Preliminary System Objectives and Characteristics for an Automated Highway System (AHS) in the United States

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ABSTRACT

Before an Automated Highway System (AHS) can be specified, designed, tested and built, the overall goals for an AHS must be defined. This paper provides the overall objectives and characteristics of an AHS balancing the needs of users and other stakeholders. These objectives and characteristics will be used to guide the AHS Program and the National Automated Highway System Consortium (NAHSC) to perform its mission.

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.[1]

The AHS program is a government-industry-academia collaboration to apply automated vehicle control technology to the U.S. highway system to greatly improve the safety, mobility, and quality of highway travel. The efficiency of the automated highway is expected to help conserve energy resources and 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. In most cases, these improvements will be made using the existing highway infrastructure.

Twenty-three top-level system objectives and characteristics have been defined for an AHS in the United States. These include:

- Improve Safety
- Increase throughput
- Enhance Mobility
- More convenient and comfortable highway traveling
- Reduce environmental impact
- Operate in inclement weather
- Ensure affordable cost and economic feasibility
- Beneficial effect on conventional roadways
- Easy to use
- Infrastructure compatible
- Facilitate intermodal and multimodal transportation
- Ensure deployability
- Provide high availability
- Apply to rural roads
- Disengage the driver from driving
- Support travel demand management policies
- Support sustainable transportation policies
- Provide flexibility
- Operating in a mixed mode with non-AHS vehicles
- Support a wide range of vehicle types
- Enhance operations for freight carriers
- Support automated transit operations
- Provide system modularity

INTRODUCTION

The following depict the performance objectives and characteristics of the AHS. They were derived from the original Request for Application [2], and revised based on the efforts by the AHS Precursor System Analyses and the NAHSC System Definition efforts. The objectives and characteristics have been divided into three categories shown in Table 1.

Performance Objectives — The fundamental reasons for developing and deploying AHS,

representing the purpose of the program. These define the reasons for investing resources to develop and deploy AHS.

Essential Characteristics — Those design attributes that *must* be included in the AHS for system success. They may be specific to AHS or they may be a common attribute of any successful new system.

Desirable Characteristics — Those attributes that are *wanted*, but do not absolutely have to be included in the system for success.

AHS OBJECTIVES AND CHARACTERISTICS

Improve Safety - The AHS will be collision free in the absence of malfunctions and will include malfunction and incident management capabilities that minimize the number and severity of collisions that 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.[3] By eliminating driver control over AHS vehicles on AHS designated highway lanes under non emergency situations, 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.

Table 1
Classification of AHS Performance Objectives and Characteristics

Objectives and Characteristics	*Performance Objectives*	*Essential Characteristic*	*Desirable Characteristic*	Implemen-tation Locally Determined
Improve Safety	●			
Increase Throughput	●			
Enhance Mobility	●			
More Convenient and Comfortable Highway Traveling	●			
Reduce Environmental Impact	●			
Operate in Inclement Weather		●		
Ensure Affordable Cost and Economic Feasibility		●		
Beneficial Effect on Conventional Roadways		●		
Support for Vehicle Control		●		
Easy to Use		●		
Infrastructure Compatible		●		
Facilitate Intermodal and Multimodal Transportation		●		✓
Ensure Deployability		●		
Provide High Availability		●		
Apply to Rural Highway		●		✓
Disengage the Driver from Driving		●		
Support Travel Demand Management Policies		●		✓
Support Sustainable Transportation Policies		●		✓
Provide Flexibility		●		✓
Operate in a Mixed Mode with Non-AHS Vehicles			●	✓
Support a Wide Range of Vehicle Types			●	✓
Enhance Operations for Freight Carriers			●	✓
Support Automated Transit Operations			●	✓
System Modularity			●	

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.

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.

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 Dedicated AHS lanes will prevent intrusion by pedestrians, animals, environmental conditions (rock and snow), and vehicles in adjacent lanes.

Increase Throughput - 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.[4] Throughput gains will be obtained through significant reduction of incidents and accidents. 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 site specifics.

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 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, the state DOT may plan to operate the AHS initially at 90 km/h and evolve to a speed of 140 km/h, and may have a maximum design speed of 200 km/h.

Enhance Mobility - The AHS will enhance the nation's ability to effectively and predictably move people and freight using the highway system. The human desire, and need for mobility is at the heart of all transportation systems, including the vehicle-highway system. Motor vehicles and highways are the most used, most flexible, and most intrusive transportation system we have. Increasing the capability and utility of the highways will increase our mobility and is one of the major promises of automated vehicles and highways.

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 commercial as well as personal 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 accidents. Transit service providers will have increased ability to maintain their published schedules. Predictable trip times will increase the feasibility of just-in-time deliveries for commercial trucking companies.

AHS will be a system that requires less skill and concentration than is needed on current highways. The diversity and range of driving opportunities will be extended 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, automated driving will reduce driving stress and should permit them to gain, or regain, use of a highway after it has been automated.

More Convenient and Comfortable Highway Traveling - 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. One of the major expected 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. Under normal circumstances, the driver will not be required to resume any driving tasks until the requested exit is approached. 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.

Reduce Environmental Impact - 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 will be consistent with and help satisfy the nation's long-term air quality and energy usage goals as exemplified in national legislation.[5] The AHS, when coupled with policies that are aimed at limiting growth of 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. The 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.

The AHS will reduce fuel consumption and tailpipe emissions per VKT for internal combustion engines through smoother vehicle operation (fewer accelerations and declarations), reduce congestion, and automated monitoring of emissions performance. AHS operations at very close spacing 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 capacity from AHS 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 and policies for ensuring that this added capacity ultimately results in reduced congestion and increased passengers-per-vehicle will be studied and further defined.

Operate in Inclement Weather - 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. 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.

Ensure Affordable Cost and Economic Feasibility - Economic efficiency is the requirement that benefits derived from a system must exceed its costs. Specifically:

- 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 this 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.

The affordability question will be asked by consumers in the purchase of an AHS-equipped vehicle, by AHS vehicle and equipment manufacturers, by federal, state and local governments that regulate and manage the facilities, by potential private owner-operators, and by

vestors 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.

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. AHS will be seamlessly integrated into the surrounding transportation 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.

Easy to Use - Driving on the AHS will be easy and user friendly. 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. Destination (exit) selection must be flexible and given reasonable notice time, must be changeable at almost any time. Operation will be user friendly by being straight forward, intuitive, and forgiving. A minimum of special instruction and training will be required.[6]

Infrastructure Compatible - The AHS roadway will generally have highway/highway-type characteristics and be suitable for installation on or near existing highways. The AHS may require physical changes to the existing roadway. The changes will be evaluated to identify repercussions, both physical and operational, 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 for development of special construction vehicles, materials, or techniques. The AHS capability is not intended for application to urban/suburban arterials or local streets or rural roads without access control.

Facilitate Intermodal and Multimodal Transportation - 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. The AHS will support all these transportation modes in combination and separately. AHS will interface with parking and transit to connect with other mode stations (e.g., rail, airports, etc.). Local planners will be able to use AHS capabilities to build transportation systems that meet the needs of their locality and region.

Ensure Deployability - The AHS will develop from today's vehicle/highway system, and build on collision avoidance products and services, as well as the broader array of ITS services. The AHS will be progressively deployable in a planned and managed manner, building from today's highway/vehicle systems.

There are many basic deployment issues that must be considered: technology, infrastructure, human factors, vehicle manufacturing and maintenance, insurance, regulatory, and public will/buyer motivation. The deployment scenario will consist of a phased implementation, where each phase provides additional functionality and benefits. To maximize the likelihood of deployment success guidance will be developed to influence the direction of relevant collateral activities and leverage upon design innovations of such activities.

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.

Provide High Availability - The 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 for high availability 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. Access of emergency vehicles and concepts which accommodate rapid removal of defective vehicles from the traffic stream, will be a part of the AHS design.

Apply to Rural Roadways - The AHS will support the diversity of uses that is found in highway-type roadways in the nation including urban, suburban, and 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. These differences call for unique capabilities in the AHS when it is applied to a specific roadway use.

The AHS technology will also support operation of AHS-equipped vehicles on AHS-instrumented highways that are not dedicated to AHS vehicles only but which may also be used at the same time by conventional vehicles. Although this does not give all the benefits of AHS, it still will provide some safety benefits and reduce the stress of long-distance trips.

Disengage The Driver From Driving - During full automatic vehicle operation in the AHS, the system will effectively and safely control the vehicle, requiring no support from the driver. Full automatic control will be a learned condition for the driver brought about by trust in the reliability, safety, and convenience of the AHS. Once 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.

Support Travel Demand Management Policies - 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.

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.

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. Table 1 indicates which of the AHS objectives and 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.

Operate in a Mixed Mode With Non-AHS Vehicles - As a local option, AHS vehicles will be able to operate in a partially automated mode on an AHS highway that is also being used by non-AHS 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 dedicated AHS operation. But it may be desirable to install the AHS infrastructure as a step toward dedicated operations. The AHS vehicles may still enjoy some of the benefits of automation under partial automated control while the AHS lanes are also being used by non-AHS equipped vehicles.

Support a Wide Range of Vehicle Types - The AHS will support all normal vehicle types including cars, buses, and trucks, in either the same or separate lanes. 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 on a specific roadway.

Enhance Operations For Freight Carriers - The AHS will support freight carrying vehicles. AHS will include features to permit the local highway operator to give priority 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.

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. AHS will provide the ability to offer enhanced support to carpools and transit vehicles. 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 buses may be able to equal or even exceed the passenger carrying capabilities of today's light and heavy rail systems. However, today's use of transit is limited for several reasons, including longer trip times, unpredictable schedules because of congestion, and inconvenient transfers between modes. AHS approaches will enable transit to become more cost and time competitive as 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, attracts increased ridership while reducing unit costs.

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.

SUMMARY

The AHS program objectives, characteristics and requirements will continue to mature over the next seven years as the stakeholder and user needs are defined and the National Automated Highway System Consortium (NAHSC) develops and tests the AHS concepts and prototypes. For the current and complete version of the AHS System Objectives and Characteristics document please contact the NAHSC Program Office.

REFERENCES

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

[2] United States of America Department of Transportation Federal Highway Administration Request for Applications, DTFH61-94-X-00001, Dec. 15, 1993, Tables 1 &2.

[2] *Application To Establish a National AHS Consortium*, DTFH61-94-X-00001, December 15, 1993.

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

[4] *IVHS Strategic Plan*, Report to Congress, U.S. DOT, Dec 1992, pg 33.

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

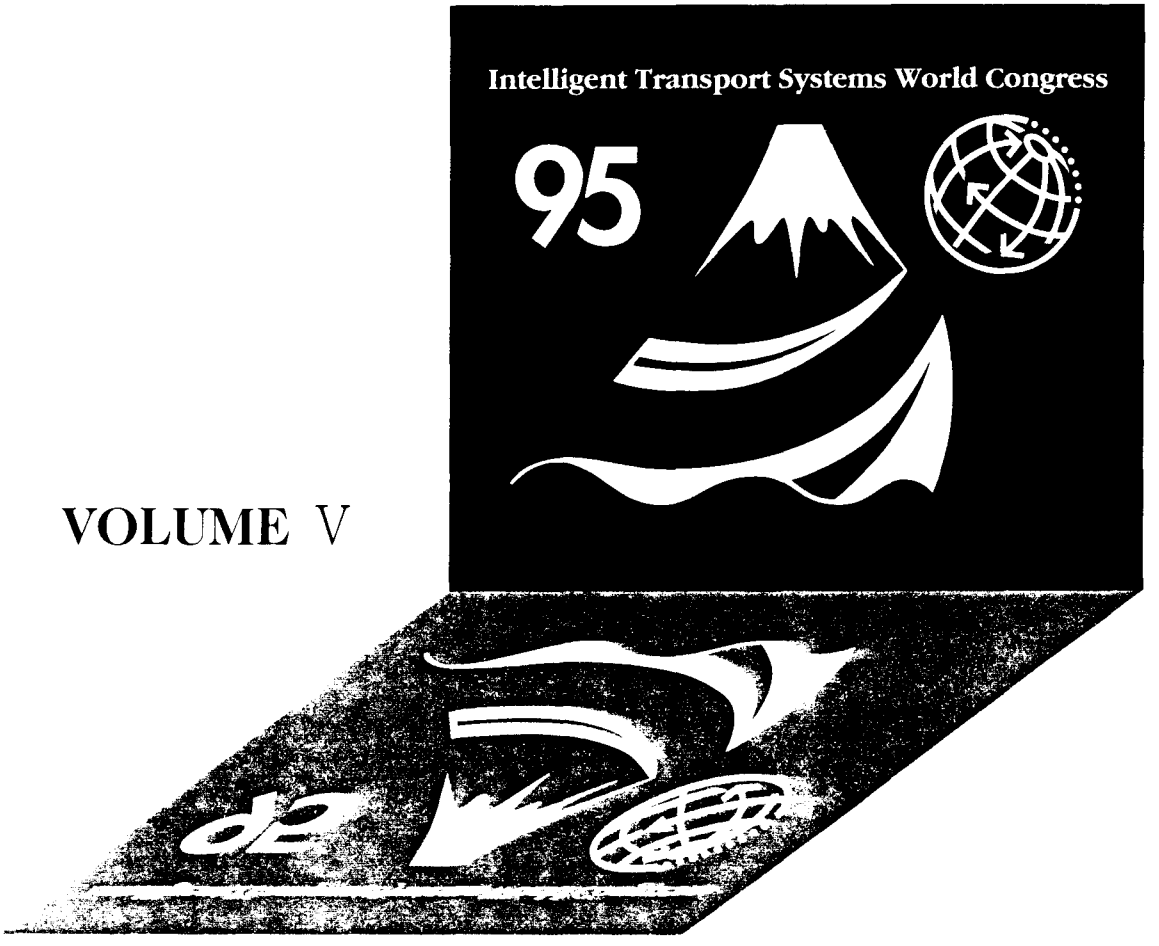
[6] *Precursor Systems Analyses of AHS Overview Report*, Calspan, Nov 1994, Vol I, pg 9.

[7] Slater, Rodney, *Administrator Slater's speech on the AHS Program*, October 21, 1993.

[8] *Automated Highway System (AHS) System Objectives and Characteristics*, 2nd Draft, National Automated Highway System Consortium, May 22, 1995.

PROCEEDINGS

"Steps Forward"



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