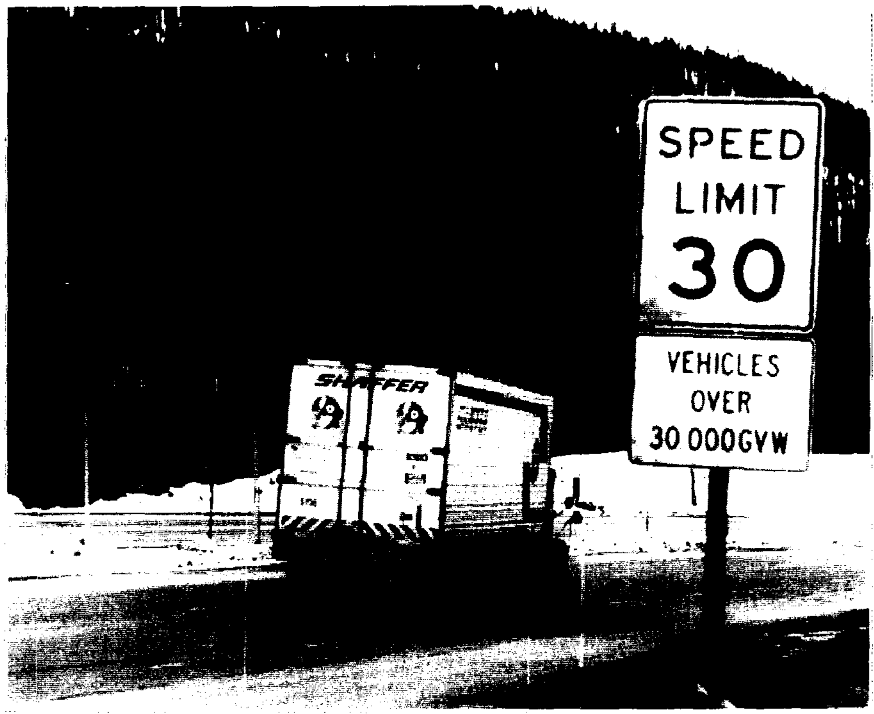
4.3 Enhance Operations for Freight Carriers

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



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

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.

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

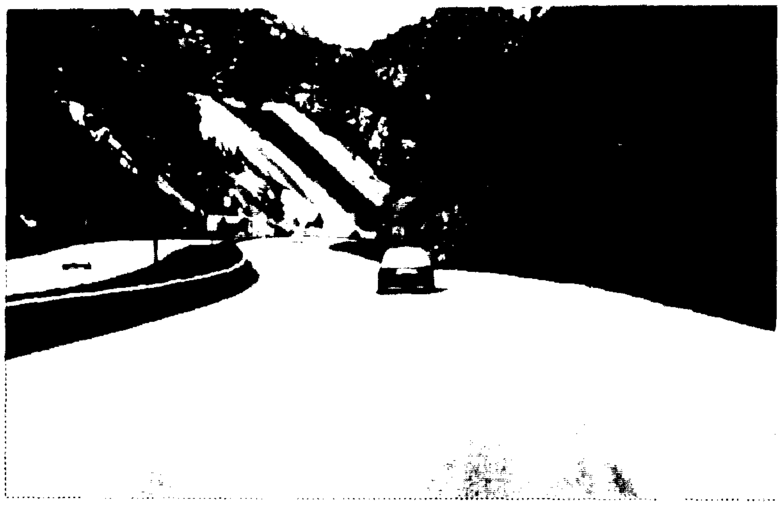
- Longer trips, often through unfamiliar areas;
- Irregular terrain and road alignment in some areas;
- Higher speeds, often coupled with lower volumes;
- Often longer reaction times due to inattention, disorientation or fatigued conditions;
- A relatively high incidence of driver impairment leading 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.

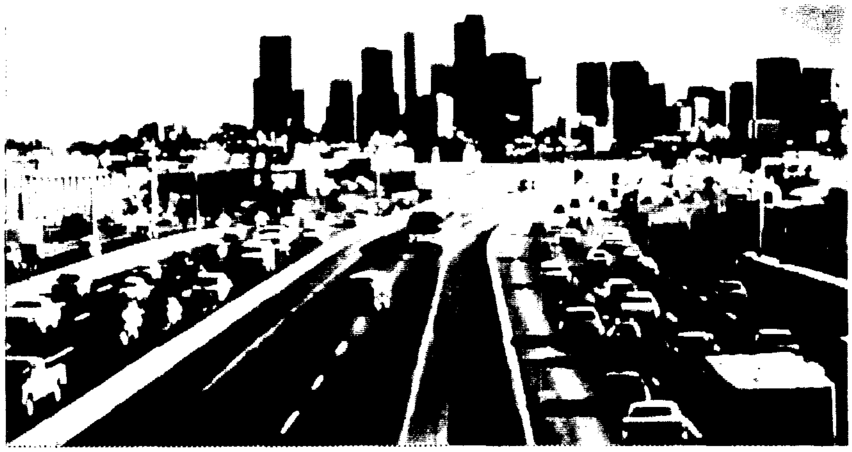
Rural highways were built to provide high-speed, long-distance travel services to all types of vehicles. AHS will support these same objectives and enhance trip time predictability. This includes AHS lanes dedicated only to AHS-equipped vehicles. These vehicles will provide shorter trip times through 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

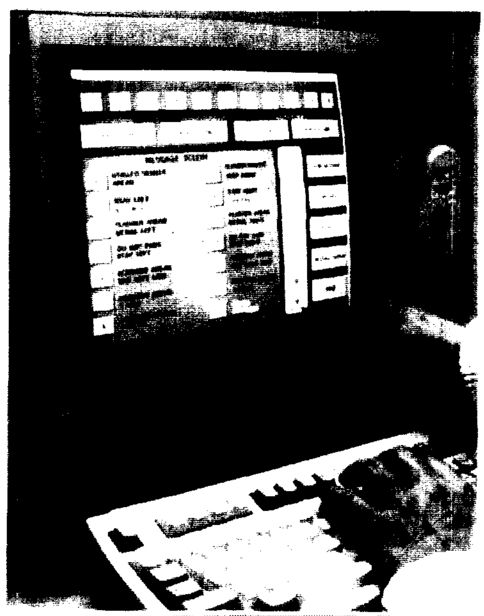
New tasks required by automation, such as destination entry and the transition to and from automatic control, must be simple, obvious, easy to learn, and accomplished with a minimum of effort for all drivers, regardless of age, cultural background, socio-economic group, or primary language. Destination (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 Report, Calspan, 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.

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.

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

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

NOTES: