portion of the NAHSC resources are planned for acquiring/developing the models and tools with which to explore these key questions.

A major characteristic of the NAHSC approach to dealing with these challenges is expressed in the management and decision making structure designed into the NAHSC program. The intent is to develop a national consensus. The process proactively involves stakeholder and interest groups in the consensus process. These groups include the vehicle industry, state and local government agencies, the highway design industry, the vehicle electronics industry, environmental interests, trucking concerns, transit operators, public transportation users, and the insurance industry.

Section 9

Recommendations For The Future

AHS needs continued support from Congress in this early research so that AHS benefits can be demonstrated.

This section addresses programmatic, legislative, and other items that may be needed for a successful AHS program and deployment. Because the AHS program is in its early stages, many of the needs have not yet been formulated. Similarly, the recommendations and needs presented in this section may change or even disappear. Therefore, this section highlights the **current** recommendations based on the status of the program today.

9.1 AHS Program Needs

When the ISTEA of 1991 was enacted, the structure of the current AHS program was unclear. The structure, as defined in section 3.2, is now clear; a multi-year program is in place to ensure that the AHS will be a tool for transportation planners in the 21st century.

Continue Congressional support for the AHS Program through Phase II until AHS feasibility is determined and the system for the Nation has been chosen.

Since the passage of ISTEA established the program, a national consortium of state/regional transportation agencies, vehicle manufacturers, and highway industry representatives has been formed and is conducting the AHS program in cooperation with the US DOT. These stakeholders are committing their skilled resources and management energies. This momentum must be maintained to realize the promise of the automated highway in operation.

The ISTEA legislation emphasized the 1997 Demonstration as an important milestone; it has been framed in a full program of six major milestones over the next seven years. For this reason, it is imperative that the support for the program go beyond the demonstration milestone.

Therefore, continued Congressional support for AHS in subsequent authorizing legislation is necessary to maintain consistent investment by the non-Federal partners, and to determine the preferred feasible configuration for the Nation.

Establish Congressional support for AHS Operational Test and Evaluation (Phase III).

Beyond the 1997 demonstration is the selection and prototype testing of the preferred AHS configuration. Upon completion of the systems definition phase, the preferred configuration will next undergo operational test and evaluation. The support for this phase of the program is crucial to the successful deployment of AHS. Only through operational testing can the public understand, experience, and appreciate the promise of AHS. As described in section 6, much of the cost associated with the operational test and evaluation phase will be shared by private sources through public/private partnerships.

9.2 Legislative Needs for Deployment

As the AHS program progresses, the special legislative needs that the AHS requires will be better understood. These special legislative needs may arise from the uniqueness of the AHS as a transportation tool. At this stage in the program, no specific legislative needs (other than continued support) have been identified.

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Appendix A

Brief Automated Highway System History

Highways are built in response to a need. For example, the Interstate Highway System was built because the Nation was rapidly expanding, and both private and commercial travelers wanted greater connectivity and mobility to visit aunts and uncles, or to reach new markets. The decision to build the interstate system was also made at the height of the Cold War when national defense and evacuation were on everyone's mind.

When a highway is built, the best design available is used. The interstate system was designed for safe, high-speed travel with wide lanes, and roadways and barriers that could provide the needed safety and comfort.

As pointed out in Section 2, the Nation is continuing to evolve and to count heavily on our vehicle-highway system as its primary mode of transportation. But times have changed. Today, industry seeks more efficient transportation to help meet foreign competition; urban planners seek more efficient use of existing highway rights-of-way to limit the need for more land; and more efficient highway operation is sought to minimize vehicle impact on air quality.

Because of the evolution of computers and information systems, we now have a new technology-automation-to apply to the Nation's vehicle-highway system to help meet the sometimes conflicting needs of greater safety, mobility, and highway efficiency. Below, the path toward highway automation is described.

A.1 Visions of Automation Since the 1930s

The concept of automated travel on a highway has been around for quite a while. The General Motors (GM) Corporation pavilion at the 1939 World's Fair presented a futuristic vision in which vehicles moved under automated control along the road. **Popular Mechanics** also depicted futuristic visions of a vehicle-highway system in which vehicle movement would be mechanically controlled, and passengers could enjoy the scenery as they were moved along an automated guideway.

A.2 Early Research

In the late 1950s, research into automated vehicle control was conducted by various industrial organizations, Government agencies, and academic institutions, both in the United States and abroad. The early research in the area of automated rubber-tired vehicles was focused on the longitudinal and lateral control of the vehicle. Vehicle movement in this early research was, for the most part, based on early visions of mechanical control, such as underground cables or conveyor belts. Vehicles could drive onto the system, be transported to their destination, and then exit and drive away-one of the first visions of intermodalism. Computers were unreliable vacuum tube-based behemoths that required large air-conditioned rooms. There were few visions for their use beyond research and business accounting.

A.3 The 1960s

By the early 1960s, the first transistor computers had appeared. They were much smaller, more dependable, and more affordable. Researchers began to think of their potential uses at the roadside to provide traffic management, as well as lateral and longitudinal control. It was then that the research began to consider the feasibility of an overall network of automated vehicles operating on a highway system.

Two initiatives that further increased the interest in automated vehicle control were the Northeast Corridor Study, initiated in 1966 by the Federal Railroad Administration, and a 1968 report by the Department of Housing and Urban Development (HUD) entitled ***Tomorrow's Transportation Today***. Part of the Northeast Corridor Study focused on an automated highway system as a means of relieving congestion along the corridor. The use of synchronous network control and estimates of system cost and performance characteristics were part of this study. The HUD report spurred increased effort devoted to automated ground transport for urban areas. Much of this effort was focused on transit, and included automated guideway transit and the application of dual-mode vehicles for intra- and interurban or intercity travel.

In addition to studies addressing the automation of individual rubber-tired vehicles, there was also an investigation into the feasibility of using automated pallets as a means of providing intracity and intercity travel. These studies envisioned automobiles and freight riding atop automated pallets that would travel along a network of guideways. The studies varied greatly in both concept and approach. For example, some of the proposed propulsion methods included a cog-railway drive technique, liner induction motors, and direct current traction motors [Bender, 1982].

Prototypes and experimental equipment were developed and tested by organizations such as GM, Ohio State University, the Japan Governmental Mechanical Laboratory, the United Kingdom Road Research Laboratory, Ford Motor Company, and the Japan Automobile Research Institute. It was not until the late 1960s that some of the research began to address the network control aspects of automated highway systems, as evidenced in a study conducted at the Massachusetts Institute of Technology [Bender, 1982].

A.4 The 1970s

Automated vehicle control research continued and expanded in the 1970s, but with heavy influence from the Nation's computer revolution. It was in the early 1970s that the first microprocessor chips became generally available. Powerful computers, by 1960 standards, could now be fit on a single one-by-three-inch chip. And these chips were cheap-enough to go inside typewriters and home appliances.

This computer revolution opened up new horizons for automated vehicle control. Computers could now be mobile and travel with the vehicle, rather than staying by the side of the road.

FHWA funded automated vehicle control work at Ohio State University, Calspan Corporation, and GM. This work took a systems-level view of AHS in the context of the overall transportation system.

The Ohio State University work built upon work begun in 1964. Studies examined headway safety policy, longitudinal and lateral control of vehicles, and highway system operations. The headway safety policy studies examined the tradeoff between short headways and safety. The longitudinal control studies focused on vehicle longitudinal dynamics and control theory, with emphasis on both the asynchronous and synchronous approaches. Both types of systems were successfully demonstrated in field testing. The lateral control studies focused on vehicle lateral dynamics, lateral reference systems, and prototyping and testing of vehicle lateral controllers. Successful field tests included the demonstration of automatic lane changing at speeds up to 77 mph (124 km/hr). Highway system operations issues at the network, regional, and sector levels were studied using extensive simulations [Bishop, 1993].

Calspan Corporation conducted AHS feasibility studies in 1976 and 1977, based on various representative AHS system concepts, with respect to both technical and socioeconomic issues. Overall, the studies concluded that the AHS concept is feasible, based on demand analyses, evaluation of the technical challenges, and cost analyses showing the advantages of AHS deployment over the construction of additional freeway travel lanes [Bishop, 1993].

In the late 1970s and early 1980s, the GM Transportation Systems Center analyzed and evaluated a set of candidate AHS system concepts to determine their practicality for deployment in the 1990 through 2000 time frame. Extensive analysis and trade studies were performed in areas such as phased automation, energy consumption, system velocity, institutional issues, and reliability. The recommended system concept emerging from these studies was a smart vehicle with a self-contained power supply, utilizing a passive guideway. Projected benefits in lane capacity, system safety, energy consumption, environmental and community impact, and level of service were reported [Bishop, 1993].

In the 1970s, work broadened to include in-depth research into the dual-mode bus-buses that operate under full automated control in confined areas such as guideways or tunnels, but under driver control on regular roads in the suburbs.

A.5 Recent Work

With sponsorship from the Caltrans and FHWA, the PATH program has carried on substantial research efforts in highway automation from the late 1980s through the present [Bishop, 1993].

PATH's focus is on full automation of the driving function. The longitudinal control task is based on car-following algorithms, with vehicle-based processors for vehicle control, including a lateral control approach based on passive reference markers inserted into the pavement at appropriate intervals. Extensive theoretical work has been conducted to analyze

the vehicle dynamics and derive the necessary control laws for lateral and longitudinal control. Testing has successfully demonstrated the feasibility of these control concepts. Longitudinal tests included tests of four-car platoons traveling at highway speeds with closer-than-normal headways, and lateral tests included a single instrumented vehicle traveling down a 480 meter test track under a range of nonideal conditions [Bishop, 1993].

In addition to the work being conducted at PATH, technologies initially developed for the Department of Defense are being researched for possible application to vehicle-highway systems. Recent work jointly performed by the National Institute of Standards and Technology (NIST) and the Florida Atlantic University (FAU), and cost-shared with FHWA, applied machine vision technology to the task of road following. In late 1992, NIST and FAU researchers demonstrated a vehicle following a well-marked road using autonomous lateral control, based on machine vision at speeds of approximately 55 mph (88 km/hr) [Bishop, 1993].

A.6 Recent European and Japanese Work

As in the United States, automobile manufacturers in Europe and Japan are performing internal research into advanced vehicle control technologies (e.g., intelligent cruise control, steer-by-wire). In addition to this internal research, both the European and Japanese governments are funding programs in the area of advanced vehicle control. The European DRIVE II program continues tests of cooperative driving functions identified in the European PROMETHEUS program. The main thrust of these tests will be towards intelligent cruise control and intelligent maneuvering control in the highway environment [DRIVE, 1992]. In Japan, the Personal Vehicle System (PVS) project was initiated in 1987 to explore the feasibility of autonomous vehicle operation. Under this project, a van was equipped with instrumentation for supporting autonomous steering and braking based on stereo imaging, laser range-finding of obstacles, and ultrasonic sensing of adjacent guardrails. In 1991, feasibility studies were begun on a very long-range Japanese project called Super Smart Vehicle System (SSVS). The SSVS study is intended to investigate accident recognition and avoidance, assistance to the driver's control manipulation task, and control supplements that may improve highway throughput [Ervin, 1991].

Appendix B

List of Precursor Systems Analyses Contract Team Members and Locations

Battelle Team

• Battelle	Columbus, OH	Seattle, WA
• B R W	Minneapolis, MN	Phoenix, AZ
• JHK & Associates	Emeryville, CA	Norcross, GA
• Mass. Institute of Technology	Cambridge, MA	
• Ohio State University	Columbus, OH	
• Transportation Research Center	East Liberty, OH	
• University of Minnesota	Minneapolis, MN	

BDM Team

• B D M	McLean, VA	
• CambridgeSystematics, Inc.	Cambridge, MA	
• George Mason University	Fairfax, VA	
• SNV	Germany	
• Sverdrup Civil, Inc.	Boston, MA	White River, VT

Calspan Team

• Calspan	Buffalo, NY	
• Arvin Automotive	Buffalo, NY	
• B M W	Germany	
• Connecticut DOT	Hartford, CT	
• Dunn Engineering	Plainview, NY	W. Hampton Beach, NY
• Massachusetts DOT	Boston, MA	
• New Jersey DOT	Trenton, NJ	
• New York State DOT	Albany, NY	
• NY State Thruway Authority	Albany, NY	
• Farradyne Systems, Inc.	Rockville, MD	
• Parsons Brinkerhoff	New York, NY	
• Princeton University	Princeton, NJ	
• TRANSCOM	Jersey City, NJ	

Delco Team

- | | | |
|----------------------------|---------------|---------------|
| • Delco Systems Operations | Goleta, CA | |
| • DMJM | Phoenix, AZ | |
| • General Motors Corp. | Detroit, MI | |
| • Hughes Aircraft Co. | San Diego, CA | Fullerton, CA |
| • Univ. of Calif. (PATH) | Richmond, CA | |

Honeywell Team

- | | |
|-------------------------------|--------------------|
| • Honeywell Technology Center | Minneapolis, MN |
| • Purdue University | West Lafayette, IN |
| • Univ. of Calif. (PATH) | Richmond, CA |
| • University of Minnesota | Minneapolis, MN |

Martin Marietta Team

- | | |
|-------------------|------------|
| • Martin Marietta | Denver, CO |
|-------------------|------------|

Northrop Team

- | | |
|------------|-----------------|
| • Northrop | Pica Rivera, CA |
| • P A T H | Richmond, CA |

PATH Team

- | | |
|----------------------------------|---------------------|
| • P A T H | Richmond, CA |
| • Bechtel | San Francisco, CA |
| • California DOT | Sacramento, CA |
| • Calif. Polytechnic State Univ. | San Luis Obispo, CA |
| • Lawrence Livermore Nat'l Lab. | Berkeley, CA |
| • Rockwell International | Anaheim, CA |
| • Univ. of Southern California | Los Angeles, CA |

Raytheon Team

- | | |
|------------------------------|---------------|
| • Raytheon Company | Tewksbury, MA |
| • Daimler Benz | Germany |
| • Ford | Dearborn, MI |
| • Georgia Institute of Tech. | Atlanta, GA |
| • Tufts University | Medford, MA |

- Univ. of Southern Calif. Los Angeles, CA
- vHB Watertown, MA

Rockwell Team

- Rockwell International Corp. Anaheim, CA Thousand Oaks, CA
- Univ. of Calif. (PATH) Richmond, CA
- Systems Technology, Inc. Hawthorne, CA
- JerryWard El Cajon, CA

SAIC Team

- SAIC McLean, VA
- McDermott, Will & Emery Washington, DC
- McGuire, Woods, Battle & Booth McLean, VA

SRI Team

- SRI International Menlo Park, CA

TASC Team

- TASC Reading, MA Arlington, VA

TRW Team

- TRW San Diego, CA Redondo Beach, CA
- Calif. Polytechnic State Univ. San Luis Obispo, CA

UC Davis Team

- Univ. of California, Davis Davis, CA
- California DOT Sacramento, CA

Appendix C

Phase 1 Results To Date

This appendix summarizes some of the results to date of the analytical phase AHS program.

C.1 AHS Human Factors Study Results

Below is a summary of the results to date developed by the Honeywell team. Activities in both analytical and empirical research have been ongoing. The project is currently **in the** second stage of activities, with completion scheduled for March 1996.

C.1.1 Analytical Tasks

The following analytical tasks have been completed.

AHS objectives and performance requirements have been identified. Within this identification effort, several AHS scenarios were developed. These scenarios had a high degree of concordance with the representative system configurations developed separately for the AHS precursor systems analyses. Three of the scenarios were selected to serve as the basis for the continued analyses.

Functions the AHS must support have been defined. Several issues were identified that relate to specific AHS functions:

- The selection of traveler destination was determined to cause significant workload for the driver while the vehicle is operating in the manual mode.
- The use of the driver as a back-up in AHS operation may be ineffective because of the limited time available for response.
- The incorporation of “free-agent” vehicles (i.e., highly intelligent vehicles making all individual vehicle control decisions) may cause drivers to place too much trust in the automation.

Systems comparable to the AHS have been analyzed. The following systems were analyzed to discover possible lessons learned from their experiences:

- The Washington Metrorail surface and underground subway system. This system operates under automatic control, whereby the driver’s primary function is to open and close the train doors at the stations.
- The German 0-Bahn buses, which operate in automated mode on concrete guideways.

- The English Channel Tunnel Repair Vehicle, which operates under automated lateral control.
- Autopilot and flight director systems, specifically, the Airbus A-320 and Boeing 757 systems. These systems allow automated control after takeoff.

Some valuable lessons learned from these systems can be applied to the AHS: (1) noncritical messages to the driver should be kept to a minimum; (2) if a driver disregards a system alert, the vehicle should be stopped; and (3) locked versus reflective controls should be considered for the AHS (i.e., the steering wheel and throttle and brake pedals would not have to move during AHS operation).

Driver performance requirements and parameters have been developed. Some conclusions were discovered related to driver performance requirements:

- Route selection by the driver could be a problem in the transition lanes of an AHS.
- Low-priority annunciations should be suppressed for experienced drivers.
- The driver as a back-up for longitudinal control is possible if lateral control is maintained.

Ongoing analytical tasks include development of the human factors handbook for AHS design, intended to meet the requirements for an AHS design team. In addition, this handbook can be used as educational reference material for the AHS design process. It will also recommend specific guidelines for AHS interface design parameters. As noted, a first draft of this handbook was completed during the fall of 1994.

C.1.2 Empirical Research

Empirical research is ongoing, focused on the following issues:

- Driver performance in entering the AHS.
- Driver performance in exiting the AHS.
- Transfer-of-control methods to enter the AHS.
- Driver acceptance of different inter-vehicle distances on the AHS.
- Driver performance with reduced AHS control.
- Effect of automated driving on subsequent manual driving.

Early results from the simulation studies of drivers transitioning from an automated to a manual mode have been collected. One interesting result relates to the amount of distance that is “lost” as a result of automated vehicles exiting the system. This “lost” distance corresponds to the disruption caused in the automated lane (i.e., slowing down and speeding up) during a vehicle exit maneuver versus steady-state operation in the automated lane. At an operating speed of

104.5 km/h (65 mph), the lost distance is approximately 60 meters; at an operating speed of 153 km/h (95 mph), it is approximately 220 meters. Of interest is that at lower operating speeds, most of the lost distance is attributable to limitations of the driver. However, at higher operating speeds, the automated vehicle system response is responsible for an increasing percentage of the total lost time. This result is highly dependent on the infrastructure configuration posed for the analysis, and points out the effects of large variances between operating speeds in the automated and manual lanes.

This human factors research is ongoing and will continue to provide the AHS community with much-needed data.

C.2 Collision Avoidance Results

As discussed in Section 4, NHTSA is implementing its five-element collision avoidance program. This is a long-term, multidisciplinary program that will (1) build research tools and use these tools to compile driver/vehicle performance data bases, (2) determine problem size and the statistical description of major crash types, (3) develop technology-independent performance requirements (both hardware and human factors) for advanced technology systems to assist drivers in avoiding crashes, (4) work with the industry to facilitate development and early deployment of effective collision avoidance systems, and (5) ensure no loss of safety as mobility- and productivity-enhancing systems are incorporated into motor vehicles. Those NHTSA collision avoidance projects which are relevant to AHS are described below grouped according to the elements of the NHTSA strategic plan:

C.2.1 Thrust 1: Build Research Tools and Compile Knowledge Bases

- NHTSA (Contraves and TRW) are developing competitive designs for a state-of-the-art National Advanced Driving Simulator that will serve as a national research asset for scientists and engineers in both the public and private sectors. The simulator will enable researchers to safely conduct multidisciplinary investigations and analyses of driver performance in hazardous, crash imminent situations. In 1995, the contractor with the winning design will be selected to construct the NADS. The NADS should be operational in 1998.
- NHTSA (UMTRI) is developing and validating a measurement system that can quantify the specific motions vehicles exhibit as they move in traffic under the full array of traffic operations. In subsequent projects, the system will be used to gather information such as reaction to other drivers cutting in front, normal following distance, typical lane change trajectories, and response to inclement weather. This information will provide the foundation for development of ITS collision avoidance systems that identify the need for intervention and/or collision avoidance instructions to the driver.

- NHTSA (Oak Ridge National Laboratory, Scientific Atlanta) is developing an easily installed, portable instrumentation package and a set of analytical methods/tools to allow driver-vehicle performance data to be unobtrusively collected in-situ using a variety of vehicle types.
- NHTSA (Jet Propulsion Laboratory) is developing an instrumented test bed vehicle featuring adjustable ride and handling characteristics with capability for vehicle control through on-board and off-board computer/communication systems as well as instrumented measurement of driver and vehicle responses. This test bed could be utilized to provide critical information on driver/vehicle interaction in support of AHS.
- NHTSA (UMTRI) is developing an analytical framework that can be used to assess the safety impact of collision avoidance concepts and systems and ultimately AHS.
- NHTSA (Battelle) is conducting a driver workload study to (1) develop a capability to evaluate the effects of high technology systems on driver safety performance, (2) develop standardized driver workload measurement protocols, obtain baseline workload data, and evaluate high-technology systems currently being implemented, and (3) identify aspects of system design and operation that can compromise safety, and (4) obtain data relevant to human factors guidelines for the driver-vehicle interfaces of these systems.

Knowledge Bases

- NHTSA (Millitech Corporation, Carnegie Mellon Research Institute) are assessing the potential health hazards that might result from wide-spread usage of collision avoidance systems using active sensors.
- NHTSA (Comsis) is identifying driver requirements for effective warning system design and evaluating the potential of warning systems to help drivers avoid crashes. A report on preliminary human factors guideline and research needs has been completed.

C.2.2 Thrust 2: Identify Promising Crash Avoidance Opportunities

Analytical methodologies for defining, analyzing, and modeling target crashes and ITS crash avoidance countermeasure action for the purpose of assessing potential effectiveness and for identifying research and development needs have been developed by NHTSA (Battelle, Calspan). Initial problem size assessment and statistical descriptions have been completed and published for the following crash types:

- Rear-end.
- Backing.
- Lane change/merge
- Single vehicle roadway departure.
- Opposite direction.
- Intersection.
 - Signalized intersection, straight crossing path.
 - Unsignalized intersection, straight crossing path.
 - Left turn across path.

and crashes occurring under conditions of:

- Reduced visibility.
- Drowsy driver.

Each performance specification project will probe the available crash data in more detail in order to further define the pre-existing event/condition that contributed to the crash occurrence (driver state, vehicle state, roadway alignment and state, obstacles, etc.), driver response (steering, braking, steering and braking, etc.) and resulting on-road or off-road dynamic state (controlled movement, uncontrolled movement), and the resolution of these actions and resultant crash type.

C.2.3 Thrust 3: Demonstrate Proof of Concept for Crash Avoidance Systems

The performance guideline development projects will lead to the development of performance requirements (both hardware and human factors) for advanced technology systems to assist drivers in avoiding crashes and decrease the severity of crashes that do occur. These projects are initially focused on systems that will be self-contained within the vehicle. However, countermeasure systems which require, or whose performance might be improved by, auxiliary equipment installed in or along the roadway or in other vehicles will also be considered. Those performance specification projects of most relevance to AHS include:

- Countermeasures against rear-end (Frontier Engineering) and backing (TRW) crashes (longitudinal).
- Countermeasures against lane change/merge (TRW) and roadway departure (Carnegie Mellon University) crashes (lateral).
- Vision enhancement systems for nighttime and inclement weather (Carnegie Mellon Research Institute).
- Driver status and performance monitoring systems (Virginia Polytechnic and State University, MTI Research Inc., and Carnegie Mellon Research Institute).

C.2.4 Thrust 4: Facilitate Commercial Development

- NHTSA, in partnership with the Environmental Research Institute of Michigan and TRW, is developing a knowledge base of radar cross-section data from measurements in the laboratory and a variety of freeway settings using a prototype forward-looking automotive radar sensor.
- NHTSA, in partnership with the Eaton Corporation, is studying the feasibility of adding automatic braking systems to heavy commercial vehicles. The project includes braking performance modeling, development of design requirements, and fabrication and testing of prototype hardware. The project will conclude with extensive test track work and a demonstration of the prototype system.
- NHTSA, in partnership with the University of Michigan Transportation Research Institute and Leica, is investigating the addition of service braking to adaptive cruise control systems to produce a rear-end collision avoidance system. A prototype ACC systems developed by Leica to demonstrate its infrared sensor technology is serving as the development testbed.
- NIITSA, in partnership with the Ford Motor Company, is addressing a range of human factors issues associated with implementation of Adaptive Cruise Control systems. These issues include: (1) driver useability in terms of ease of learning ACC operation, (2) driver reaction to the ACC limits for maximum deceleration and acceleration and minimum headway, and (3) driver attention and response to braking situations.
- NHTSA, in partnership with Rockwell International, is evaluating a prototype machine vision lane detection sensor. Sensor performance will be evaluated under various operating conditions and general lane detection sensor performance requirements will be identified. Estimation of future vehicle position is a key capability that will be an integral part of collision avoidance and automatic vehicle control systems. No viable technology to perform this function reliably and inexpensively is currently commercially available.
- NIITSA, in partnership with the Delco Electronics/GM Partnership (under ARPA/TRP funding), is developing low cost sensors for use in automotive collision avoidance systems.

C.2.5 Thrust 5: Assess the Safety of Other Systems

In general, NHTSA's participation in the safety evaluation of other systems focuses on mobility- and productivity-enhancing systems which will have little relevance to AHS. The human factors aspects of the in-vehicle hazard warning/speed advisory system being evaluated in the TravelAid project in Washington State may have some relevance.

C.3 AHS PSA Summary Results

The main body of this report summarizes some of the AHS Precursor Systems Analysis results. Altogether, 15 contractor teams addressed 16 activity areas, with at least three contractors addressing each activity area. In total, there were 69 separate activity taskings. This section includes a few of the more interesting results of that work.

As described in section 4.5.2, several key themes and points of agreement emerged from the PSA work. These were:

- Basis for 21st Century Highway Transportation
- Transit Industry as a Leader
- Transition from Today
- AHS is a Tool for Highway Planners
- AHS Program Faces Many Challenges

Section 8 of this report addresses many of the challenges to AHS that were identified as a result of the PSA studies.

Appendix D

National Automated Highway System Consortium Core Members

The Core Participants of the Consortium include representatives from each category of key stakeholders required by the RFA.

- State/regional/metropolitan transportation agencies are represented by **the California DOT (Caltrans)** the largest and one of the most technically advanced in the United States. In addition, Caltrans is reaching out to encourage participation by many other State and local transportation, planning and operating agencies, nationwide.
- The vehicle industry is represented by **General Motors Corporation** (Detroit, Michigan), the largest automotive vehicle manufacturer in the United States and a pioneer in ITS technologies. General Motors, through its European subsidiary, Adam Opel AG, is a member of the PROMETHEUS project and steering committee, and can bring the benefits of that experience to the AHS program.
- The highway design industry is represented by **Bechtel** (San Francisco, CA and Gaithersburg, MD) and **Parsons Brinckerhoff** (New York, NY and Rockville, MD), premier architecture, engineering and design firms. Both have considerable experience in program management, high-technology projects and ITS. A recent example is Bechtel's and Parson Brinckerhoff's joint management of the Boston Central Artery project, including a Traffic Operations Center, traffic sensor system, traveler information system, electronic toll collection and supervisory control and data acquisition for tunnel operations. Parsons Brinckerhoff includes Farradyne System, Inc. a subsidiary with extensive experience and skill dedicated to the design, development and operation of ITS programs an projects.
- The vehicle electronics industry is represented by **Delco Electronics** (Kokomo, IN), the world's largest supplier of electronics components and systems for vehicles and an experienced developer of intelligent vehicle systems for ITS. Delco Electronics is the developer of the TELEPATH navigation and communications concept vehicle and a long-time partner in previous GM AHS Programs.

Additional Core Participants of the National AHS Consortium, listed below, are world leaders in the development and application of advanced vehicle and infrastructure electronic systems.

- **Carnegie Mellon University (CMU) Robotics Institute** (Pittsburgh, PA) is a world leader in application of machine intelligence to vehicle sensing and control. It also brings an outstanding capability in application specific computer architectures for machine intelligence. CMU has performed extensive R&D in support of the Department of Defense UnManned Ground Vehicle program, and continues to be a key research facility in this area. CMU Robotics Institute has developed and demonstrated obstacle avoidance systems using a variety of sensor technologies and has developed and demonstrated highway vehicles that track and follow road and lane boundaries.
- **Hughes Aircraft** (Fullerton, CA) brings expertise in system engineering, communications, remote sensing, vehicle electronics and human factors. In ITS, Hughes is developing and installing automated vehicle identification and driver communications for the Advantage I-75 project along the Eastern States' I-75 corridor.
- **Lockheed Martin** (Denver, CO) brings program management and systems engineering experience from high technology military vehicles, unmanned ground vehicles and the DOD-Advanced Research Project Agency's Autonomous Land Vehicle program. In the commercial sector, Lockheed Martin is currently working with the Colorado DOT to develop the Metro Denver Traffic Operations Center.
- **University of California PATH Program** (Richmond, CA) performs research and development of ITS technologies for the California DOT and US DOT. PATH brings a legacy of AHS research reaching back to the 1980's. PATH provides expertise in analysis and simulation for safety systems and highway automation as well as a depth of experience in the application of advanced sensing and control technologies to road vehicles.

Appendix E

National Automated Highway System Consortium Associate Participants

The NAHSC Associate Participants bring broad expertise on technical, social, and environmental issues to what will ultimately be deployed as the next major performance upgrade of the nation's vehicle/highway system. Numerous additional Associate Participants are expected to join as the program progresses. As of September 1995, the participants are:

American Trucking Associations
Alexandria, VA

BRW, Inc.
Phoenix, AZ

Contract Compliance, Inc.
Philadelphia, PA

Daniel Consultants, Inc.
Columbia, MD

Dynamic Technology Systems, Inc.
Alexandria, VA

Idaho National Engineering Lab
Idaho Falls, ID

ITS America
Washington, DC

Matrix Corporation
Raleigh, NC

Michigan Department of Transportation
Lansing, MI

National Institute of Standards and
Technology
Gaithersburg, MD

Argonne National Laboratory
Argonne, IL

CCG Associates, Inc.
Silver Spring, MD

Creative Transit Alternatives
Falls Church, VA

Dunn Engineering Associates
Westbampton Beach, NY

Honda R&D North America, Inc.
Torrance, CA

IMRA America, Inc.
Ann Arbor, MI

L. S. Gallegos & Associates, Inc.
Englewood, CO

Metropolitan Transit Authority of Harris
County
Houston, TX

Ministry of Transportation of Ontario
Downsview, ONT

New Jersey Institute of Technology for
Transportation
Newark, NJ

The Participants (Concluded):

Oakland University
Rochester, MI

Red Zone Robotics, Inc.
Pittsburgh, PA

State University of New York University
at Stony Brook
New York, NY

Toyota Motor Corporation
Toyota, Aichi Japan

Virginia Department of Transportation
Richmond, VA

Western Transportation Institute Montana
State University

Zapata Engineering, P.A.
Charlotte, NC

Pennsylvania Turnpike Commission
Harrisburg, PA

Robotic Technology Inc.
Potomac, MD

The Ohio State University
Columbus, OH

Toyota Technical Center USA, Inc.
Ann Arbor, MI

Virginia Polytechnic Institute & State
University
Blacksburg, VA

Wilbur Smith Associates
Columbia, SC

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