Automated Highway System (AHS)

System Objectives and Characteristics

November 3, 1995

National Automated Highway System Consortium
3001 West Big Beaver Road, Suite 500
Troy, MI 48084

NAHSC

Automated Highway System (AHS)

System Objectives and Characteristics

November 3, 1995

NAHSC

National Automated Highway System Consortium
3001 West Big Beaver Road, Suite 500
Troy, MI 48084

MISSION STATEMENT

The National Automated Highway System Consortium (NAHSC) will specify, develop, and demonstrate a prototype Automated highway System (AHS). The specification will provide for an evolutionary deployment that can be tailored to meet regional and local transportation needs. The consortium will seek opportunities for early introduction of vehicle and highway automation technologies to achieve benefits for all surface transportation users. The NAHSC will incorporate public and private stakeholder views to ensure that an AHS is economically, technically, and socially viable.

INVITATION

The AHS is being designed to meet the future highway needs of all stakeholder groups including:

- Vehicle industry
- Government agencies
- Highway design industry
- Vehicle electronics industry
- Environmental interests
- Trucking operators
- Transit operators
- Transportation users
- Insurance industry

The NAHSC invites you to participate in developing the next generation of the National Highway System to ensure it meets your needs for the next century. For more information about how to participate, please contact:

National Automated Highway System Consortium
3001 West Big Beaver Road, Suite 500
Troy, MI 48084
Attn: Rob Meinert
Phone (810) 816-3404
Fax (810) 649-9569

FOREWORD

This document was prepared by the National Automated Highway System Consortium (NAHSC) for the United States of America Department of Transportation under cooperative agreement DTFH61-94-X-00001. It was developed with the help of AHS stakeholders. The NAHSC is soliciting comments, inputs, suggestions, and feedback on the objectives and characteristics of an AHS described herein. The resulting objectives and characteristics will be used to guide the definition of the Automated Highway System.

Please submit your comments by sending them to the:

National Automated Highway System Consortium
3001 West Big Beaver Road, Suite 500
Troy, MI 48084
ATTN: Systems Engineering Team
pat.langley@den.mmc.com

Revisions:

1st Draft	First public version prepared for the 1st AHS workshop, April 12,13, 1995, in Ft Lauderdale	4/3/95
2nd Draft	This version incorporates the stakeholder feedback from the first workshop	5/22/95
3rd Draft	This version incorporates extensive stakeholder feedback from focus meetings, surveys, and mailings.	9/15/95
Final Draft	This version incorporates feedback from the AHS System Requirements Review with associate participants. Provided to attendees of Workshop #2, Oct 19, 20, San Diego, Ca.	10/5/95
Milestone I	Incorporates feedback from Workshop #2 stakeholders. Submitted as a deliverable for achieving Milestone I in the program plan.	11/9/95

TABLE OF CONTENTS

TABLE OF CONTENTS (cont)

List of Tables

1.0 INTRODUCTION

The Secretary [of Transportation] shall develop an automated highway and vehicle prototype from which future fully automated intelligent vehicle-highway systems can be developed.[1]

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 directed the Secretary of Transportation to enhance and focus the nation's research into fully automated intelligent vehicle-highway systems. The Automated Highway System (AHS) program is a government-industry-academia collaboration to apply automated control technology to the U.S. vehicle-highway system to greatly improve the safety, mobility, and quality of highway travel. The efficiency of the automated vehicle-highway system is expected to help conserve energy resources to make more efficient use of existing transportation facilities and to contribute to a sustainable future transportation system. The deployment of AHS is intended to support community economic development and land use planning goals and to be compatible with urban air quality goals. Wherever possible, these improvements will be made using the existing highway infrastructure.

1.1 Automated Highway System/Intelligent Transportation System Architecture Relationship

The AHS program has been established to be the stepping stone to automated vehicle-highway transportation in the 21st century. The program focuses on a planned evolution 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 during 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 automated 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

[1] Section 6054 (b) in the Intermodal Surface Transportation Efficiency Act (ISTEA) of 1991

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 Program. With nationwide planning and infrastructure integration, AHS will become both a logical and major evolutionary step in our highway transportation system.

"Why is the Department of Transportation pursuing this development of AHS so vigorously? Let me share with you my sense of the need for the Automated Highway System and the potential benefits created by the future deployment of this system. Our current highway transportation system, as effective and elegant as it is, is at a critical crossroads in its evolution and has started to plateau in its ability to provide significant new operating performance in its present form.[2]

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. During 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. Therefore, the promise of AHS is an expansion of the collision avoidance safety benefits and a major performance gain in flow capacity for a given land area 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 security 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.

1.2 Document Purpose

The National Automated Highway System Consortium has prepared this document to introduce the current objectives and

[2] Administrator Slater's speech on the AHS Program, October 21, 1993

characteristics expected of a fully automated highway system, with the goal of balancing the needs of users and other stakeholders. These objectives and characteristics are goals and measurable targets used to guide requirements, system specifications, constraints, and criteria for AHS design concepts, prototype testing and deployment of the system. This document is useful as a point-of-departure to stimulate discussions with stakeholders and interested parties.

1.3 Document Scope

This document provides an initial description and reference concept for an AHS that will be built for operational test and evaluation beginning in the early part of the next decade. It defines the AHS objectives and characteristics independent of concept, design, or physical architecture. The reader should note that the objectives and characteristics specified herein are goals that may not be attainable, but serve as a target for the system designers.

2.0 AHS OVERVIEW

2.1 The Need for an AHS

Today's vehicle-highway system functions surprisingly well with its more than 6 million kilometers of streets, roads, and highways and its 190 million vehicles. However, it cannot keep pace with society's increasing transportation needs. Driven by population growth, the demand for mobility as a fundamental economic need is in direct conflict with our ability to fund new conventional highways and maintain a clean environment. The total vehicle kilometers traveled in the nation is predicted to nearly double by the year 2020, and our population will grow 50 percent by the middle of the twenty-first century.[4] We will need to make more efficient use of existing transportation facilities.

There are approximately 40,000 lives lost annually on the nation's roads and highways, and there are over 1,700,000 serious disabling injuries. The annual cost to the nation is estimated at over $156 billion.[3]

Although traffic fatalities have decreased significantly in recent years, there are still more than 40,000 lives lost annually on the nation's highways, and there are more than 1,700,000 serious disabling injuries. The annual cost to the nation in dollars is estimated at more than $156 billion.

Traffic volume has increased anywhere from 38 and 54 percent for each of the last three decades. Because system capacity has not kept pace with peak demand, 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.[5] A large portion of this congestion is caused by incidents on our highways (e.g., crashes, breakdowns, obstacles in the lane). Congestion is projected to worsen by 300 to 400 percent over the next 15 years unless significant changes are made in the surface transportation system.[6] In many areas, the traditional solution of building more lanes is becoming less viable because of limited rights-of-way, cost, citizens' concerns about the impact on the quality of life in their communities, and environmental requirements.

Our nation's economic growth, competitiveness and productivity is limited by the inability of our current vehicle highway system to meet the mobility demands for people and goods of our growing population.

[3]Focus on Environment: An IVHS New York Forum, v1, #1, 1994.
[4]ITS America Energy and Environment Committee
[5]U.S. DOT, Federal Highway Administration
[6]General Accounting Office

Today, congestion alone costs the nation an estimated $100 billion in lost productivity annually.[7] It also increases driver frustration and discomfort as congestion becomes worse and travel times become less predictable. Also, some drivers, including the elderly, are intimidated or frightened by highway travel. Moreover, fuel consumption will rise as trip times increase due to either length of the trip or time delays. In addition, predictability of delivery times will become less reliable, thereby increasing the frustration of customers of the shipping industry.

As traffic volume and congestion continue to increase, methods to reduce exhaust emissions will be necessary to maintain air quality. The key emissions produced by individual vehicles have decreased between 70 percent (oxides of nitrogen) and 100 percent (lead) since 1970. Nevertheless, the vehicle-highway system is still one of the largest contributors to air pollution in urban areas as a result of increases in the vehicle kilometers traveled, vehicles idling in congestion, and the driving habits of the vehicle operators. The nation's concern is reflected in the Clean Air Act, which has established emission guidelines that must be accommodated in transportation planning. Therefore, the vehicle-highway system must continuously strive to meet this demand. In particular, the system must improve in the areas of safety, congestion, air quality, and trip quality.

The AHS program addresses fundamental human limitations to improving the vehicle-highway system, such as driver reaction times and fatigue. These factors are major contributors to accidents and congestion on our nation's highways. "Automated vehicle control" directly addresses these issues. It is because of human limitations that automation is essential for improving our vehicle-highway system. To illustrate, the most common form of crash is the rear-end collision. Ten percent of all cars and 25% of all trucks experience a crash of this type during the vehicle's lifetime.[8] Single vehicle roadway departure and lane change/merge crashes represent about 32% of all accidents.[9] Often times secondary accidents occur with each primary accident as a result of gawking, intrusion, and obstacles associated with the primary incident. The fatality rate is sharply higher at night: the night fatality rate is twice as high in urban and three times as high in rural areas compared with the day rate.[10] More than 40% of the fatal

[7] IVHS Strategic Plan, Report to Congress, U.S. DOT, Dec. 1992pg 32.

[8] National Highway Traffic Safety Administration Analysis

[9] Fatal Accident Reporting Database

[10] National Safety Council, 1993.

crashes involve impaired drivers (drivers under the influence of alcohol, or experiencing drowsiness and fatigue). In addition, about 25% of crashes that result in fatalities occur on wet or icy roads. Finally, a lane volume of 2,200 vehicles per hour may be close to what humans can safely manage, and in many cases this rate is not achieved because of weaving or distractions such as stalls, collisions, or incidents in other lanes.

2.2 Building Solutions

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

Improvements in highway design, traffic management, vehicle safety design, and improvements in driving under the influence, safety, and speed enforcement programs have allowed modern highways to sustain passenger vehicle flow rates of up to 2,200 vehicles per lane per hour, while decreasing the number of fatalities per 100 million kilometers traveled by 30 percent. These benefits should be delivered with due care for natural resources and the environment.

With all vehicles under full automatic control, the system will provide significant benefits in enhanced safety, increased throughput, and shorter and more predictable trip times.

The results of a significant body of research suggest that a fully operational AHS can dramatically affect 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, commercial, and transit vehicles. These improvements may also reduce vehicle emissions through reductions in stop and start traffic. Projections indicate that AHS lanes will double or triple the safety and efficiency of existing highway lanes.[11] In sheer economic terms, if the AHS even approaches these kinds of benefits, this program will represent one of the most productive transportation investments ever made.[12]

2.3 AHS Concept

The AHS will support a broad range of vehicle types (passenger cars, trucks, and buses) in a widely varied array of highway configurations.

The NAHSC has established the fundamental guidelines and capabilities for the AHS concept.[13] An AHS will safely operate properly equipped vehicles under automated control on properly equipped lanes. Human errors and inefficiencies will be virtually

[11] AHS Precursor Systems Analysis Studies byCalspan, PATH and Delco, December 1994.

[12] Administrator Rodney Slater, Federal Highway Administration, October 7, 1994.

[13] The NAHSC working with the Federal Highway Administration (FHWA) and based on the AHS Precursor System Analysis contract work.

eliminated when all vehicles in the lane are fully automated. It is currently assumed that AHS lanes will be adjacent to, and similar in structure to, the other highway lanes. Entry to the AHS may be similar to entry to some of today's high occupancy vehicle (HOV) lanes or through dedicated entry stations.

With nationwide planning and vehicle and infrastructure integration, AHS will result from logical progressive steps over time.

The fully automated AHS will be developed through a planned progression from today's vehicle-highway system. This transition will be simplified because some of the basic services needed for an AHS are starting to appear in today's vehicles and highway systems. Use of these services is expected to increase during the next decade. Metropolitan areas are already upgrading their highway infrastructure with such services as electronic toll systems for nonstop toll collection, and automated incident detection for faster responses to crashes and other incidents. All have the potential to improve the efficiency of highway systems. The AHS will build on and guide this progression to ensure vehicle and infrastructure compatibility. With nationwide planning and vehicle and infrastructure integration, AHS will result from logical progressive steps over time.

An AHS will use modern electronics to safely and efficiently move AHS equipped vehicles along instrumented, dedicated highway lanes under fully automated vehicle control with no driver involvement required. Manually driven vehicles will be denied access to the AHS lanes. AHS-equipped vehicles will be able to operate under manual control on conventional lanes. On conventional lanes, the driver may choose to use partial automated vehicle control capabilities (e.g., adaptive cruise control). This mode of operation known as "partial-AHS" will offer some increase in safety and reduced driving strain compared to completely manual operation while on highway lanes used by all vehicles.

AHS will be able to accommodate private, commercial, and transit vehicles. The extent of support for each type of vehicle is likely to be a local implementation decision.

The AHS primary system control may require interaction between the vehicle and the roadway. This interaction will be a non-contact electronics-based design as opposed to a mechanical, physical contact design.

The AHS will consist of at least two major subsystems: the vehicles and an infrastructure. The vehicle subsystem will contain the portion of the system that actually moves along an AHS. The vehicle subsystem includes sensors, data processing, actuator, linkage, and communications equipment. The AHS will automate the following driver functions to control vehicle movement.

The fully automated AHS will be developed through a planned progression from today's vehicle-highway system.

AHS Entry — The system will enter vehicles onto the automated highway with simultaneous speed adjustment between several vehicles to successfully merge vehicles.

AHS Exit — The system will move vehicles from the AHS lane and will return control of the vehicle to the driver after ensuring that the driver is prepared to safely operate the vehicle.

Object Detection and Collision Warning/Avoidance — The system will detect moving and stationary objects on the automated lanes and will avoid collisions with these objects.

Longitudinal Vehicle Control — The system will adjust the vehicle speed, both to maintain a safe overall speed (as influenced by environmental conditions), and the appropriate longitudinal distance between vehicles.

Lateral Vehicle Control — The system will steer the vehicle by sensing the lane boundaries or lane centers of the automated lane and control vehicle steering to keep the vehicle in the lane, coordinating lane changes and entry/exit maneuvers.

Navigation — The system will track the vehicle's position on the highway network to ensure that the vehicle leaves the system at the driver's desired exit or guide the vehicle to another exit of the desired exit becomes unavailable.

Maneuver Coordination — Using the vehicle's absolute or relative position on the highway with communication between vehicles, the system will coordinate vehicle maneuvers.

The infrastructure subsystem will contain all other aspects of the AHS not found in the vehicle. This includes, but is not limited to, communications equipment, roadways, control centers, sensors, and operations and maintenance facilities.

The AHS will not be a standalone system. It will be developed and integrated with other transportation systems. It will supplement existing vehicle-highway systems for state and Metropolitan Planning Organization (MPO) transportation planners and other policy makers. It will allow safer, more efficient, and cost-effective highways to be designed while still meeting a region's environmental guidelines and societal goals.

The AHS can be tailored to meet the needs of the individual states and regions that choose to implement the system.

An AHS will support varying modes of transportation, including, but not limited to, local and trunk line transit services, commercial truck and taxi services, and shuttle services to major trip generators such as airports and commercial centers. All of the improved conveniences in the flow of information as a result of ITS technologies will be incorporated. In addition, AHS will provide faster transit and more reliable guideways on which to operate. Users will not only be better informed of available service, but more attracted to faster, more reliable, and more direct service. Travelers as well as commercial users will find many new important ways to facilitate their activities. Typical of the early stages of any important innovation, it is impossible to anticipate all the entrepreneurial responses that will serve the user needs.

An AHS will support varying modes of transportation including, but not limited to, transit systems, trucking including intermodal terminal shuttles, and airport and downtown shuttle systems.

There will be common standards so that an AHS-equipped vehicle from one region of the country will be able to travel on an AHS in any other part of the country. Local vehicle size and performance restrictions may be different not to allow, for example, AHS-equipped heavy trucks to operate in high-congestion central business districts at certain times of the day.

The AHS will be adaptable to the local needs. This flexibility and tailoring of AHS includes, but is not limited to the applications listed in Table 2-1.

Table 2-1 The AHS concept is flexible to accept local tailored needs like these examples.

Highway Networks in Highly Congested Megalopolises
AHS lanes could be implemented throughout the highway networks of our largest and most congested metropolitan areas, where they would help alleviate the daily congestion that plagues these regions. The primary focus of such an AHS implementation would be on maximizing throughput to relieve congestion and air quality problems, diverting traffic from arterials and other highways. Examples could include Los Angeles and New York metropolitan areas.
Highway Corridors in Large, Congested Metropolitan Areas
AHS lanes could be implemented on the most heavily traveled portions of the highway networks in many large, congested metropolitan areas, where they would help relieve congestion bottlenecks, enabling the entire road network to function more efficiently. The emphasis in these applications would be on achieving high enough throughput to relieve the bottleneck problems, and reducing congestion and pollutant emissions. Examples include cities such as Boston, Washington, D.C., San Francisco, and Houston.
Exclusive Transit and HOV Lanes
In order to encourage use of transit and HOVs, giving them advantages in average travel time, travel time predictability and safety over SOVs, priority could be given to the implementation of AHS on special lanes reserved for use of transit vehicles and HOVs. These could provide express services for relatively long-distance suburban and urban commuters, from park-and-ride facilities to transit terminals or major activity centers. Examples include the Houston Metro HOV network, the Shirley Highway in Virginia, the El Monte Busway in Los Angeles and the Lincoln Tunnel contra-flow busway in New York.
Heavily Traveled Intercity Highways
AHS could be implemented for intercity travel in high-density corridors, where long-distance traffic is combined with urban and suburban commuter traffic to produce both congestion and safety problems. In this setting, AHS could substantially improve the comfort and convenience of travel for a wide range of users, both personal and commercial, while reducing fatigue and safety problems in particular for the long-distance travelers. Examples of such applications include the I-95 corridor between Boston and Washington, I-94 between Detroit and Chicago, and I-5 between Los Angeles and San Diego.
Exclusive Commercial Vehicle Lanes
In areas having very heavy truck traffic, separate AHS lanes could be established to provide safe, efficient movement of goods with greatly enhanced trip time reliability, as well as reduced average trip time. Such services should be very beneficial to trucking operators and their shippers, especially those involved with just in time delivery. It should help improve the productivity of truck fleets and drivers, reduce their number of incidence of crashes, and reduce the impacts that heavy truck traffic have on the rest of the highway network. This could be particularly beneficial in areas with multi-modal terminals and major ports, such as the northern portion of the New jersey Turnpike or the Alameda Corridor between Los Angeles and San Pedro.
. . . . continued on next page.

Table 2-1 The AHS concept is flexible to accept local tailored needs like these examples. (cont)

Sparse Rural Areas
AHS-equipped rural roadways could be designed to operate intermixed with conventional vehicles to help prevent the two major causes of rural accidents - accidents with animals and single vehicle road departure. The AHS equipment would maintain a safe distance from the vehicle in front and help detect obstacles on the road. It would also help the driver keep the equipped vehicle in its lane and avoid road departure accidents. The driver could choose to turn the AHS services on or off as needed.
Long Distance Interstate Highways
AHS could make long-distance travel significantly safer and more comfortable and convenient for both personal and commercial goods travel. By relieving the monotony and fatigue associated with long-distance highway travel, AHS should be beneficial to a broad range of travelers. This kind of application would probably begin on the most heavily traveled Interstates such as I-95 along the east coast, I-5 along the west coast, I-75 from Michigan to Florida, or I-80 from coast to coast.
Roadway Powered Electric Vehicles (RPEV)
Roadway powered electric vehicles use opportunity roadway-based charging to supplement the vehicle's battery supply, thereby extending the vehicle's range and capability. An integration of AHS and RPEV would enable the vehicles, for example, to lane-keep directly over the charging elements. A region could stimulate the electric vehicle market by supplying power from the roadway to keep the vehicle moving without draining (and possibly charging) the vehicle's batteries. The vehicle would continue off the highway via battery power. The integration of AHS and RPEV may be particularly beneficial for transit vehicles.

2.4 AHS Benefits

A prime goal of the NAHSC is that AHS be viewed as a desirable option for vehicle-highway system enhancement by all stakeholders; users, communities, state and regional transportation agencies, environmental organizations, and industry, who have a stake in the design and implementation of an AHS. "The Automated Highway System offers the potential for dramatic changes in the driving experience, such that safety would be vastly increased and drivers would be free from the stress of driving in heavy, congested traffic. The expected ability of an Automated Highway System to handle large volumes of traffic also creates benefits for the entire road network, relieving stress on the surrounding highway, thereby benefiting all users."[14] AHS will attempt to balance the inherent tradeoffs among safety, environment, congestion, speed, and community liability, and the goals of each stakeholder group.

Benefits for AHS Users

The AHS will provide users with the following benefits:

- Safer travel.
- More efficient travel.
- More predictable trip times.
- Environmental benefits.
- Additional mobility to an increasingly aged population.
- Reduced insurance rates due to reduced numbers/severity of crashes.

Specific safety goals include the following:

- Significantly reduced driver error by providing for increasing degrees of automated assistance, from partial control in conventional lanes, up to full control of the vehicle while in AHS lanes.

[14] Administrator Rodney Slater's speech on the AHS Program, Oct. 21, 1993.

- Less frequent and lower severity crashes.

- No collisions in the absence of AHS malfunctions.

- In the event of malfunctions, the use of fail-soft and fail-safe designs. Fail-soft and fail-safe designs have been used successfully in the defense, aerospace, transit, and vehicle industry to minimize the effects of failures in the system. AHS will be designed to minimize both the number of crashes that occur and their severity.

The AHS will make highway travel less stressful and more enjoyable for all travelers, including transit and other multiple occupant vehicles. Specific comfort and convenience goals include the following:

- Reduce travel time and stress of travel for commuters.

- Enhance personal mobility for the elderly or other drivers with special needs in performing the driving task.

- Increase the comfort of traveling as a result of increased safety and less frustration resulting from the decrease in congestion and unpredictable travel times.

- Reduce the strain of driving on crowded, high-speed highways.

AHS users can expect shorter and more predictable trip times. As a result of reduced congestion, smoother flow, and higher average speeds, average trip times on the AHS will be shorter.

Benefits to Society

For the U.S. Department of Transportation and the public to fully support the AHS, the long-range AHS effort must also provide benefits that consider the nation's societal needs. The following have been identified as societal needs that the AHS can help to achieve:

- Provision of increased, equitable access to transportation by all segments of society

- Reduced highway congestion and increased safety and security.

- Reduced overall fossil fuel consumption and emissions.

- Support for response to national emergencies, both civil and national defense.

- Support for enhancing the nation's robustness and vitality with a sustainable transportation system.

- Transportation system that increases mobility of people and goods, which can potentially increase productivity, enhance competitiveness, and result in economic growth.

Benefits to State and Regional Transportation Agencies

AHS should be seen as a desirable, cost-effective investment alternative that can be tailored to meet the state and regional transportation needs. The AHS will provide the following benefits to the state and regional transportation agencies:

- Remove or reduce traffic from conventional streets and highways.

- Move traffic more safely and quickly through urban areas.

- Serve as a long-term supplement for major highways that in many cases uses existing infrastructure to increase safety and throughput.

- Favorable return on investment when compared with other transportation alternatives in many deployment environments.

- Increased service to citizen users and higher customer satisfaction.

- Improved productivity, safety and reliability will benefit transit operators using AHS. Steady vehicle speeds, automated operations and controlled guideway access will reduce transit trip times, reduce driver error, and ensure on-time performance.

- Integration with other ITS services, including travel demand management approaches.

Benefits to Communities

The AHS will represent an attractive alternative for handling community transportation needs and issues. It will provide communities with the following benefits:

- Enhanced quality of life and environmental sustainability in communities. This includes improved personal security due to improved communications and reduced response time of emergency vehicles.

- Better support for community policies to reduce demand for new land use for highway rights-of-way by allowing increases in traffic demand to be handled on existing rights-of-way.

- More efficient support for community policies to reduce air pollution.

- More efficient use of scarce resources in ways that minimize environmental impacts and are compatible with local land use plans.

- Less need for emergency services (e.g., fire, rescue, emergency room treatment) because of fewer crashes on the highway. Better response time from these services (including law enforcement) when they are needed in the community as a result of the increased efficiency of the transportation system and system notification of emergency personnel.

Benefits to U.S. Industry

The AHS offers major benefits to industry and U.S. competitiveness in the world market.

- New business opportunities are created by public-private partnerships in support of AHS.

- Many vehicle manufacturers, highway construction firms, and vehicle electronics companies will see substantial, long-range market opportunities because of the open architectures and interoperability standards used by the system.

- Trucking firms will benefit from safer highways and more efficient roadway operations, particularly shorter, more predictable, and reliable point-to-point travel times that will translate into realistic just-in-time delivery inventory control and lower operating costs. In addition, reduced driver workload will translate into the potential for higher productivity.

- Industry in general will benefit from increased transportation reliability, mobility, and flexibility that should translate into faster market response times and reduced operating costs.

- Industry will benefit from the new business opportunities from spin-off products from AHS technologies.

- Defense and aerospace firms can use their expertise in this civilian application providing dual-use technology and products.

"...the Automated Highway System offers the potential for dramatic changes in the driving experience, such that safety would be vastly increased and drivers would be free from the stress of driving in heavy, congested traffic. The expected ability of an Automated Highway System to handle large volumes of traffic also creates benefits for the entire road network, relieving stress on the surrounding highway, thereby benefiting all users."[15]

[15] Administrator Rodney Slater's speech on the AHS Program, Oct. 21, 1993.

3.0 AHS PERFORMANCE OBJECTIVES

This section describes the performance objectives of the AHS. These objectives were derived from the original Request for Application to establish a National AHS Consortium,[16] and revised based on the results from the AHS Precursor System Analyses and the ongoing NAHSC System Definition efforts including stakeholder feedback provided at the first Workshop.[17]

The following sections (3.1 through 3.5) describe the AHS performance objectives. The objectives are the fundamental reasons for developing and deploying AHS, representing the purpose of the program. They define the reasons for investing resources to develop and deploy the AHS. Appendix B defines a preliminary set of measures for assessing the of AHS designs meet the objectives.

3.1 Improve Safety

The AHS will be collision-free in the absence of AHS malfunctions and will include malfunction and incident management capabilities that minimize the number and severity of collisions that occur, as well as reducing the amount of time needed to respond to incidents that do occur.

The AHS will provide substantially increased safety to vehicle-highway users. Automated control will greatly eliminate driver-generated errors attributable to poor judgment, fatigue, unpredictable behavior, and personal impairments. Up to 93% of highway crashes are attributed to driver error.[18] By transferring driver control to the AHS vehicles while on AHS highways, the automated system will reduce vehicle mishaps per highway kilometer by as much as 50 to 80 percent. The AHS will interact positively with on-board vehicle monitoring systems so that defective and manually controlled vehicles are excluded from automated control lanes.

The AHS will be significantly safer than today's highways.

- ***Reduce vehicle crashes per highway kilometer by as much as 50 to 80 percent.***
- ***Reduce fatal and major injury crashes at least one half the current rate.***
- ***May allow reduction in insurance costs***

16 Request for Application To Establish a National AHS Consortium, U.S. DOT, DTFH61-94-X-00001, December 15, 1993.

17 AHS System Requirements Workshop, NAHSC, Ft. Lauderdale, FL, April 12-13, 1995.

18 IVHS Strategic Plan, Report to Congress, U.S. DOT, Dec. 1992pg 32.

Up to 93% of highway crashes are attributed to driver error

The AHS will show a reduction in the occurrence rate per highway kilometer of fatalities, severe injuries, and property damage for AHS vehicles under automated control of at least one half the current rate for highway traffic. This reduction will be accompanied by an ability to decrease the rate of mishaps resulting in minor injury or property damage on similar types of highways. The AHS will be designed to ensure that the safety of manually operated vehicles will not be degraded by AHS.

In normal operating conditions, the driver will transfer vehicle control to the automated system as a condition of entry into the automated lanes. The AHS will control the vehicle while it is in the system. Control will be returned to the driver upon exiting the automated system. This will help ensure that driver errors, both personal and those by drivers in nearby vehicles, will not result in a mishap. The automated system will take appropriate measures to ensure that the driver is ready to take control from the automated system before control transfer. To help increase safety in case of unexpected events, the system will enable the driver to signal an emergency and bring the system to a halted condition or other fail safe state of operation. This is similar to the emergency signaling provided on public buses and trains.

The AHS should result in lower insurance costs to drivers and shippers as a result of a significantly lower rate of loss due to crashes. The AHS system will provide safe operation under degraded service in the presence of multiple concurrent failures of AHS components. Individual failures may occur periodically and the AHS will be designed to ensure continued safety during and after the failure. Any individual failures occurring within system facilities or equipment will be transparent to the motoring public. The AHS will be designed so that multiple failure occurrences result in decreased levels of service while maintaining safety standards. Individual failures in individual vehicles will result in the vehicle being removed from the system in a safe and efficient manner. This may include a concept that has the failed vehicles removed at the nearest available exit, stopped in a breakdown lane, or stopped in the lane of travel if continued operation compromises safety.

To ensure the safety of its users, the AHS will be resistant to outside interference and tampering. The AHS will use protocols and techniques in its communications services that prevent unauthorized access or interference. The AHS will be designed to respond to intrusion by pedestrians, animals, environmental conditions (rock and snow), and vehicles in adjacent lanes.

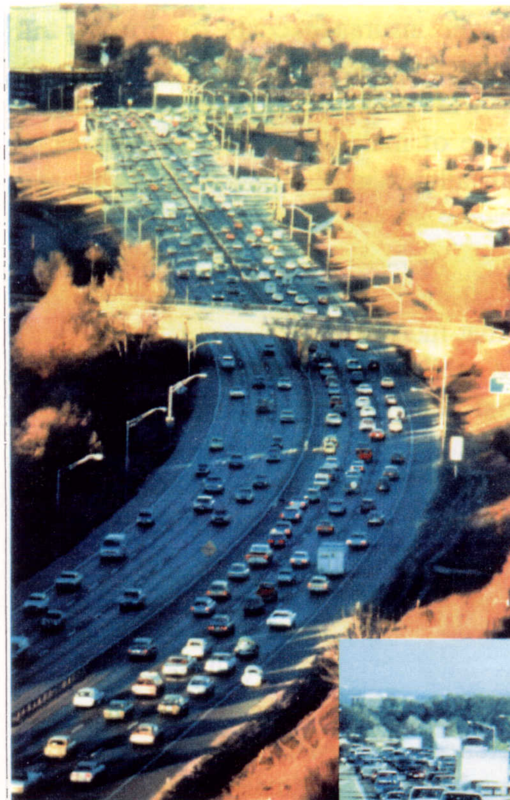
3.2 Increase Efficiency

The AHS will significantly increase the throughput of all accommodated vehicle types in the United States. As much as a 300% increase may be possible.[19] Throughput improvement varies depending on weather conditions, traffic conditions at egress points, and vehicle types accommodated on a specific AHS. Throughput gains will be obtained through significant reduction of incidents and crashes. The net per-lane throughput of an automobile-only AHS will be at least double and perhaps triple the per-lane throughput of a conventional highway under dry and good weather conditions, barring reductions due to specific site conditions. The throughput gains of those AHS lanes accommodating heavy vehicles intermixed with automobiles will be lower.

The AHS will enable significant increase in vehicles-per-hour per-lane flow through increased density at free-flow speeds, stable traffic flow, and possible increase in speed.

Throughput refers to predicted achievable flow in a particular lane given the physical configuration (e.g., frequency of entry or exit points), demand pattern and operating policy (e.g., ramp metering or speed limits). Total conventional roadway capacity refers to the

[19] IVHS Strategic Plan, Report to Congress, U.S. Dot, Dec. 1992pg 33.



The total vehicle kilometers traveled in the nation is predicted to nearly double by the year 2020

maximum rate of flow at which persons or vehicles can be reasonably expected to traverse a point or uniform segment of a lane or roadway during a specified time period under prevailing roadway, traffic, and control conditions. Dedicated automated lanes on an urban/suburban AHS may require additional supporting space, e.g., shoulder (breakdown lane), transition lane, and areas required at the interface with conventional roadways (including possible check-in or check-out facilities).

In calculating the capacity increase of the roadway as a whole (e.g., roadway capacity), the additional amount of supporting space required must be considered. Because the AHS lane width may be narrower than today's standards, it should also be considered in the capacity calculations. Roadway capacity measures for AHS must include those measuring maximum possible flow for the most critical of the following:

- Check-in (the process of determining if the vehicle and driver have the necessary certification, training, and equipment; verifying the operability of the vehicle; and processing the vehicle into the system);

- Entry to automated traffic, with or without physical segregation from manual traffic;

- Longitudinal flow;

- Lateral flow, with or without barriers/openings between automated lanes;

- Merging at on-ramps, lane merges and highway-to-highway interchanges;

- Exiting from automated traffic, with or without physical segregation from manual traffic;

- Check-out (the process of verifying the readiness of the driver, processing the vehicle out of the system, and returning the vehicle to manual control).

These basic capacity measures, including physical configuration and operating policy determine the roadway capacity. Speed regulation is a key performance characteristics of the AHS in achieving increased throughput. For high-demand urban highways, the AHS will regulate the speed of all vehicles to achieve the optimum speed to ensure maximum AHS lane throughput. The AHS will give local highway operators the ability to set the normal operating speed of a roadway segment to meet local needs, including any desire for shorter trip times. The maximum design speed of the AHS must be able to provide a desirable service level on intercity highways, where dedicated AHS lanes are an affordable option and high speeds can be accommodated by the existing right-of-way. Also, the maximum design speed must accommodate and provide an acceptable safety margin for the expected range of operating vehicle designs. For example, a state DOT may plan to operate the AHS initially at 90 kph, then advance to a speed of 140 kph, and may ultimately consider a maximum design speed of 200 kph.

3.3 Enhance Mobility and Access

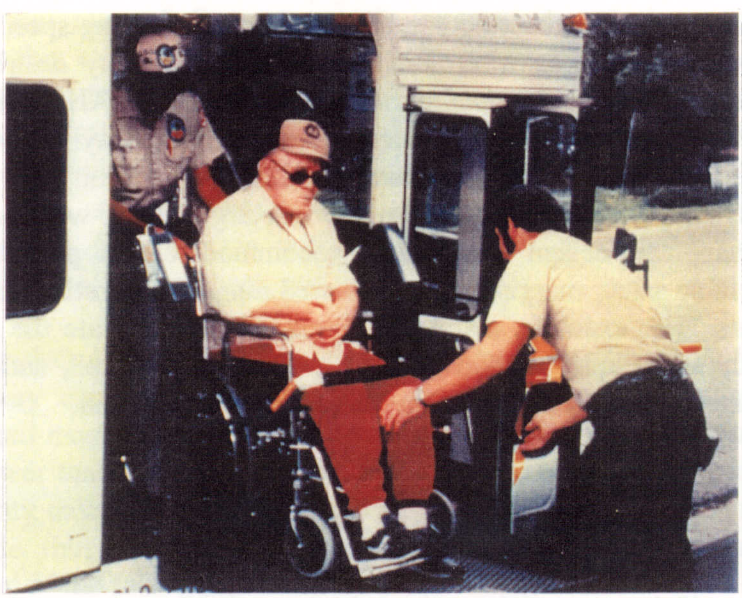
More efficient use of the nation's highways will increase mobility and access. This is one of the major premises of the AHS program. Motor vehicles and highways are the most used, most flexible, and most intrusive transportation system we have.

The AHS will provide more rapid movement of people and freight by reducing highway congestion caused by increasing demand and by driver errors resulting in incidents. More rapid movement will translate into noticeably shorter trip times and into the ability to move people and freight to more locations in the time available. This has significant implications for private, commercial, and transit vehicle users and operators.

The AHS will provide shorter and more predictable trip times resulting from increased throughput and the ability to maintain free flowing speeds at high levels of throughput. People will be able to plan trips with much less uncertainty about the possibility of delay caused by congestion or crashes. Transit service providers will have increased ability to maintain their published schedules. Implementation of an AHS may encourage people to use alternative modes of transportation instead of single occupancy vehicles. Predictable trip times will increase the feasibility of just-in-time deliveries for commercial trucking companies.

AHS will integrate with and support various ITS services, such as pre-trip planning to avoid areas of congestion and possible delay. In addition, the AHS will integrate with services to monitor and track the movement of individual trucks or transit vehicles.

AHS will enhance the nation's ability to effectively and predictably move people and freight using the highway system



The AHS will provide vehicles — private automobiles, transit vehicles, or trucks with seamless highway transportation. To assess the ability of an AHS to enhance mobility and access, measures can be developed to estimate differences in: trip times for selected origination/destination pairs in typical or actual locations before and after an AHS installation; variation in trip times with an AHS for varying traffic conditions; and the ability to achieve on-time transit service in varying traffic conditions with and without an AHS.

Increase travel reliability

- ***Reliable point-to-point travel times***
- ***Dependable service***
- ***Graceful accommodation of service interruptions***

AHS will be a system that requires less skill and concentration than is needed on current highways. Its goal is to extend the diversity and range of driving opportunities for all drivers, including senior citizens, the drivers who are fearful of highway driving, and the less experienced driver. For those people who may normally avoid highway driving, automation will reduce driving stress and should permit them to gain, or regain, access to the highway after it has been automated. The driver interface for AHS must accommodate the capabilities and limitations of people whenever possible. However, drivers will have to drive on conventional roadways to reach the AHS. It is not the intent of the AHS to encourage individuals who are temporarily impaired due to alcohol or drugs, to drive.

3.4 Provide More Convenient and Comfortable Highway Traveling

One of the expected major benefits of the AHS will be to increase the convenience of motor vehicle travel by relieving the driver of the driving task while on the AHS. After entering the automated highway, the driver will be free to relax and engage in non-driving tasks, thus improving personal productivity. Under normal circumstances, the driver will not be required to resume any driving tasks until the requested exit is approached.

AHS will substantially increase the quality of traveling by motor vehicle, will substantially reduce the stress of driving, and will make highway driving more accessible to the aged and less experienced.

To achieve this improvement in trip quality, the AHS will reduce the stress associated with manual driving and must not induce stress during automated driving. There will be less stress on the driver because he or she does not need to control the vehicle or concentrate on traffic conditions while on the AHS. The driver must feel secure while on the AHS — confident of their own well-being and of the system's ability. The driver should have less fear from other errant, inattentive, or overaggressive drivers. The drivers also should have less fear of the consequences of their own driving mistakes. The driver should also suffer less frustration due to congestion and/or unreliable travel. The driver should have a feeling of increased safety because far fewer crashes will occur on the AHS. The ride must be as smooth as good manual driving, with no sudden changes in speed or direction under normal circumstances. AHS must not permit sudden jerky motions of the vehicle. Automated maneuvers will be consistent and occur the same way when the conditions are the same.

3.5 Reduce Environmental Impact

The AHS will be consistent with and help satisfy the nation's long-term air quality and energy usage goals as exemplified in national legislation.[20] The AHS, when coupled with policies that are aimed at limiting growth of vehicle kilometer traveled (VKT), will help meet the nation's long-term air quality goals. It will be used by environmental and transportation professionals to (1) reduce emissions per VKT and (2) enhance the operation of other pollution-reducing transportation approaches. Reduced trip time, improved reliability, and more direct non-transfer service available to transit with AHS are highly valued by potential transit users. As AHS guideways become more available for transit vehicle use throughout a metropolitan area, these positive service attributes will be available to more residents, further reducing VKT.

AHS will improve fuel economy and reduce emissions per vehicle kilometers traveled through smoother flow and compatibility with future vehicle propulsion and fuel designs

The AHS is expected to reduce fuel consumption and tailpipe emissions per VKT for internal combustion engines through smoother vehicle operation (fewer accelerations and decelerations), and reduced congestion. AHS operations at very close spacings can dramatically reduce aerodynamic drag on vehicles, thereby substantially reducing fuel consumption and tailpipe emissions. Also, traffic formerly on surface streets will be attracted to use AHS. However, the increased AHS capacity may attract additional traffic. Further, the environmental impact of much larger volumes of vehicles traveling in concentrated corridors must be understood and accounted for. Approaches such as encouraging more passengers per vehicle, and policies for ensuring that this added capacity ultimately results in reduced congestion with no substantial environmental impact must be developed.

[20] Intermodal Surface Transportation Efficiency Act of 1991 (ISTEA) and Clean Air Act Amendments of 1990 (CAAA).

Air quality continues to be a major problem in most cities.

AHS will also support the environment by utilizing existing highways and right-of-ways, reducing the demand for building new highways that have a detrimental impact on the land.

The AHS will support and enhance the deployment and operation of known alternative propulsion systems. In addition AHS will provide a base on which roadway-powered electric vehicle systems might feasibly be developed.

An ongoing trade-off and issue is that the increased throughput enabled by AHS may negate the positive benefits on emissions. All of these objectives will need to be balanced to find the best solution for each community.

4.0 AHS USER SERVICE OBJECTIVES

The AHS performance objectives described in section 3.0 are common needs for all users; however, the users of an AHS are a diverse group including: transit, trucking, commuters, and vacationers. Each of these groups have unique needs that the AHS must service. Many of these user service objectives can be implemented differently depending on local needs or uses, as shown in Table 4-1. The following sections (4.1-4.7) describe the unique top-level service objectives for AHS users.

Table 4-1 AHS User Service Objectives

User Service Objectives	Section Number	Implementation Locally Determined
Disengage the Driver from Driving	4.1	
Facilitate Intermodal and Multimodal Transportation	4.2	✓
Enhance Operations for Freight Carriers	4.3	✓
Support Automated Transit Operations	4.4	✓
Apply to Rural Highway	4.5	✓
Support Travel Demand Management and Travel System Management Policies	4.6	✓
Support Sustainable Transportation Policies	4.7	✓

4.1 Disengage the Driver from Driving

Full automatic control "hands-off and feet-off driving" is a service to be provided to all drivers on the AHS. Full automatic control will be a learned condition for the driver brought about by trust in the reliability, safety, and convenience of the AHS. After the driver gains that level of trust in the AHS, the stress associated with driving will be greatly reduced. The driver will become a passenger in the fully automated AHS and may sleep, read, or work and will not be required to attend to any driving-related tasks.

During the full automatic vehicle operation in the AHS, the system will effectively and safely control the vehicle, requiring no support from the driver.

Some drivers may want to remain alert to passing vehicles, progress on the AHS, and the existence of hazards. If the driver detects a mishap, debris, or potential incident, the driver will be able to communicate that condition to the system. However the system will not rely on driver detection of these hazards. The system will respond to these conditions, but will retain vehicle control unless the situation warrants and allows a safe return to driver control.

In addition, the system will attempt to make the driver aware of situations where the driver must again become engaged. Until a driver responds to these alerts and demonstrates to the system that manual control can be reassumed, the system will retain control even to the point of exiting and stopping the vehicle in a safe and effective manner. The return to safe manual control with short notice during emergency situations requires a strategy of notification to the driver that encompasses all levels of driver capabilities, including the aged, impaired, hard of hearing, and inexperienced driver. It also requires a strategy for dealing with drivers who do not respond to this notification.

One ongoing issue being studied is whether to allow a driver to resume manual control of a vehicle while in an automated lane. In some situations, driver response times and capabilities may be inferior to the capabilities provided by the AHS, and permitting the driver to resume control may present a serious hazard to the system.

4.2 Facilitate Intermodal and Multimodal Transportation

The AHS will support an intermodal and multimodal surface transportation systems.

The highway system of the United States today supports a wide variety of transportation modes, including the personal automobile, public and private transit vehicles, and trucks for transportation of freight. A commuter may carpool to a park'n ride and take a bus to work. The AHS will support all these transportation modes and services in combination and separately. AHS will interface with parking and transit operators to connect with other mode stations (e.g., rail, airports). Local planners will be able to use AHS capabilities to build transportation systems that meet the needs of their locality and region.[21]

[21] See sections; 4.16 Enhanced Operations for Freight Carriers and 4.17 Support of Automated Transit Operations

4.3 Enhance Operations for Freight Carriers

The AHS will provide capabilities to support and enhance the use of freight vehicles.

The AHS will support freight-carrying vehicles. The AHS could ensure safe, efficient movement of goods with far greater trip predictability. AHS will include features to permit the local highway operator to give preference to commercial vehicles, such as priority at entry and exit points. AHS automatic vehicle guidance features will be available in freight terminal areas to facilitate intermodal transfers of freight. AHS automatic vehicle guidance features will also be capable of guiding trucks through commercial vehicle inspection areas. The AHS should be compatible with existing and planned automated features of these inspection stations as well. As a local option, in areas of high truck traffic, such as between major east coast cities, separate lanes could be established for heavy vehicles. The specially designated lanes could be extended into nearby weigh stations and docking facilities.

The AHS should ensure safe, efficient movement of goods with far greater trip predictability

4.4 Support Automated Transit Operations

The AHS will provide capabilities to enhance the quality of service that transit can provide so its use becomes more attractive to the public

Transit vehicles can offer several advantages over the personal automobile, including lower per-passenger costs, less exhaust emissions per passenger kilometer, and increased passenger throughput. 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 mechanical-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. AHS approaches will enable transit to become more cost and time competitive. Reduced trip time, improved reliability and predictability, and more direct non-transfer service, using the same vehicles on both the local neighborhoods and destination ends as well as the through trunk line service, will attract increased ridership while reducing unit costs.

AHS highways will provide capabilities to support and enhance the use of carpools and transit. The AHS will support transit vehicles both in lanes with automobiles and in exclusive lanes. AHS will include features to permit the local highway operator to give preference to transit vehicles, such as priority at entry and exit points. AHS automatic guidance features will also be available to facilitate passenger loading in station areas by the proper

AHS will enable transit to become more cost and time competitive

positioning of buses at platforms. As a local option, separate lanes could be set up for transit vehicles on certain highways. 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 terminal points for local transit vehicles. Another benefit for transit will be the ability to provide such lanes safely on narrower roadways resulting from the lateral control feature of AHS.

4.5 Apply to Rural Roadways

Roadways with highway-type characteristics have now been built in all corners of the country. Although all these roadways have many similar or identical characteristics, there are differences between urban, suburban, and rural highways in form and purpose. The rural highway environment is unique in that it has the following characteristics:[22]

The AHS will support the diversity of uses that is found in highway-type roadways on the nation including urban, suburban, and rural roadways

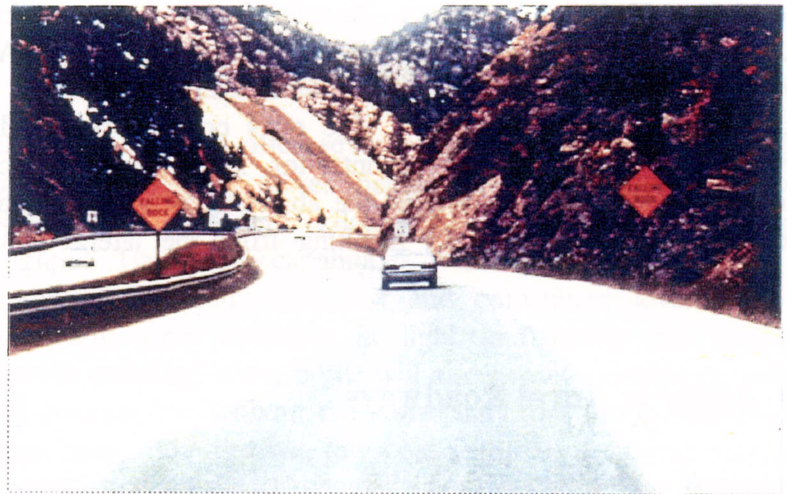
- Longer trips, often through unfamiliar areas;
- Irregular terrain and road alignment in some areas;
- Higher speeds, often coupled with lower volumes;
- Often longer reaction times due to inattention, disorientation or fatigued conditions;
- A relatively high incidence of driver impairment leading to many hazardous actions;
- Often older vehicles amongst rural residents;
- More severe effects of bad weather;
- Generally unlit roadway at night;
- Unexpected hazards such as animals or slow moving vehicles;
- A generally "less friendly" environment with more unexpected events and road-side obstructions.

Likewise the needs of the transportation provider differ in rural areas and small communities:

- More lane-mileage per capita to operate and maintain;
- Generally poorer quality and maintained roads;
- Wider extremes of weather and its effects;
- Fewer staff;
- Less resources with which to operate.

[22] "Summary of Conference Proceedings," CALTRANS, September 1992, and "National Conference for Rural IVHS", Summary, Colorado Department of Transportation, February 1993

AHS technology may be deployed on the rural infrastructure in a phased, evolutionary approach.



These differences call for unique capabilities in the AHS when it is applied to a specific roadway use.

Rural highways were built to provide high-speed, long-distance travel services to all types of vehicles. AHS will support these same objectives and enhance trip time predictability. This includes AHS lanes dedicated only to AHS-equipped vehicles. These vehicles will provide shorter trip times through higher average speeds, and support concurrent use by a variety of vehicle types (trucks and buses) with different speed capabilities. But affordability constraints may severely limit the deployment of AHS on rural roadways. Therefore, the AHS technology may be deployed on the rural infrastructure in a phased, evolutionary approach, supporting partially automated operation of AHS-equipped vehicles along with conventional vehicle operations.

Although this does not give all the benefits of AHS, it would still provide significant safety benefits and may reduce the stress of long-distance trips.

4.6 Support Travel Demand Management and Travel System Management Policies

The AHS will support local travel demand management policies

Any transportation technology, such as AHS, that serves to reduce congestion and increase the efficiency and reliability of travel on our nation's roadways has the potential to make driving on those roadways a more attractive alternative. Thus, AHS has the potential to induce additional demand for the use of these roadways, resulting in more trips, more vehicles in use, more miles

AHS will support and enhance community travel demand management policies, such as HOV corridors, congestion and parking pricing, and increased transit use

traveled, and a modal preference for personal automobiles. Such an outcome would diminish the mobility and environmental benefits achieved by the AHS in the first place by adding to congestion in non-AHS lanes and increasing overall vehicle emissions. To offset these potential effects, travel demand management (TDM) and travel system management (TSM) policies will be implemented concurrently with the deployment of the AHS. TDM measures intend to influence individual traveler behavior by discouraging personal travel and/or encouraging drivers to switch travel modes to carpools, vanpools, or transit during traditionally congested travel times. The following TDM mechanisms will reduce single occupancy vehicle (SOV) use:

- HOV lanes;
- Express bus;
- Car/van pool;
- Rideshare, commuter matching and guaranteed ride programs;
- Park and ride lots;
- Alternate/flexible work hours;
- Incentive programs;
- Congestion pricing;
- Telecommuting.

The goal of the TSM is to increase the performance of the existing transportation network through such measures as incident management, traffic signal coordination and ramp metering, exclusive lanes for HOVs, and other traffic engineering strategies. The approaches that will be taken with AHS to counter the potential for induced demand effects will include coupling of appropriate TDM and TSM strategies along with the deployment of the AHS, and deploying AHS in such a way as to support or encourage the

TDM and TSM strategies used at the state and local levels. The AHS efficiency and control will support and enhance community travel demand management policies, such as HOV corridors, congestion and parking pricing, and increased transit use. AHS will be compatible with systems that allow monetary incentives to be used to promote transit use, such as demand or congestion pricing.

4.7 Support Sustainable Transportation Policies

The AHS will support sustainable transportation policies.

There are various dimensions of sustainable transportation. The AHS will be compatible with and support transportation policies that are sustainable. These effects will in many cases be highly dependent on local conditions and implementation decisions, rather than being inherent attributes of the AHS design. Important aspects of sustainability are low maintenance and operating costs, the ability of self-sustaining markets to support deployments, the ability of AHS to permit effective sequences of deployment to evolve, and the ability of AHS to support deployments that have long-term sustainable impacts on resources and the environment.

AHS will contribute to more efficient vehicle travel, thereby reducing air emissions attributable to stop-and-go traffic and congestion. AHS will need to be designed so that it does not lead to increased congestion and traffic burden in neighborhoods adjacent to entry and exit points to/from AHS lanes. In addition, policy options to support sustainable transportation may include coupling AHS with programs that encourage fuel efficiency and renewable energy technologies, implementing AHS on advanced propulsion system vehicles first, emphasizing AHS support for public transportation, and deploying AHS in ways that do not adversely impact urban growth patterns.

5.0 AHS DESIGN CHARACTERISTICS

This section describes the characteristics to be included in the design of a fully operational AHS. The characteristics were derived from the original Request for Application To Establish a National AHS Consortium[23] and revised based on the results from the AHS Precursor System Analyses and the ongoing NAHSC System Definition efforts, including stakeholder feedback provided at the first Workshop.[24] Many of the key design characteristics for an AHS are tailorable by local Departments of Transportation depending on local needs and applications, as indicated in Table 5-1.

The following sections (5.1 through 5.11) describe the AHS design characteristics. These baseline design attributes should be included in the AHS for system success.

Table 5-1 AHS Design Characteristics

Design Characteristics	Section Number	Implementation Locally Determined
Easy to Use	5.1	
Operate in Inclement Weather	5.2	✓
Ensure Affordable Cost and Economic Feasibility	5.3	
Provide Beneficial Effect on Conventional Roadways	5.4	
Provide Infrastructure Compatibility	5.5	
Operate with Non-AHS Vehicles	5.6	✓
Support a Wide Range of Vehicle Types	5.7	✓
Ensure the AHS is Progressively Deployable	5.8	
Provide High Availability	5.9	
Provide Flexibility	5.10	✓
Provide System Modularity	5.11	

23 Request for Application To Establish a National AHS Consortium, U.S. DOT, DTFH61-94-X-00001, December 15, 1993.

24 AHS System Requirements Workshop, NAHSC, Ft. Lauderdale, FL, April 12-13, 1995.

5.1 Easy to Use

New tasks required by automation, such as destination entry and the transition to and from automatic control, must be simple, obvious, easy to learn, and accomplished with a minimum of effort for all drivers, regardless of age, cultural background, socio-economic group, or primary language. Destination (exit) selection must be flexible, and given reasonable notice time, be changeable at almost any time. Notification of an approaching exit and the need to resume manual driving must effectively gain the driver's attention. Confirmation of all driver input must be provided.

Information must be available to the driver on the progress of the trip: for example, the present location and time or distance to exit. Information must also be available on roadway status, required deviations such as for a blocked exit, and incident occurrences.

Operation will be user friendly by being straight forward, intuitive, and forgiving. A minimum of special instruction and training will be required.[25]

Most system malfunctions should be transparent to the driver; that is, the trip should continue normally without the driver being aware of the malfunction. If repairs will be required eventually, this must be brought to the attention of the driver without causing a sudden concern for his or her safety.

New tasks required by automation must be simple, obvious, easy to learn, and accomplished with a minimum of effort

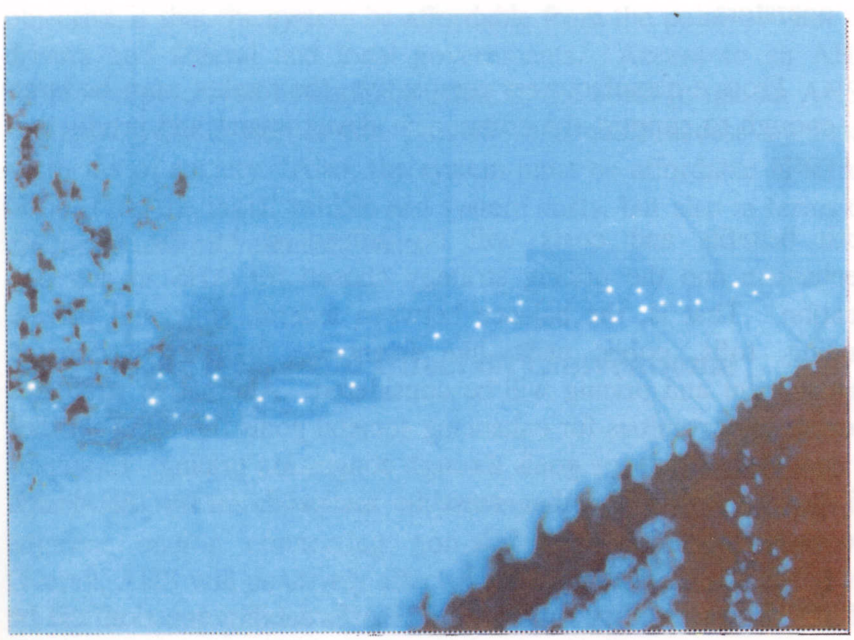
[25] Precursor Systems Analyses of AHS Overview ReportCalspan, Nov. 1994, Vol. I, pg 9.

In circumstances such as an extreme malfunction or a very serious externally caused incident, where continuing fully automated operation is no longer possible, control may be returned to the driver after the AHS has determined that the driver can safely resume control of the vehicle. Automatic control of the vehicle will continue until the vehicle is stopped or the driver takes over manual control.

5.2 Operate in Inclement Weather

Through the application of new and existing technologies, the AHS has the capability of producing significant improvements in vehicle operation in inclement weather and in times of reduced visibility. Ranging and obstacle detection systems that can "see" under conditions of poor driving visibility, and sensors that constantly monitor roadway and environmental conditions provide the opportunity for significant advances in safety and system performance during adverse weather conditions. The AHS will optimize vehicle spacing and vehicle speed, based on weather conditions and make real-time adjustments as conditions vary. Increases in congestion currently found in manual driving resulting from relatively minor inclement weather will be avoided by AHS. The degree of improvement offered by AHS over manual lanes will likely be much greater than during normal conditions.

The AHS will be able to operate at or exceed the performance levels of manual systems in the range of weather conditions that are typical in the continental U.S.



The AHS has the capability of producing significant improvements in vehicle operation in inclement weather and in times of reduced visibility

5.3 Ensure Affordable Cost and Economic Feasibility

Table 5-2 Examples of costs and benefits that must be considered for an affordable AHS

COSTS
• Infrastructure Design and Construction • Infrastructure Operation and Maintenance • Construction-Related Disruptions • Land • Vehicle Design and Production • Vehicle Purchase • Vehicle Operation and Maintenance • Environmental Damage Mitigation
EXPECTED BENEFITS
• Safety Enhancement • Congestion Reduction (Highways and Surface Streets) • Pollution/Fuel Consumption Reductions • Driving Time Reduction • Transit Time Reduction • Lower Insurance Rates • Driver Comfort Improvements • Improved Productivity of Goods and Improved Freight Movement • Economic Stimulus, Both Locally and Nationally • Potential Lifestyle Enhancements • Trip Time Predictability/Reliability • Transit Cost Reduction

Economic Feasibility - Economic efficiency is the requirement that the benefits derived from a system must exceed its costs. Economic efficiency is viewed from several different points of view, including those of consumers/users, non-users and owners. Both costs and benefits include monetary and non-monetary values including the following quantifiable and non-quantifiable factors:

- The benefits must outweigh the initial capital and operating costs for drivers, and the net benefits must exceed that of other transportation alternatives.

- At the federal, state and local government levels, AHS must maximize net benefits compared with other solutions and demonstrate that it is complementary with community and regional development plans.

- AHS must maximize net benefits from the point-of-view of society, including both users and non-users.

- As traffic is drawn onto an AHS, it will relieve overall demand on adjacent conventional highways.

- The system must be profitable for potential private owner-operators.

- From a manufacturers perspective, the market must be large enough to support the component development and production costs.

Both benefits and costs will be influenced by the financing mechanism and the pricing strategy chosen for AHS in any one location. That is, the balance between federal, state and private funding, tolls, public utility-like financing, fuel taxes, demand management and pricing will be considered. Alternative strategies provide opportunities for enhancing societal goals through subsidies or economic efficiency goals through congestion pricing. Examples of costs and benefits that must be analyzed during the design process are shown in Table 5-2.

Affordability (Ability To Pay) - The affordability question will be asked by consumers in the purchase of an AHS-equipped vehicle, by

The system must be affordable in terms of not only the initial vehicle and system costs, but also in terms of operating and maintenance costs

AHS vehicle and equipment manufacturers, by federal, state and local governments that regulate and manage the facilities, by potential private owner-operators, and by investors in an AHS-equipped highway. While the benefits may exceed the costs, the out-of-pocket cost may exceed the ability to pay. Again, this is closely tied to the financing and pricing strategies used. The objective is that the system be affordable from the point-of-view of drivers and federal and local governments. Access to an AHS should be perceived as equitable; that is, the costs to use an AHS-equipped vehicle should not prevent reasonable access by most segments of society. Also, the system must be affordable in terms of not only the initial vehicle and system costs, but also in terms of operating and maintenance costs.

5.4 Provide Beneficial Effect on Conventional Roadways

The AHS will be consistent with continued efficient operation of adjacent and/or connecting non-automated traffic operations. Overall, AHS will positively affect adjacent conventional roadways. As traffic is drawn onto an AHS this will relieve overall demand on adjacent conventional highways, as long as potential induced demand effects are adequately managed (see Section 4.6). AHS will be seamlessly integrated into the surrounding transportation

As traffic is drawn onto an AHS, it will relieve overall demand on adjacent conventional highways.

system for a smooth transition between the AHS roadway, the conventional roadway, and other transportation modes. With the high vehicle capacities inherent in the AHS, design of AHS entry and exit transitions is critical if congestion at the transfer point is to be minimized.

Improvements in trip-time predictability as a result of the AHS will provide increased opportunities for coordination of the AHS with the surrounding transportation system. The conventional roadways also can benefit because the AHS-equipped vehicles, when operating on conventional roadways, will use AHS technologies to perform functions such as adaptive cruise control and obstacle detection, thus enhancing the safety of the conventional roadways.

In many areas, existing interchanges between highways and arterial streets are already jammed to capacity. If highway throughput is doubled or tripled, a bad condition will be worsened. The NAHSC realizes that the challenge exists, to improve the transition from highway to arterial roadway under today's conditions, as well as with an AHS.

5.5 Provide Infrastructure Compatibility

The AHS may require physical changes to the existing roadway. These changes may include, but are not limited to the following:

The AHS roadway will generally have highway/highway-type characteristics and be suitable for installation on or near existing highways

- Embedded sensors or markers,
- Barriers,
- Widened roadway sections,
- Increased super-elevation,
- New pavement resurfacing,
- Highway-to-highway interchange ramps,
- Exit and entrance ramps.

The changes will be evaluated to identify repercussions, including physical, operational, and monetary, to the existing facility. To minimize the impact to the existing highway, the changes will be tailored to meet the physical constraints of the facility. To do this, there may be a need to develop special construction vehicles, materials, or techniques that are integrated with and facilitated by the electronics installed for the AHS. The AHS capability is not intended for application to urban/suburban arterials or local streets or rural roads without access control.

5.6 Operate with Non-AHS Vehicles

As a local option, AHS vehicles may be able to operate under partial automation on a highway that is also being used by conventional vehicles. AHS is defined as AHS-equipped vehicles operating under automatic control on dedicated AHS highways; that is, with no manually controlled vehicles in the AHS lane(s). However, for some highways it may not be practical, at least initially, to install a dedicated lane or convert a manual lane to

AHS vehicles will be able to operate on a highway along with conventional vehicles

dedicated AHS operation. But it may be desirable to begin installation of AHS technology into the infrastructure as a step toward dedicated operations. The AHS vehicles will still enjoy some benefits of automation under partial automated control while the highway is also being used by non-AHS equipped vehicles. Even without any AHS infrastructure, many of the in-vehicle AHS capabilities will enable significant improvements over conventional vehicle operations. Adaptive cruise control will enhance driver comfort and convenience, and should be safer than conventional vehicles. The sensors and signal processing used for AHS can also be applied to collision warning and avoidance systems that should enhance safety for vehicle operations on all roads.

5.7 Support a Wide Range Of Vehicle Types

The AHS will be able to meet its performance requirements given use by a wide variety of vehicles. However, some types of vehicles may not qualify for AHS use. For instance, vehicles with fewer than four wheels (e.g., motorcycles) will be excluded. Some vehicles may not meet minimum performance, handling, and braking requirements for a desired level of AHS throughput.

The capability to operate at various throughput levels will be designed into the system to allow local authorities the flexibility to implement AHS with characteristics appropriate to their areas. Local governments will be able to control access by different vehicle types dynamically as a matter of policy. For instance, it will be possible to exclude certain low-performance vehicles (like heavy trucks) at rush hour to increase efficiency.

5.8 Ensure the AHS is Progressively Deployable

The AHS will be progressively deployable in a planned and managed manner, building from today's highway/vehicle systems. AHS will be designed for a smooth progression towards automation of the roadway network. Because the full functionality of a mature AHS cannot be realized suddenly, discrete logical steps will be identified and optimized. The early steps such as adaptive cruise control and collision avoidance equipment, will provide significant benefits to both users and non-users. The AHS design will be compatible with, and work within the national ITS architecture.

There are many basic deployment issues that must be considered, e.g., technology, infrastructure, liability, human factors, vehicle manufacturing and maintenance, insurance, regulatory, community benefit/impact, cost, emergency response, and public acceptability. The deployment scenario will consist of a phased implementation, where each phase provides additional functionality and benefits. In addition, to support the deployment process, guidance will be developed to influence the direction of relevant associated activities. This guidance will provide the opportunity to take advantage of the design innovations of these activities. The deployment plans will provide contingency plans in case predicated events do not occur.

It is expected that the AHS will progress in a planned fashion, with certain components and capabilities being enhanced and introduced at regular intervals. Manufacturers will need to provide vehicle system enhancements in coordination with infrastructure enhancements. Retrofitting of vehicles will require a minimum of modification time and cost. This is an essential feature that enhances AHS evolvability. Vehicles will be designed so that many anticipated future functions can be added without extensive modification. For example, upgrading a vehicle with adaptive cruise control to a forward collision avoidance system can be much easier if components need only be added to the adaptive cruise control system.

In addition, deployability depends on addressing issues of critical importance to state legislatures, state DOTs, MPOs, and other regional/state/local transportation planning agencies. These organizations must make decisions about the allocation of scarce resources to support transportation and the criteria used to make these choices. AHS must be responsive to these concerns to be well received in light of other alternatives.

5.9 Provide High Availability

AHS will be available for service to the maximum extent possible.

To ensure that the AHS system provides increases in roadway throughput without compromising safety and usability, the AHS system will be designed to be operational and functional, under a wide range of roadway conditions. The AHS will ensure continued, safe operation or safe system shutdown under conditions of hardware or software failure. System degradation and loss of system services as a result of infrastructure failures will be extremely rare. If the level of service must be degraded, the degradation will be as minimal as possible under the specific circumstances. The components of the system will be designed for rapid diagnosis and repair. Detection and rapid removal of roadway obstructions should be a part of the AHS design. This includes the access of emergency vehicles and concepts for the rapid removal of disabled vehicles.

5.10 Provide Flexibility

The AHS will be adapted to satisfy the needs of local users and operators.

Flexibility includes local flexibility and system flexibility. The AHS will be flexible to meet the needs of the individual states and regions that choose to implement the system. Common standards will enable AHS-equipped vehicles from one region of the country to travel on an AHS in any other part of the country. However, local applications may vary depending on policies and performance restrictions. The example applications shown in Table 2-1 illustrate how individual states and regions may tailor the AHS to meet their needs. Tables 4-1 and 5-1 indicate which of the AHS objectives and design characteristics are applicable to locally determined implementation.

The AHS will be robust in its ability to deal with the many types of uncertainty that the system will confront over its lifetime.

5.11 Provide System Modularity

The AHS will be modular to facilitate the introduction of advances in technology.

The interfaces between the various subsystems that comprise the AHS will be defined to enhance modularity and ensure compatibility with an open architecture. Modularity of subsystems and components will allow the system to be progressively upgraded to accommodate advances in the technologies. Replaceable modules will minimize any downtime for servicing caused by a failure or scheduled periodic maintenance.

6.0 SUMMARY

Though the interstate highway system of today was well-planned, it will not accommodate the projected increase in demand by the motoring public during the next 25 years. Users of an AHS will realize significant benefits in terms of improved safety, improved convenience, and reduced congestion. Deployment of the AHS will be an incremental process that will introduce components of the system to the public, in a phased, convenient, cost-effective manner. Components likely for initial deployment include adaptive cruise control and collision warning. Implementation of these components should result in a marked improvement in safety by reducing the number of rear-end collisions.

There are no "showstoppers," although there are many challenges to overcome.

The NAHSC recognizes there are numerous issues that must be resolved before the fully operational AHS can be deployed. All of the objectives and characteristics defined in Sections 3 and 4 have been voiced by the different stakeholders. However, to achieve some objectives (like improve safety), could have the potential to have a negative impact on other objectives, (like affordability). These issues and eventual design trade-offs will be assessed and balanced to meet most of the needs of all stakeholders.

Technically, an automated highway system is achievable. However, the institutional and societal issues pose a more difficult challenge. The system must be environmentally sound, affordable, and be adaptable to meet the needs of both local stakeholders and future generations. This document is only the first step in the process to achieve a safer, more reliable transportation system. As the NAHSC learns more about stakeholder's needs, the objectives and characteristics will mature, reflecting these changes. They also provide a focal point from which local stakeholders can learn about AHS, enabling them to make "smart buys" in terms of implementing an AHS, based on local needs.

APPENDIX A — AHS Measures of Effectiveness

The following series of tables provide *example* measures of effectiveness for each of the AHS performance objectives, user services, and design characteristics that have been defined in Sections 3.0, 4.0, and 5.0. Measures of effectiveness are intended to provide a quantitative evaluation of the ability of a conceptual approach to meet the system performance objectives relative to current highway capabilities. Specific numerical quantities will be developed as the system performance specification matures.

PERFORMANCE OBJECTIVES	**MEASURES OF EFFECTIVENESS** (Δ's to present values)	**EXPLANATION**
Improve Safety	Number of crashes	Number of auto crashes per VKT Number of transit crashes per VKT Number of commercial vehicle crashes per VKT
	Number of annual fatalities due to crashes	Number of annual fatalities related to auto crashes Number of annual fatalities related to transit crashes Number of annual fatalities related to commercial vehicle crashes
	Fatality rate	The number of fatalities per vehicle kilometer traveled compared with conventional highway for: - Light vehicle - Transit - Commercial
	Number of injuries due to crashes	Number of annual injuries due to: - Light vehicle crashes - Transit crashes - Commercial vehicle crashes
	Injury rate	The number of injuries per VKT compared with conventional highway for: - Light vehicle - Transit - Commercial vehicles
	Severity of injuries on AHS vs conventional highways	Severity of injuries due to: - Light vehicle crashes - Transit crashes - Commercial vehicle crashes
	Accident rate per vehicle kilometer traveled	Number of crashes per VKT for: - Light vehicle crashes - Transit crashes - Commercial vehicle crashes

PERFORMANCE OBJECTIVES	MEASURES OF EFFECTIVENESS (Δ's to present values)	EXPLANATION
Improve Safety (cont)	Total annual cost of all accident-related injuries	Value, in dollars, of required medical service, lost time, lost wages, pain and suffering, etc. for: - Light vehicle crashes - Transit crashes - Commercial vehicle crashes
	HAZMAT crashes	The number of crashes involving HAZMAT per VKT
	Property loss	The total annual cost in dollars of all accident related property losses. This includes vehicles (light, transit, and commercial), damage, transportation facility damage, and damage due to hazardous material crashes.
	Property loss per VKT	The total cost in dollars of all accident related property loss per VKT
	Travel security cost	The total dollar cost of the annual number of assaults, thefts, and vandalism occurring during AHS travel. The cost of assaults includes the value of required medical services, lost time, lost wages, pain and suffering, etc. Total cost is the sum of the total dollar values of assaults and thefts occurring during light vehicle, transit, commercial vehicle, and hazardous material transport, and in transportation facilities.
	AHS vs non-AHS ratio of occurrence of catastrophic crashes	Ratio of occurrence rate of catastrophic crashes on AHS to the rate on today's highways, where a catastrophic accident is defined as a accident involving 'M' vehicles or 'N' fatalities.
	Accident response time	The number of minutes needed for service vehicles to respond to a accident, service the accident, and clear the accident.
	Incident clearance time	The change in time needed to completely clear minor & major incidents from the roadway
	Infrastructure damage by vehicles	The change in roadway down-time (or lane closure) as a result of vehicle damage to infrastructure
	Time to respond to malfunction	The change in time needed to respond to and repair a malfunction, and return the system to nominal operations.
	Down time due to vandals	The amount of down time of the system due to damage caused by vandals
	Security vs Hackers	Probability of hacker being able to get into the system. Probability that if a hacker gets into the system he will be able to degrade system performance. Length of time needed to detect intrusion by hackers.

PERFORMANCE OBJECTIVES	MEASURES OF EFFECTIVENESS (Δ's to present values)	EXPLANATION
Increase Efficiency	Vehicle per AHS lane per hour	Capacity of lane to move vehicles - Light duty vehicles - Transit Vehicles - Trucks
	Vehicles per right-of-way width per hour	Vehicles per right-of-way width (including shoulders, transition lanes, and automated lanes) per hour -Light duty vehicles -Transit vehicles -Trucks
	Cargo per lane per hour	The capacity of lane to move cargo -Passengers -Freight
	Check-in delay time	Amount of time added to trip time by AHS check-in process (user MOE)
	Entry rate - Number of vehicles per hour	Number of vehicles allowed on to automated lanes relative to lane capacity
	Exit rate - Number of vehicles per hour	Number of vehicles allowed off the automated lanes relative to lane capacity
	Check-out delay time	Amount of time added to trip time by check-out process (user MOE)
	Reduction of throughput resulting from incidents/ crashes	The change in hours of delay
	Equivalent conventional lanes to support traffic carried by one AHS lane	Number of square meters of right-of-way
	Incidents	The number of incidents per VKT
	Local delays	The probability of local blockages that reduce throughput
	Maximum safe speed	The speed limit on an AHS -Urban -Rural -Night -Inclement weather
	Vulnerability to single-point failure (SPF)	To what extent could a SPF shut down the entire system
	Average trip time	The average amount of time spent driving per origin/destination pair The average amount of time spent on the AHS
	Standard deviation of trip time	The standard deviation of trip time for each trip per origin/destination pair The standard deviation for each trip on the AHS
Enhance Mobility and Access	Trip-time deviation (Fixed OD pair)	Ability to maintain predictable trip times. Standard deviation of AHS trip times compared to today's trip times for same locations
	Trip-time (Fixed OD pair)	Trip time compared to today's trip time under similar traffic conditions

PERFORMANCE OBJECTIVES	MEASURES OF EFFECTIVENESS (Δ's to present values)	EXPLANATION
Enhance Mobility and Access (cont)	Trip-time distribution (Fixed OD pair)	The AHS trip time distribution compared to today's highway trip-time distribution (e.g., expected value, standard deviation, and percentiles) taking into consideration traffic congestion, check-in and check-out waiting time and vehicle/system failures
	Trip length distribution	The average length, in km, of trips taken
	Wait time at ingress	The average amount of time, in minutes, spent at the ingress point
	Wait time at egress	The average amount of time, in minutes, spent at the egress point
	Use by drivers with disabilities	Change in percentage of drivers with disabilities, or whose capabilities temporarily fall outside the norm, that use the highways Change in percentage of aged drivers who use the highway Change in percentage of drivers with temporary limitations who use the highway
	Equity	Accessibility by all socio-economic groups
	Transit Coordination	Time spent waiting for transit
	Transit coverage	Change in availability of transit to various population segments as a result of AHS
	User perceptions	The user perceptions of mobility enhancement
	Training/licensing	The number of hours of training per driver per year need to qualify the driver to use the AHS The number of years between update of training
Provide More Convenient and Comfortable Highway Traveling	Driver involvement	The amount and difficulty of driver actions required during driving - Steady state - Emergencies
	Driver access	The amount of time and effort required to enter and exit relative to conventional highway access
	Interface complexity	The degree of difficulty and time required to enter destination information
	Serviceability	Frequency and cost of maintaining and servicing AHS-specific equipment
	Control usability	The range of movement required to access AHS interfaces
	Attention load	Demand placed on the driver to perform simultaneous tasks
	Comprehension delay	The amount of time required to determine the function of a control or message
	User compatibility	The range of driving population capable of performing AHS-specific tasks
	Learnability	The time required to learn system and control operations. Degree of driver training, skill or certification needed to gain access to the AHS compared to that needed for access to conventional highways

PERFORMANCE OBJECTIVES	MEASURES OF EFFECTIVENESS (Δ's to present values)	EXPLANATION
Provide More Convenient and Comfortable Highway Traveling (cont.)	Driver population	Ratio of percentage of driving-age population who can use AHS relative to percentage who can use today's highways
	Accessibility distribution	Probability distribution of length of time a high percentage of driver population can use AHS continuously compared to conventional highway driving
	Distance accessibility	Probability distribution of distance that a high percentage of driver population can travel on AHS continuously compared to conventional highway driving
	Stress reduction	The degree of stress reduction compared to conventional highway driving
	User perception	The way users perceive or understand various aspects of AHS such as mixed traffic operation, close spacing, speed, and operations during inclement weather conditions
	Ride comfort	Variability of acceleration, deceleration, and lateral maneuvers
	Vehicle certification	Frequency, time needed, and cost to certify each vehicle
Reduce Environmental Impact	Idle time	Amount of time per vehicle spent where forward velocity is zero while the vehicle is operating
	Speed variability	Variation in steady-state vehicle speed
	Acceleration/deceleration rates	Acceleration and deceleration rates in non-emergency modes
	Alternate propulsion compatibility	Ability to support alternative propulsions systems
	Per-VKT primary air pollutant sources	CO, HC, CO2, NOx and O3
	Per-VKT other pollutant sources	SOx and particulate matter
	Fuel efficiency	Kilometers/liter on AHS compared to that of conventional highways
	Fuel consumption	Liters/kilometer, i.e., inverse of fuel efficiency
	Fuel consumption - overall	Liters consumed per year
	Acoustic noise level	Decibels as a function of vehicle type, traffic density, speed, and distance from the AHS
	Land use	Acres of land needed/reclaimed resulting from AHS implementation
	Aesthetics	Visual impacts due to possible AHS-related infrastructure modifications
	Electromagnetic field	Full characterization of all imposed magnetic fields relative to ambient fields prior to AHS construction

USER SERVICES OBJECTIVES	MEASURES OF EFFECTIVENESS (Δ's to present values)	EXPLANATION
Disengage the Driver from Driving	Driver engagement	The percentage of time on AHS driver is allowed to do non-driving tasks
	Driver tasks	The events that require driver interaction
	Driver workload	The percentage of time the driver must perform AHS tasks
	Ease of reingaging the driver	How difficult will it be for the driver to regain control of the vehicle
Facilitate Intermodal and Multimodal Transportation	Mode connectivity	Distribution of modes directly supported/connecting to AHS highways vs. conventional highways per lane kilometer
	Modal interfaces	Incentives for efficient use of resources - By mode (vehicle type) - Infrastructure
	Mode specific training	Training costs and requirements for transit and commercial vehicle operators (including taxis) beyond regular AHS training
	Indirect mode benefits	Improved passenger delivery/pickup at ports (air, sea, rail)
Enhance Operations for Freight Carriers	Improved safety of freight carriers	Accident rate involving commercial vehicles on an AHS vs conventional highway
	Increased throughput of freight carriers	Capacity of lane to move goods and commercial vehicles
	Length of time needed for CV inspection	Reduction of the amount of time needed for vehicle inspection, both per inspection, and per trip
	Predictable trip times	Predicted trip time error rate on AHS vs conventional highways for commercial vehicles
Support Automated Transit Operations	Capital costs	Facility costs for transit under AHS
	Safety of transit carriers	Accident rate involving transit vehicles on an AHS vs conventional highway
	Throughput of HOV lanes	Capacity of lane to move transit and HOV passengers and vehicles
	Unit operating costs	Unit operating costs for transit before & after AHS
	Transit coverage	The amount of transit service added through use of AHS
	Transit vehicle speeds	Average transit vehicle speeds before and after use of AHS guideway.
	Service reliability	On-time performance after AHS.
	Transit ridership	Use of transit after AHS
	Passengers per driver hour	The change in the number of transit passengers per driver hour after AHS implementation
	Mode shift	The number of people that begin using transit as a result in improvements in the transit system.
Apply To Rural Highway	Limitations	Limitations on operation of different vehicle types accommodated by AHS compared to conventional highways

USER SERVICES OBJECTIVES	MEASURES OF EFFECTIVENESS (Δ's to present values)	EXPLANATION
Apply To Rural Highway (cont)	Vehicle class	Limitations on different classes of vehicle within a vehicle type accommodated by rural AHS compared to conventional rural highways
	Rural road access	Percentage of rural roads equipped to support full or partial AHS capabilities
Support Travel Demand Management and Travel System Management Policies	Demand management	Ability to provide priority to multiple-occupancy-vehicles
	Induced Travel	New travel resulting from AHS
	Dependence	Local degree of dependence on the automobile or public transit for mobility
Support Sustainable Transportation Policies	Land use	Enhance community/urban form viability Supports present form Does not require extra land Does not encourage unmanageable growth Community should not have to work around the transportation system
	Energy use	Changes in fuel resources consumed per km of passenger travel

DESIGN CHARACTERISTICS	MEASURES OF EFFECTIVENESS (Δ's to present values)	EXPLANATION
Easy to Use	Driver in-vehicle interface	The time required to learn system and control operations. Degree of driver training, skill or certification needed to gain access to the AHS compared to that needed for access to conventional highways.
	User acceptance of automated control	The degree of acceptance of the AHS
	Emergency Response	Difference in degree of driver participation required compared with present system
Operate In Inclement Weather	Throughput	Each of the throughput measures at each of the weather conditions compared to its manual highway counterpart
	Incident rate	Ability to prevent incidents otherwise caused by human error in reduced traction and visibility conditions
	Minimum operating conditions	Minimum (i.e., worst) permissible operating conditions (e.g., snow accumulation, snow rate, rain rate, fog density, water accumulation, wind speed, dust density, minimum and maximum temperature)
	Safety	Each of the safety measures at each of the weather conditions compared to today's manual highway traffic
	Maximum speed	Maximum permissible speed at each of the weather conditions compared to today's manual highway traffic
Ensure Affordability and Economic Feasibility	System life-cycle cost	The total discounted cost of an AHS implementation over the operational life-time of the facility
	Infrastructure capital costs	The cost of AHS implementation, including instrumentation of the roadway and installation of zone or regional equipment. Total capital costs compared to that of conventional infrastructure.
	Infrastructure operation and maintenance costs	The cost of labor and equipment required to operate and maintain AHS specific instrumentation and equipment in the infrastructure.
	Societal costs and non-user costs	For example, crashes, mobility, economic growth, air pollution, noise, and neighborhood disruption.
	User costs	Travel time of drivers and passengers (including access time). Net change in capital and operating costs for transit and commercial vehicle operators
	Bus or truck specific costs	Capital/maintenance/operational costs of AHS capable bus/truck to AHS ready and non-AHS bus/truck

DESIGN CHARACTERISTICS	MEASURES OF EFFECTIVENESS (Δ's to present values)	EXPLANATION
Ensure Affordability and Economic Feasibility (cont)	Benefits and/or willingness to pay	The ability and willingness of all segments of the population to pay the AHS costs
	Automobile vehicle purchase costs	The price of AHS-specific equipment on the vehicle
	Automobile capital vehicle costs	Capital cost of AHS capable automobile to AHS ready and non-AHS automobile
	Automobile maintenance costs	Maintenance costs (e.g. inspection and repair of AHS-capable automobile to AHS-ready and non-AHS automobile.)
	Automobile operational	Operational costs (e.g. fuel) of AHS-capable automobile to AHS ready and non-AHS automobile
	Enforcement cost	Change in policing costs
	Indirect societal and non-user costs	Changes in transit fares and goods costs as a result of AHS implementation
	Availability of funds	Are funds for infrastructure modifications available to use
	System liability	Change in legal costs associated with the implementation of the AHS
	Education	Additional cost to train user of the system - Drivers - Operators - Passengers
	Property loss	The total annual cost in dollars of all accident-related property losses. This includes vehicles (light, transit, and commercial), damage, transportation facility damage, and damage due to hazardous material crashes.
	Out-of-pocket driver expenses	Fee for automobile/bus/truck per VKT needed to defray the infrastructure capital and operating costs. Transit fares
Provide Beneficial Impact On Conventional Roadways	Trip time	The average reduction in trip time due to increased capacity on AHS lanes that reduce demand on conventional highway lanes.
	Arterial loading	The number of vehicles traveling AHS access and egress routes in excess of existing traffic patterns.
	Interface congestion	Level of congestion/delay at or near the interfaces (e.g., AHS transition lanes and highway-to-arterial interchanges) and resulting environmental impacts (e.g., emissions, fuel consumption and noise)
	AHS access congestion	Level of congestion/delay on roadways nearby the AHS (e.g., central business districts and town centers) and the resulting environmental impacts (e.g., emissions, fuel consumption, and noise)

DESIGN CHARACTERISTICS	MEASURES OF EFFECTIVENESS (Δ's to present values)	EXPLANATION
Provide Beneficial Impact On Conventional Roadways (cont)	AHS throughput reduction impacts	Effect of throughput reduction on AHS (e.g., inclement weather conditions and incidents/crashes on AHS) on non-AHS roadways
Provide Infrastructure Compatibility	Extent of modifications required	Percentage of existing infrastructure requiring modification for AHS due to system incompatibilities
Operate in a Mixed Traffic with Non-AHS Vehicles	Cost of mixed traffic operation	The incremental cost or savings of AHS to provide a mixed traffic capability - Urban - Rural - Intercity
Support A Wide Range Of Vehicle Types	Vehicle type limitations	Limitation on operation of different vehicle types (i.e. automobile, bus and trucks) on AHS compared to conventional highways
	Vehicle class limitations	Limitations on different classes (e.g., multi-unit truck) within a vehicle type (e.g. truck) accommodated by AHS compared to conventional highways
	Vehicle compatibility	The percentage of vehicle population that may be accommodated on AHS lanes
Ensure the AHS is Progressively Deployable	Infrastructure modification	Cost of infrastructure modification
	Public acceptability	Meets market needs of users
	Agency acceptability	Meets local needs and mandates of transportation agencies
	Usage of existing facilities	Percentage of existing infrastructure not requiring modification for AHS
	Usage of existing instrumentation	The percentage of automated control functions achieved using previously available services such as sensors and communications resulting from ITS
	Traffic interruption	Interruption to existing traffic level of service for AHS deployment
	Planned upgrades	Applicability of planned infrastructure modification independent of future deployment of AHS
	Intermediate benefits	Safety and capacity benefits at intermediate deployment stages
	Market penetration	Percentage of vehicles in place to use an AHS
Provide High Availability	System online percentage	The fraction of time that the AHS operates at full service
	System off-line percentage	The fraction of time that the AHS is not operating at full service
	Reliability	The mean time between failures of automated subsystems integral to AHS operation
	Downtime	Downtime duration and affected area per unit time per lane-length for AHS compared to that of conventional highways (including HOV lanes)

DESIGN CHARACTERISTICS	MEASURES OF EFFECTIVENESS (Δ's to present values)	EXPLANATION
Provide High Availability (cont)	Downtime distribution	Downtime duration and affected area distribution compared to that of conventional highways (including HOV lanes)
	Restart time	Time from AHS failure to restart compared to today's highway incident response times (including HOV lanes)
	Mean time to repair	The time required to restore service
	Maintenance frequency	Frequency of AHS roadway infrastructure inspection/maintenance compared to conventional highway infrastructure
Provide System Flexibility	Applications	Number of variations and local applications supported by the AHS architecture
	Vehicle accumulations	Peak numbers of vehicles accumulated in high traffic areas (i.e.. urban cores, major activity centers, regional centers) after AHS implementation
	Number of user choices	The number of choices the user will have for each operation that the user must perform while on the AHS
	Open architecture	Percentage of the overall AHS architecture that is open and not proprietary
Provide System Modularity	Infrastructure modularity	Percentage of the AHS infrastructure that is modular
	Vehicle modularity	Modularity of AHS vehicle instrumentation compared to that of conventional vehicles
	Upgradability	Percentage of vehicles that are upgradable compared to that of conventional vehicles not capable of upgrading

APPENDIX B — Glossary

Definitions

Adaptive Cruise Control	A cruise control system that maintains a safe following distance from the vehicle in front of it. (Also referred to as Intelligent Cruise Control or Autonomous Intelligent Cruise Control.)
AHS Mode of Operation	Instrumented vehicles operating under fully automated control in instrumented dedicated roadway lanes in which manually operated vehicles are not permitted.
Capacity	The maximum rate of flow at which persons or vehicles can be reasonably expected to traverse a point or uniform segment of a lane or roadway during a specified time period under prevailing roadway, traffic, and control conditions; usually expressed as vehicles per hour or persons per hour.[26]
Common Mode Failures	Common mode failures as used herein are defined as those failures that affect more than one process or function at any time.
Destination Selection	Selection of the vehicle's destination either at the beginning of the trip or enroute.
Fail Safe	A failure within the system will not result in injury to the users.
Fail Soft	A failure within the system will not cause a complete loss of system performance.
Impaired Drivers	People that have a valid drivers license but avoid driving on some types of limited access highways because of actual or perceived limitations.
Incident	Any unplanned occurrence on the highway that could cause a degradation in system performance.
Incident Management	The steps taken to detect and recover from an incident that has affected traffic flow.
Intermodal	Refers to stopping points where people or cargo change modes of transportation.

[26] Highway Capacity Manual, Special Report 209, Transportation Research Board, National Research Council, Washington D.C. 1985

Measure of Effectiveness	The means by which we quantify the system's ability to meet objectives and characteristics.
Mixed Traffic Operations	Allows for manual vehicles to be driven on an AHS roadway.
Multimodal	Refers to mixed types of vehicles, i.e. personal, transit, freight, on the same highway.
Obstacle	Any object not part of the roadway, which, if struck, could damage a vehicle.
Partial AHS	Allows for some AHS features to be used on a conventional roadway.
Performance Objectives	The fundamental reasons for developing AHS, representing the purpose of the program. These define the reasons for investing resources to develop and deploy AHS.
Retrofit (Infrastructure)	Installation of AHS systems into an existing infrastructure.
Stakeholders	People with an interest, or have a stake in (or are affected by) decisions associated with the design, development, deployment, or use of AHS.
Super-Elevation	The vertical distance between the heights of inner and outer edges of highway pavement.[27]
Throughput (Rate of Flow)	The equivalent hourly rate at which vehicles pass over a given point or section of a lane or roadway during a given time interval less than one hour, usually 15 minutes.
Travel Demand Management (TDM)	TDM refers to a set of strategies for influencing, or more particularly, reducing the rate of growth in demand, or even reducing the absolute level of demand, for travel.

[27] Webster's New Collegiate Dictionary

Acronyms and Abbreviations

AHS	Automated Highway System
CAAA	Clean Air Act-Amended
CO	Carbon Monoxide
CV	Commercial Vehicle
DOT	Department of Transportation
HC	Hydrocarbon
HOV	High-Occupancy Vehicle
ISO	International Standards Organization
ISTEA	Intermodal Surface Transportation Efficiency Act
ITS	Intelligent Transportation System (formerly IVHS)
IVHS	Intelligent Vehicle Highway Systems
kph	Kilometers per Hour
mm	Millimeter
MOE	Measure of Effectiveness
mph	Miles per Hour
MPO	Metropolitan Planning Organization
mps	Meters per Second
MVKT	Million Vehicle Kilometers Traveled
NAHSC	National Automated Highway System Consortium
NOx	Oxides of Nitrogen
O&M	Operations and Maintenance
O3	Ozone
OD	Origin-Destination
PSA	Precursor Systems Analyses
RPEV	Roadway-Powered Electric Vehicles
sec	Seconds
SIP	State Implementation Plans
SOV	Single Occupancy Vehicle
SOx	Oxides of Sulfur
SPF	Single-Point Failure
TDM	Travel Demand Management
TIP	Transportation Implementation Plans
TSM	Travel System management
U.S.	United States
VKT	Vehicle Kilometers Traveled

National Automated Highway System Consortium
3001 West Big Beaver Road, Suite 500
Troy, MI 48084